Statistics Finland

GREENHOUSE GAS EMISSIONS IN FINLAND
1990 to 2022

National Inventory Document under the UNFCCC

Submission to the European Union

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Finland's National Inventory Document 2024

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PREFACE

Finland’s National Inventory Report (NIR) under the United Nations Framework Convention on Climate Change (UNFCCC), Paris Agreement (PA) and the European Union (EU)[1] contains the following parts:

Part 1 Finland’s national greenhouse gas emission inventory document (NID) prepared using the UNFCCC reporting guidelines (UNFCCC 2013) and the relevant decisions under the Paris Agreement as well as the Governance Regulation[1] and the Commission Implementing Regulation[2].

Part 2 CRF (Common Reporting Format) data tables showing Finland’s greenhouse gas emissions for the years 1990 to 2022. The CFR tables were compiled using the UNFCCC CRF Reporter Inventory software (version 6.0.10_AR5).

Statistics Finland is the national entity with the overall responsibility for the compilation and finalisation of inventory reports and their submission to the UNFCCC Secretariat and the European Commission. Statistics Finland approves the inventory submissions to the EU and UNFCCC independently.

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[1] Regulation (EU) 2018/1999 of the European Parliament and the Council of 11 December 2018 on the Governance of the Energy Union and Climate Action. (EU Governance Regulation)

[2] Regulation (EU) 2020/1208 Commission Implementing Regulation of 7 August 2020 on structure, format, submission and review on information reported by Member States pursuant to Regulation (EU) 2018/1999 of the European Parliament and the Council and repealing Commission Implementing Regulation (EU) 749/2014

EXECUTIVE SUMMARY

ES.1 Background information on greenhouse gas inventories and climate change

Finland is a Party to both the United Nations Framework Convention on Climate Change (UNFCCC) and the Paris Agreement (PA). Under these international agreements, Finland is committed to annually provide information on its national anthropogenic greenhouse gas emissions by sources and removals by sinks for all greenhouse gases not controlled by the Montreal Protocol. As a member of the European Union, Finland has reporting obligations also under Regulation (EU) 2018/1999 on the Governance of the Energy Union and Climate Action (hereafter referred to as the EU Governance Regulation). The implementation of EU Governance Regulation is further specified in the Commission Implementing Regulation (EU) 2020/1208 on structure, format, submission processes and review of information on reported by Member States pursuant to Regulation (EU) 2018/1999 of the European Parliament and of the Council of repealing commission Implementing Regulation (EU) 749/2014. Also the Commission Delegated Regulation (EU) 2020/1044 supplementing Regulation (EU) 2018/1999 of the European Parliament and of the Council with regard to values for global warming potentials and the inventory guidelines and with regard to the Union inventory system and repealing Commission Delegated Regulation (EU) 666/2014 provides further guidance for the reporting of the EU and its member states.

This report has been prepared in accordance with the Modalities, procedures and guidelines for the transparency framework for action and support referred to in Article 13 of the Paris Agreement agreed by the Conference of Parties serving as the meeting of the Parties to the Paris Agreement at is first session (18/CMA.1) and known as MPGs, and Guidance for operationalizing the modalities, procedures and guidelines for the enhanced transparency framework referred to in Article 13 of the Paris Agreement (5/CMA.3). This report aims at fulfilling the reporting commitments related greenhouse gas emission inventories under all above-mentioned agreements and regulations, as specified above.

The annual greenhouse gas inventory provides information on the trends in national greenhouse gas emissions and removals since 1990. This report presents emissions and removals for each of the major greenhouse gases as carbon dioxide equivalents (CO_2 eq.) using the 100-year global warming potentials (GWPs) from the 2014 IPCC Fifth Assessment Report (AR5). Information of the greenhouse gas inventory is essential for the planning and monitoring of climate policies in Finland.

In accordance with the Government resolution of 30 January 2003 on the organisation of climate policy activities of Government authorities in Finland, Statistics Finland assumed the responsibilities of the National Entity for Finland’s greenhouse gas inventory from the beginning of 2005. The Climate Act (609/2015 and 423/2022) enforces Statistics Finland’s role as the national entity responsible for Finland’s national greenhouse gas inventory. Statistics Finland as the general authority of the official statistics of Finland is independently responsible for greenhouse gas inventory submissions under the UNFCCC, the Paris Agreement and EU regulations. Besides Statistics Finland, the Finnish Environment Institute and the Natural Resources Institute Finland take part in the inventory preparation. Statistics Finland also acquires parts of the inventory calculations as purchased services from VTT (VTT Technical Research Centre of Finland Ltd).

In Finland, the national institutional arrangements as intended under the Paris Agreement (in Annex of 18/CMA.1 Modalities, procedures and guidelines for the transparency framework for action and support referred to in Article 13 of the Paris Agreement)), are based, besides laws and regulations concerning Statistics Finland, including the Climate Act, on agreements on the production of emission/removal estimations and relevant parts of the reports between the inventory unit at Statistics Finland and the expert organisations mentioned above. Statistics Finland has also agreements with the responsible ministries defining the responsibilities and collaboration in relation to the reporting requirements under the UNFCCC and Paris Agreement, as well as the EU. A description of the national inventory arrangements, including institutional, legal and procedural arrangements in Finland is provided in Section 1.2.

ES.2 Summary of trends related to national emissions and removals

In 2022, Finland’s greenhouse gas emissions totalled 45.7 million tonnes of carbon dioxide equivalent (Mt CO_2 eq.) without the LULUCF sector. The total emissions in 2022 were approximately 36% (25.6 Mt) below the 1990 emissions level. Emissions in 2022 were 4% lower than in 2021, they decreased 1.9 Mt CO_2 eq.

A summary of the Finnish national emissions and removals for 1990 to 2022 is presented in Table ES.2-1.

The energy sector is the most significant source of greenhouse gas emissions in Finland and, therefore, the key driver behind the trend. Energy related CO_2 emissions vary much in Finland, mainly according to the economic trend, the energy supply structure and climate conditions. The overall trend since 2010 has been declining. The important drivers in the trend of the energy sector’s greenhouse emissions have been the changes in the level of annually imported electricity and fossil fuel-based condensing power in annual energy production as well as the growth in the consumption of renewable energy (see also 2.2.1). In 2022 emissions from energy sector were decreased 4% since 2021, being 32.9 Mt CO_2 eq. Emissions were 38% below the level in 1990.

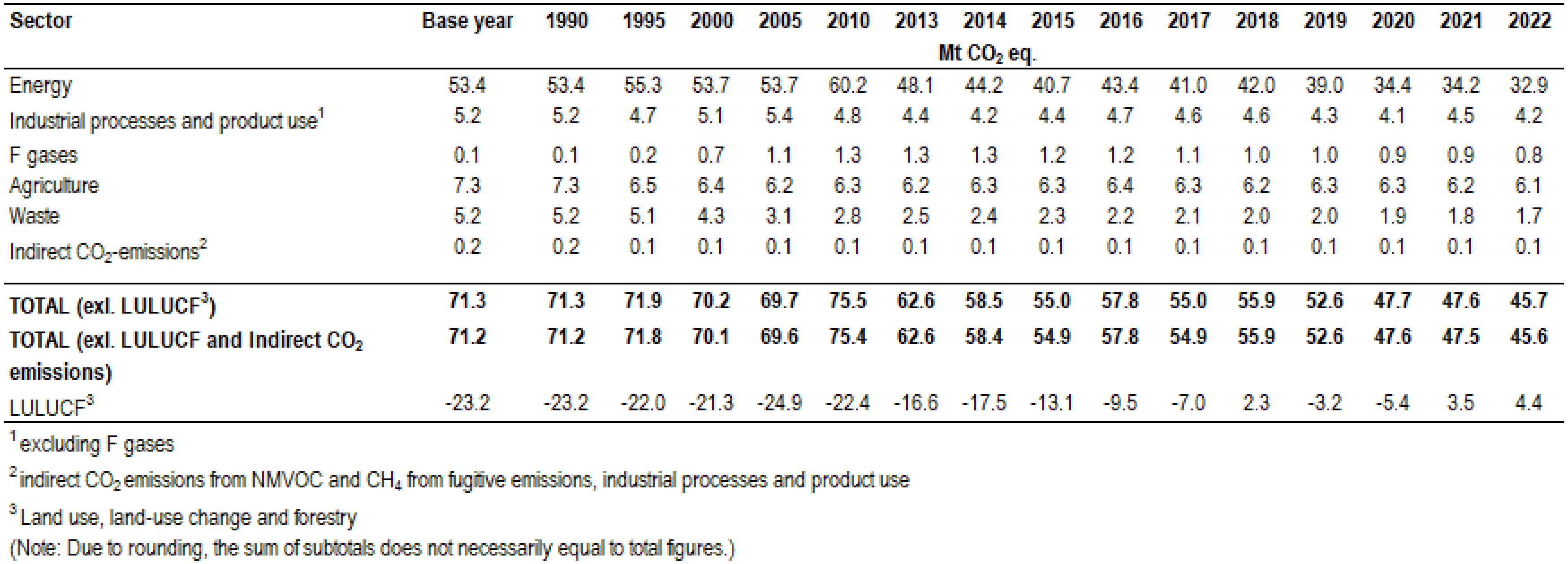
In the industrial processes and product use sector, emissions increased between 1993 and 2008 to a level over 40% higher than the 1990 emissions. In 2009 the emissions decreased by over 20% compared to 2008 due to the economic downturn and technical abatement measures implemented to reduce N_2O emissions in nitric acid production in 2009. The emissions took an upward trend again in 2010 but during 2010 to 2022 emissions have been 19 to 33% lower than the peak value in 2008. In early 1990s, several plants were closed down due to an earlier economic recession. The technical abatement of N_2O emissions from nitric acid production has contributed much to the lowering of the emissions since 2009 in the industrial processes and product use sector. A key driver behind the increasing trend of F gas emissions in the 1990s and 2000s has been the substitution of ozone depleting substances (ODS) by F gases in many applications. During 2010s F gas emissions started to decline due to decreased leakage rates and restrictions on the use of high GWP refrigerants.

Emissions in the Agriculture and Waste sectors have decreased since 1990. The decrease in the waste sector can largely be attributed to changes in waste legislation and to the implementation of the Landfill Directive (1999/31/EC). In the agriculture sector, livestock and livestock related emissions decreased notably in the early 1990’s. Since 1990, the reduced use of nitrogen fertilisers due to agri-environmental policies has also decreased the emissions in the agriculture sector, being the most important single factor for the reduced emissions in the sector. Also, the reduced use of lime has significantly decreased the emissions. The area of cultivated organic soils has, however, increased during the period 1990 to 2022, which has increased nitrous oxide emissions.

The LULUCF sector in Finland has been a net sink until 2017, after which it has acted as both a net sink and a net source. The net emissions in the sector were 4.4 Mt CO_2 eq. in 2022 which was 28% greater than in the previous year. There are several reasons for the net removals turning into net emissions in the LULUCF sector, of which an increase in commercial fellings is the most important. Compared to the net removals in 1990, the net emissions in 2022 were 119% higher. Most of the removals in the LULUCF sector have come from tree biomass; that is to say the tree volume increment in forest land has exceeded the annual total drain. The increment of the growing stock has increased in Finland since 1990 until 2013 after which it has been decreasing according to the latest measurements. Annual variations in the total drain (consisting of roundwood removals, logging residues and natural losses) have been considerable. In addition, the aggregated dead organic matter and soil organic matter pool in mineral soils has been a significant sink during the reporting period. The largest emissions in the LULUCF sector have come from changes in the soil organic carbon pool in organic forest and agricultural soils.

Indirect CO_2 emissions have decreased by 69% since 1990, the main reason being reduced use of solvent chemicals in industry. Most of the reductions occurred in the 1990s. In 2020 these emissions increased 19% mostly due to substantial use of hand sanitizer during COVID-19 pandemic, but in 2022 they were 23% lower than in 2020.

Table ES.2-1 Finnish greenhouse gas emissions and removals (Mt CO_2 equivalent). The base year refers to 1990 which is Finland’s base year under the UNFCCC



Sector	Base year	1990	1995	2000	2005	2010	2013	2014	2015	2016	2017	2018	2019	2020	2021	2022
							Mt CO_2 eq.									
Energy	53.4	53.4	55.3	53.7	53.7	60.2	48.1	44.2	40.7	43.4	41.0	42.0	39.0	34.4	34.2	32.9
Industrial processes and product use[1]	5.2	5.2	4.7	5.1	5.4	4.8	4.4	4.2	4.4	4.7	4.6	4.6	4.3	4.1	4.5	4.2
F gases	0.1	0.1	0.2	0.7	1.1	1.3	1.3	1.3	1.2	1.2	1.1	1.0	1.0	0.9	0.9	0.8
Agriculture	7.3	7.3	6.5	6.4	6.2	6.3	6.2	6.3	6.3	6.4	6.3	6.2	6.3	6.3	6.2	6.1
Waste	5.2	5.2	5.1	4.3	3.1	2.8	2.5	2.4	2.3	2.2	2.1	2.0	2.0	1.9	1.8	1.7
Indirect CO_2-emissions[2]	0.2	0.2	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1
TOTAL (exl. LULUCF[3])	**71.3**	**71.3**	**71.9**	**70.2**	**69.7**	**75.5**	**62.6**	**58.5**	**55.0**	**57.8**	**55.0**	**55.9**	**52.6**	**47.7**	**47.6**	**45.7**
TOTAL (exl. LULUCF and Indirect CO_2 emissions)	**71.2**	**71.2**	**71.8**	**70.1**	**69.6**	**75.4**	**62.6**	**58.4**	**54.9**	**57.8**	**54.9**	**55.9**	**52.6**	**47.6**	**47.5**	**45.6**
LULUCF[3]	-23.2	-23.2	-22.0	-21.3	-24.9	-22.4	-16.6	-17.5	-13.1	-9.5	-7.0	2.3	-3.2	-5.4	3.5	4.4

[1] excluding F gases

[2] indirect CO_2 emissions from NMVOC and CH_4 from fugitive emissions, industrial processes and product use

[3] Land use, land-use change and forestry

(Note: Due to rounding, the sum of subtotals does not necessarily equal to total figures.)

ES.3 Overview of source and sink category emission estimates and trends

The greenhouse gas emissions and removals are divided into the following reporting categories according to the UNFCCC reporting guidelines on annual inventories following incorporation of the provisions of decision 14/CP.11 (UNFCCC 2006): Energy (CRF 1), Industrial Processes and Product Use (CRF 2) Agriculture (CRF 3), Land Use, Land-use change and Forestry (LULUCF) (CRF 4), and Waste (CRF 5). In addition, Finland reports indirect CO_2 emissions due to atmospheric oxidation of CH_4 and NMVOCs. National totals are presented with and without indirect CO_2 consistent with the UNFCCC reporting guidelines.

The composition of Finnish greenhouse gas emissions in 2022 is presented in Figure ES.3-1.

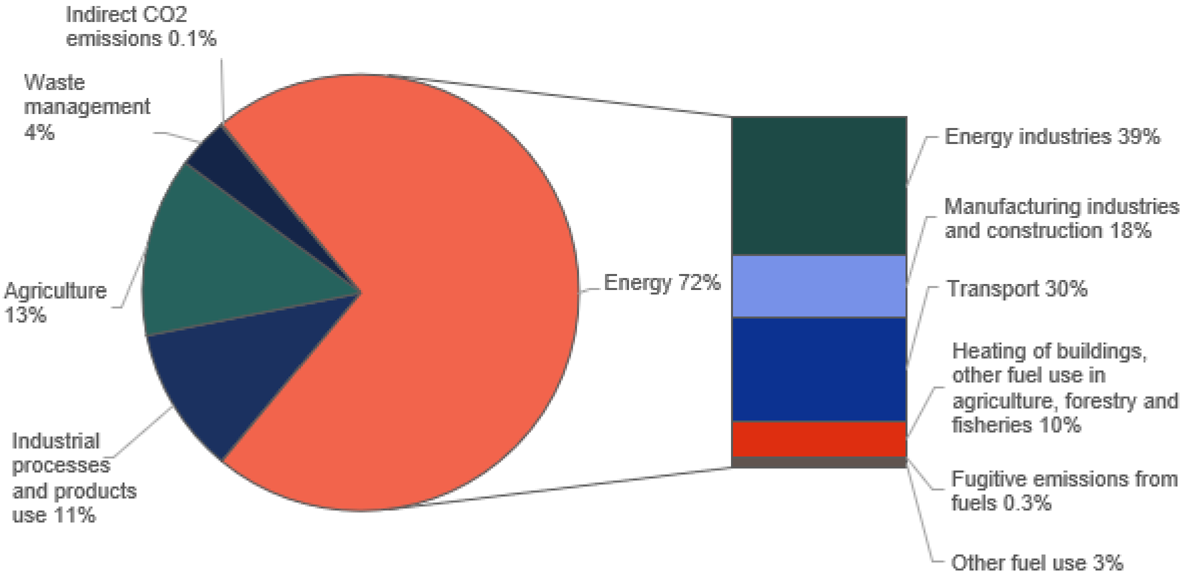


Figure ES.3-1 The composition of Finnish greenhouse gas emissions in 2022 (LULUCF sector excluded). Due to independent rounding the sums do not add up.

The energy sector is the most significant source of greenhouse gas emissions in Finland with a 72% share of the total emissions in 2022, being 32.9 Mt CO_2 eq. Emissions have decreased by 38% (20.6 Mt CO_2 eq.) since 1990, and they decreased 4% since 2021. Energy-related CO_2 emissions vary mainly according to the economic trend, the energy supply structure and climate conditions. This results from the high energy intensity of the Finnish industry, extensive consumption during a long heating period, as well as energy consumption for transport in a large and sparsely inhabited country. Total consumption of energy in Finland amounted to 1.29 million terajoules (TJ) in 2022, which corresponded to a decline of 5% compared with the previous year. The use of fossil fuels and peat decreased by 6% in total. The use of renewable energy sources also decreased by 6% but their share of total consumption remained at 42%. The increase in the use of renewable energy compared to the situation in 1990 is the main reason for the decreased emissions despite the growth in total energy consumption.

Agriculture is the second most significant source of greenhouse gas emissions in Finland. In 2022, agricultural emissions accounted for 13% (6.1 Mt CO_2 eq.) of total emissions. The annual emissions have declined by 17% (1.2 Mt CO_2 eq.) since 1990 due to decreases in the number of livestock and in nitrogen fertilisationTotal agricultural emissions have been quite steady since the beginning of 21st century (yearly variation from 6.1 to 6.4 Mt CO_2 eq.) and they decreased 2% since 2021. The reasonably steady emission levels during the last 20 years are mostly a result of the emission trends that are affecting in the opposite directions, i.e. remarkably decreased emissions from nitrogen fertilization have been counteracted by the increasing emissions from the increased cultivation in organic soils. Changes in the agricultural policies and farming subsidies have had a considerable influence on the agricultural activities and hence the emissions from this sector.

The emissions from industrial processes and product use, including CO_2, CH_4, N_2O and F gases, were 11% (5.0 Mt CO_2 eq.) of total greenhouse gas emissions in Finland in 2022, being the third largest source of greenhouse gas emissions. Emissions have decreased by 7% (0.2 Mt CO_2 eq.) since 2021 and they were in 2022 5% lower in 1990. Their share of the total greenhouse gas emissions has varied from 7 to 11% during the reporting period. The fluctuation in the emissions from industrial processes and product use is largely consistent with the economic trend, even if the factors influencing the emissions are more diverse.

The waste sector accounted for 4% (1.7 Mt CO_2 eq.) of total Finnish greenhouse gas emissions in 2022. Emissions from the waste sector consist of CH_4 and N_2O emissions and they have had a decreasing trend since 1990. Overall, the annual emissions in the waste sector have decreased by 67% (3.5 Mt CO_2 eq.) since 1990. The decrease has been mainly due to the implementation of the Waste Act (1994) and the Landfill Directive (1999/31/EC), which require increased recycling and recovery of waste as material or energy as well as recovery of landfill gas. The ban of depositing organic waste to landfills since 2016 (Government Decree 2013) will decrease methane emissions from landfills even more.

The contribution of indirect CO_2 emissions from atmospheric oxidation of CH_4 and NMVOCs to the Finnish greenhouse gas emissions is small, about 0.1% of the total greenhouse gas emissions in Finland.

The LULUCF sector has been a net sink in Finland until the year 2017, after which it has acted as both a sink and a source. In 2022, it was a net source of 4.4 Mt CO_2 eq. Its annual net removals or net emissions have equalled approximately 4 to 51% of the annual sum of emissions from other sectors, i.e. the total emissions without LULUCF during 1990 to 2022. The most important components of the forest sink are the tree biomass growth and biomass removed from forest due to fellings. Based on the National Forest Inventory (NFI), the increment of growing stock has increased since 1990 from 78 million m^3 to 104 million m^3. Between years there is less fluctuation in the estimated growth contrary to the harvest rates. In 2022, the total drain was 90 million m^3, consisting of roundwood removals, logging residues and natural losses.

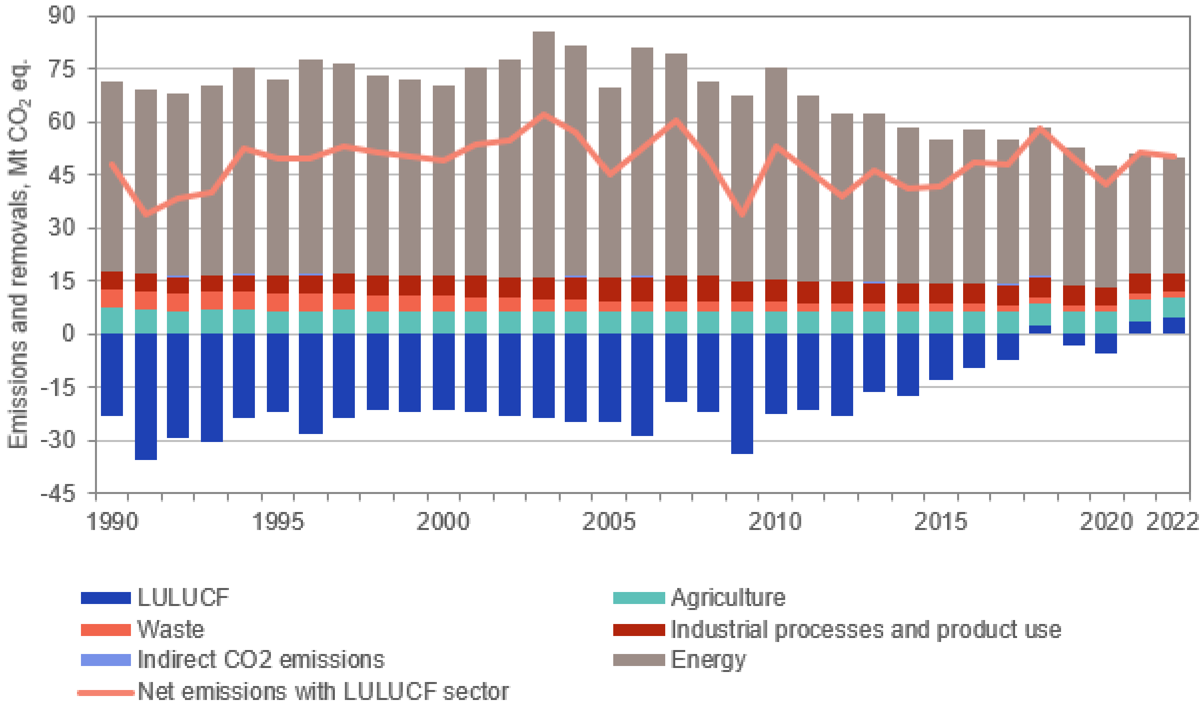


Figure ES.3-2 Greenhouse gas emissions and removals in Finland by reporting sector (Mt CO_2 eq.) and net CO_2 equivalent emissions (emissions plus removals). Emissions are positive and removals negative quantities

ES.4 Other information: precursor gases and sulphur oxides)

The emissions trends of precursors; nitrogen oxides, carbon monoxide and non-methane volatile organic compounds and sulphur oxide and other sulphur emissions calculated as sulphur dioxide, are presented in Figure ES.4-1 and Table ES.4-1.

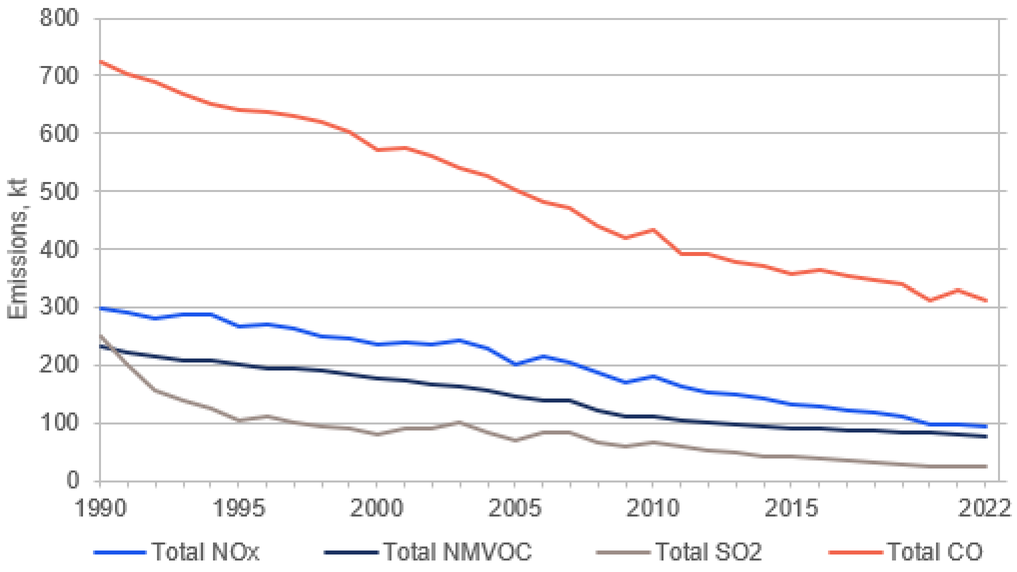


Figure ES.4-1 Precursors and sulphur dioxide emissions, kt

Nitrogen oxides (NO_x) were generated in the energy, industrial, agriculture and LULUCF sectors. The energy sector is the most significant source, 97% of emissions are energy related. Emissions have decreased by 70% compared to 1990 and were 91 kt in 2022. The biggest decrease, 82%, has happened in the transport category due to the implementation of catalytic converters to cars and these emissions were 29% of the total emissions in 2022. Energy industries generated 25% and manufacturing industries and construction generated 28% of the total emissions.

Carbon monoxide (CO) emissions totalled 306 kt in 2022, in the energy sector transport generated 15% and other sectors (including small-scale combustion and off-road machinery) 66% of the total emissions. Total carbon monoxide emissions have decreased by 58% compared to 1990.

The **non-methane volatile organic compounds (NMVOC)** totalled 75 kt in 2022. 48% of the total emissions were generated in the energy sector, 33% originated from industrial processes and product use and 18% from agriculture in 2022. Total NMVOC emissions have decreased by 68% from 1990 to 2022, the greatest decline has taken place in the energy sector, where emissions decreased by 74%.

The **sulphur dioxide (SO_2)** emissions totalled 23 kt in 2022 out of which 67% originated in the energy sector, where energy industries generated 38% of the total emissions and manufacturing industries and construction 14%. Sulphur dioxide emissions have in total decreased by 91% from 1990, the reasons being the increased use of less sulphur containing fuels and sulphur abatement technology in energy production and industrial processes.

Table ES.4-1 Trends of NO_x, CO, NMVOC and SO_2 emissions from different sources, kt

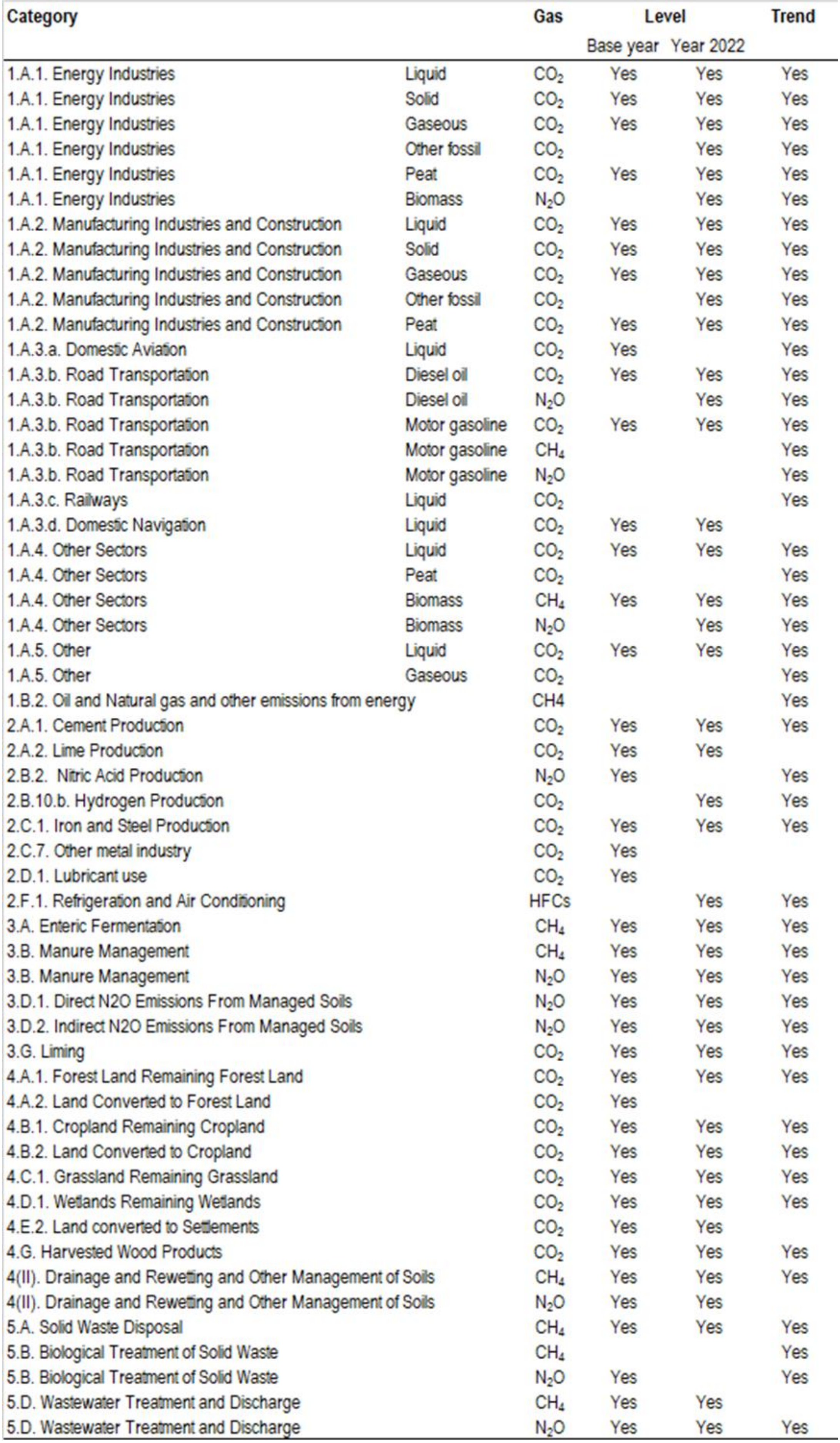
	1990	1995	2000	2005	2010	2013	2014	2015	2016	2017	2018	2019	2020	2021	2022
Total nitrogen oxides	**298**	**266**	**235**	**200**	**179**	**151**	**143**	**132**	**128**	**124**	**119**	**113**	**98**	**98**	**91**
- energy	293	261	231	196	175	147	139	128	124	119	116	109	94	94	88
- industry and product use	1.8	1.6	1.6	1.9	2.1	2.1	2.0	1.9	1.8	2.1	1.7	1.4	1.4	1.3	1.1
- agriculture	3.5	3.0	2.6	2.3	2.4	2.2	2.3	2.2	2.1	2.2	2.1	2.3	2.2	2.2	1.5
- LULUCF	0.08	0.04	0.02	0.03	0.02	0.02	0.03	0.01	0.01	0.01	0.03	0.02	0.04	0.02	0.01
Total carbon monoxides	**728**	**643**	**571**	**505**	**435**	**378**	**374**	**356**	**365**	**356**	**348**	**340**	**315**	**331**	**306**
- energy	721	639	567	501	432	374	370	354	362	352	345	336	311	330	305
- industry and product use	0.1	0.05	0.04	0.02	0.02	0.03	0.02	0.03	0.03	0.03	0.6	0.2	0.2	0.2	0.2
- agriculture	4.2	3.5	3.7	3.1	1.9	3.0	2.7	2.5	2.4	2.6	1.9	2.8	2.3	NA	NA
- LULUCF	2.7	1.3	0.5	1.0	0.5	0.7	0.9	0.3	0.4	0.5	1.0	0.7	1.4	0.8	0.4
Total NMVOCs	**232**	**202**	**176**	**147**	**112**	**97**	**95**	**91**	**90**	**88**	**86**	**85**	**85**	**82**	**75**
- energy	141	131	112	91	66	54	51	48	48	46	44	43	38	40	36
- industry and product use	71	53	46	39	29	26	26	25	25	26	25	26	31	27	24
- agriculture	20	18	18	17	17	17	18	18	17	17	17	16	16	15	15
- waste	0.3	0.3	0.2	0.2	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1
Total sulphur oxides	**250**	**105**	**81**	**69**	**67**	**48**	**43**	**42**	**40**	**36**	**33**	**29**	**23**	**24**	**23**
- energy	184	82	63	54	53	36	32	29	29	26	23	20	15	16	16
- industry and product use	66	23	18	16	14	12	11	13	11	10	10	9	8	8	8

ES.5 Key category analysis

Aim of the key category analysis is to identify category-gas combinations that are the most important in terms of the emission level and the trend. Results of the key category analysis guide decisions on methodological choice. Need for possible improvement in inventory calculations is thus assessed for the key categories. The key categories are also subject to more detailed documentation and quality control.

The national key categories for the base year and the latest reported inventory year are identified using Approach 1 and Approach 2 of the IPCC 2006 guidelines, and the key categories of Approach 2 are added to the key categories of Approach 1. The key categories listed in Table ES.5-1 were analysed with a national procedure. The aggregation level of subcategories used in the analysis is based on the suggested aggregation level in the 2006 IPCC Guidelines (Vol. 1, Table 4.1) with some differences which are described in detail in Annex 1.

Table ES.5-1 Key categories identified using Approach 1 and Approach 2 level and trend assessment



Category		Gas	Level		Trend
			Base year	Year 2022	
1.A.1. Energy Industries	Liquid	CO_2	Yes	Yes	Yes
1.A.1. Energy Industries	Solid	CO_2	Yes	Yes	Yes
1.A.1. Energy Industries	Gaseous	CO_2	Yes	Yes	Yes
1.A.1. Energy Industries	Other fossil	CO_2		Yes	Yes
1.A.1. Energy Industries	Peat	CO_2	Yes	Yes	Yes
1.A.1. Energy Industries	Biomass	N_2O		Yes	Yes
1.A.2. Manufacturing Industries and Construction	Liquid	CO_2	Yes	Yes	Yes
1.A.2. Manufacturing Industries and Construction	Solid	CO_2	Yes	Yes	Yes
1.A.2. Manufacturing Industries and Construction	Gaseous	CO_2	Yes	Yes	Yes
1.A.2. Manufacturing Industries and Construction	Other fossil	CO_2		Yes	Yes
1.A.2. Manufacturing Industries and Construction	Peat	CO_2	Yes	Yes	Yes
1.A.3.a. Domestic Aviation	Liquid	CO_2	Yes		Yes
1.A.3.b. Road Transportation	Diesel oil	CO_2	Yes	Yes	Yes
1.A.3.b. Road Transportation	Diesel oil	N_2O		Yes	Yes
1.A.3.b. Road Transportation	Motor gasoline	CO_2	Yes	Yes	Yes
1.A.3.b. Road Transportation	Motor gasoline	CH_4			Yes
1.A.3.b. Road Transportation	Motor gasoline	N_2O			Yes
1.A.3.c. Railways	Liquid	CO_2			Yes
1.A.3.d. Domestic Navigation	Liquid	CO_2	Yes	Yes	
1.A.4. Other Sectors	Liquid	CO_2	Yes	Yes	Yes
1.A.4. Other Sectors	Peat	CO_2			Yes
1.A.4. Other Sectors	Biomass	CH_4	Yes	Yes	Yes
1.A.4. Other Sectors	Biomass	N_2O		Yes	Yes
1.A.5. Other	Liquid	CO_2	Yes	Yes	Yes
1.A.5. Other	Gaseous	CO_2			Yes
1.B.2. Oil and Natural gas and other emissions from energy		CH4			Yes
2.A.1. Cement Production		CO_2	Yes	Yes	Yes
2.A.2. Lime Production		CO_2	Yes	Yes	
2.B.2. Nitric Acid Production		N_2O	Yes		Yes
2.B.10.b. Hydrogen Production		CO_2		Yes	Yes
2.C.1. Iron and Steel Production		CO_2	Yes	Yes	Yes
2.C.7. Other metal industry		CO_2	Yes		
2.D.1. Lubricant use		CO_2	Yes		
2.F.1. Refrigeration and Air Conditioning		HFCs		Yes	Yes
3.A. Enteric Fermentation		CH_4	Yes	Yes	Yes
3.B. Manure Management		CH_4	Yes	Yes	Yes
3.B. Manure Management		N_2O	Yes	Yes	Yes
3.D.1. Direct N2O Emissions From Managed Soils		N_2O	Yes	Yes	Yes
3.D.2. Indirect N2O Emissions From Managed Soils		N_2O	Yes	Yes	Yes
3.G. Liming		CO_2	Yes	Yes	Yes
4.A.1. Forest Land Remaining Forest Land		CO_2	Yes	Yes	Yes
4.A.2. Land Converted to Forest Land		CO_2	Yes		
4.B.1. Cropland Remaining Cropland		CO_2	Yes	Yes	Yes
4.B.2. Land Converted to Cropland		CO_2	Yes	Yes	Yes
4.C.1. Grassland Remaining Grassland		CO_2	Yes	Yes	Yes
4.D.1. Wetlands Remaining Wetlands		CO_2	Yes	Yes	Yes
4.E.2. Land converted to Settlements		CO_2	Yes	Yes	
4.G. Harvested Wood Products		CO_2	Yes	Yes	Yes
4(II). Drainage and Rewetting and Other Management of Soils		CH_4	Yes	Yes	Yes
4(II). Drainage and Rewetting and Other Management of Soils		N_2O	Yes	Yes	
5.A. Solid Waste Disposal		CH_4	Yes	Yes	Yes
5.B. Biological Treatment of Solid Waste		CH_4			Yes
5.B. Biological Treatment of Solid Waste		N_2O	Yes		Yes
5.D. Wastewater Treatment and Discharge		CH_4	Yes	Yes	
5.D. Wastewater Treatment and Discharge		N_2O	Yes	Yes	Yes

ES.6 Improvements introduced

The greenhouse gas inventory of Finland is improved continuously taking into account new data and science available, assessments by the inventory experts and results of external reviews. The recommendations from the previous UNFCCC inventory reviews have been taken into account. The significance of the sources based on the results of the key category and uncertainty analyses are considered when prioritising improvements to be made in the inventory calculations.

Improvements and recalculations are described in Chapter 10 as well as in the sectoral Chapters 3–9 under Recalculations. When planning and implementing improvements, time-series consistency is ensured. Effects of recalculations, i.e. improvements, activity data updates and corrections, on the time-series are discussed and summarized in the sectoral chapters and quantified for years 1990, 2005 and 2021 in Chapter 10.

For the 2024 submission the following methodological improvements were made:

Agriculture: A new country-specific method to calculate gross energy intake and nitrogen (N) excretion was implemented for cattle. Also, the methane emission factor value for calves was revised, assuming that calves do not emit methane during the period when fed with milk. These methodological improvements altered the emissions from enteric fermentation, manure management and agricultural soils.

LULUCF: Method to estimate gains in the tree biomass on forest land remaining forest land was changed. For the 2023 submission, the estimation method for the gains in living tree biomass was modified to conform to the methodology the Finnish National Forest Inventory applies to volume increment estimation, using remeasured trees on permanent sample plots. However, the approach was later found unsuitable and for the 2024 submission, the estimation of gains in the tree biomass was reverted to the previous method that uses biomass expansion and conversion factors. The consequent change in the gains of living tree biomass affected also the carbon stock changes in the litter and soil pools.

In addition to the methodological improvements, updates of activity data and corrections resulted in recalculations in all sectors. The overall effect of recalculations, including the effect of methodological improvements, is presented in the table ES6.1-1 and in more detail in Chapter 10.

Table ES6.1-1 Recalculations, including the effect of methodological improvements, made for the 2022 inventory submission by CRF category and their implications to the emission level in 1990 and 2021

CRF Category	Recalculation	Reason for the recalculation	Implication to the CRF category level (kt CO_2 eq.) 1990	2021
1. Energy	Recalculations in energy industries 1.A.1, other sectors 1.A.4 and other category 1.A.5 [3]	Updates in the activity data	**0.00**	**-139.05**
2. Industrial Processes and Product Use	Recalculations in mineral industry 2.A, chemical industry 2.B, non-energy products from fuels and solvent use 2.D, F gas categories 2.F.1a and 2.F.1f and other product manufacture and use category 2.G.1	Updates in the activity data and the inclusion of a formalin plant in chemical industry 2.B	**6.71**	**-7.17**
3. Agriculture			**71.46**	**-106.85**
A. Enteric fermentation	Implementation of a new country-specific method to calculate gross energy intake and N excretion of cattle, revision of the methane emission factor for calves	New, more detailed feeding and slaughter data, methodological change	3.74	-78.69
B. Manure management	Implementation of a new method for gross energy intake and N excretion of cattle.	New, more detailed feeding and slaughter data, methodological change.	27.04	-13.70
D. Agricultural soils	Implementation of a new method for gross energy intake and N excretion of cattle, recalculation of N_2O emissions from the cultivation of organic soils and mineralisation of nitrogen in mineral soils due to new area estimates	New cattle excretion data, new area estimates due to the updating of National Forest Inventory data	40.68	-14.47
4. Land use, land-use change and forestry			**2 631.99**	**2 987.63**
A. Forest land	Carbon stock changes, drainage and rewetting, mineralization, biomass burning	Updated activity data, methodological change, error corrections	2 659.20	3 338.73
B. Cropland	Carbon stock changes, mineralisation	Updated activity data, error correction	-27.26	-246.35
C. Grassland	Carbon stock changes, mineralisation, biomass burning	Updated activity data	-0.03	60.05
D. Wetlands	Carbon stock changes, drainage and rewetting	Updated activity data	0.00	22.31
E Settlements	Carbon stock changes, mineralisation	Updated activity data	0.50	-114.58
G. HWP	Carbon stock changes	Updated activity data, error correction	0.00	-72.16
5. Waste	Minor correction to the municipal solid waste emissions	Minor correction in the activity data	**0.00**	**-0.51**
Indirect CO_2 emissions	Correction of the activity data in paint application, chemicals products and natural gas transmission and the update of calculation of other domestic solvent use	Updated activity data and error correction	**-1.67**	**1.19**

Areas of future improvement and/or capacity-building in response to the review process or identified by the Finnish experts responsible for the calculations are described in Section 10.4.

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[3] CRF 1.A.4 includes emissions e.g. from fuel combustion in commercial, institutional, residential sectors and in agriculture. CRF 1.A.5 includes emissions e.g. from non-specified consumption of fuels and statistical corrections of fuel consumption.

1 NATIONAL CIRCUMSTANCES, INSTITUTIONAL ARRANGEMENTS AND CROSS-CUTTING INFORMATION

1.1 Background information on greenhouse gas inventories and climate change

1.1.1 Greenhouse gas inventories

The annual inventory and reporting of greenhouse gas emissions and removals provide an information base for the planning and monitoring of climate policy. Finland’s National Greenhouse Gas Inventory System was set up at the beginning of 2005. In the description of the National system of Finland the national inventory arrangements, including institutional, legal and procedural arrangements are explained as required in Paris Agreement Decision 18/CMA.1 (Modalities, procedures and guidelines for the transparency framework for action and support referred to in Article 13 of the Paris Agreement).

The national system produces data and background information on emissions and removals for the UNFCCC, the Paris Agreement and the EU Commission. In addition, the scope of the system covers the archiving of the data used in emission estimations, the publishing of the results, participation in inventory reviews and the quality management of the inventory as well as timely reporting of national inventory reports.

The EU Governance regulation and acts complementing it guides the greenhouse gas inventory reporting by the Member States (MS) of the European Union (EU) to the Commission since 2023. This regulation builds on the reporting requirements of the Paris Agreement and UNFCCC, but also includes many Union-specific requirements, including provisions for annual quality checks and a review of the submission. The MSs submit their inventories to the Commission with annual deadlines for submission being 15 January (preliminary data) and 15 March (final data).

This National Inventory Document (NID) of Finland for the submission to the EU, the UNFCCC and the Paris Agreement includes data of the anthropogenic emissions by sources and removals by sinks of all greenhouse gases (GHGs) not controlled by the Montreal Protocol, i.e. carbon dioxide (CO_2), methane (CH_4), nitrous oxide (N_2O), perfluorocarbons (PFCs), hydrofluorocarbons (HFCs), sulphur hexafluoride (SF_6) and nitrogen trifluoride (NF_3).

The inventory also includes estimates of precursors as carbon monoxide (CO), nitrogen oxides (NO_x) and non-methane volatile organic compounds (NMVOCs), and sulphur dioxide (SO_2 meaning sulphur oxides and other sulphur emissions calculated as SO_2). These gases are not greenhouse gases but impact global warming for example by influencing on the formation or destruction of direct greenhouse gases, such as tropospheric ozone.

Indirect CO_2 emissions resulting from atmospheric oxidation of fugitive CH_4 and non-methane volatile organic compounds (NMVOC) emissions from non-biogenic sources are also included in the inventory. The CO_2 emissions from fossil combustion are calculated using emissions factors based on the total carbon content of the fuel assuming all carbon not remaining in the ash to be converted to CO_2. Therefore, consistent with the IPCC Guidelines, indirect CO_2 emissions are not reported for combustion sources of CO, CH_4 and NMVOCs. Similarly, indirect CO_2 from CH_4, CO or NMVOC emissions from other emission sources where these emissions are already included in CO_2 emissions, are not reported. At present, all CO emissions reported come from such sources. More details on the estimation of the indirect CO_2 emissions can be found in Chapter 9. Finland’s national total emissions include the indirect CO_2 emissions but are presented with and without indirect CO_2. The indirect CO_2 emissions have been separately estimated for fugitive emissions in the Energy sector and sources in the Industrial Processes and Product Use sector consistent with the 2006 IPCC Guidelines for National Greenhouse Gas Inventories.

Indirect N_2O emission resulting from deposition of nitrogen due to emissions of nitrogen oxides (NOx) and ammonia (NH_3) are estimated, but only indirect N_2O emissions from agricultural sources are included in the national total emissions consistent with the UNFCCC reporting guidelines in the Annex to Decision 24/CP.19 (UNFCCC 2013).

Emissions and removals have been grouped under five sectors, in accordance with modalities, procedures and guidelines[4] for the transparency framework of the Paris Agreement and the revised UNFCCC reporting guidelines on annual inventories for Annex I Parties[5]: Energy, industrial processes and product use (IPPU), agriculture, land use, land-use change and forestry (LULUCF) and waste.

The emission estimates and removals are presented by gas and by category and refer to the latest inventory year unless otherwise specified. Full time series of the emissions and removals from 1990 to the latest inventory year are included in the Common Reporting Format (CRF) tables, which are part of the inventory submission. In the NID, the data are presented for a limited set of years consistent with the UNFCCC reporting guidelines.

The structure of this NID follows the outline given in Annex V of the guidance[6] for operationalizing the modalities, procedures and guidelines for the enhanced transparency framework referred to in Article 13 of the Paris Agreement.

1.1.2 Climate change

Over the past century, atmospheric concentrations of carbon dioxide (CO_2), methane (CH_4), nitrous oxide (N_2O) and halogenated hydrocarbons, i.e. greenhouse gases, have increased as a consequence of human activity. Greenhouse gases prevent the radiation of heat back to space and cause warming of the climate. According to the Sixth Assessment Report of the International Panel of Climate Change (IPCC 2021), the atmospheric concentrations of CO_2 have increased by 47%, CH_4 concentrations have more than doubled and N_2O concentration has risen by 23%, compared with the concentrations in 1750, i.e. in the pre-industrial era.

Climate change has effects on both human and natural systems (e.g. human settlements, human health, water and food resources, ecosystems and biodiversity). Some of the effects on environmental and socio-economic systems will be beneficial, some damaging. The larger the changes and the rate of changes in climate, the more the adverse effects will predominate. In Finland, the adverse impacts are related, for example, to the resilience of the northern ecosystems, winter tourism, increased flooding and the prevalence of pests and diseases. Positive impacts could be possible growth of productivity in agriculture and forestry and a decreased need for heating energy.

1.1.3 International agreements

Finland has ratified the United Nations Framework Convention on Climate Change, the Kyoto Protocol and its Doha Amendment as well the Paris Agreement. In addition, Finland as an EU Member State, has obligations related to climate change under EU legislation.

Finland’s commitments under the international commitment, including tracking how Finland is making progress with its commitments and how past commitments have been met, have been addressed in Finland’s National Communications and Biennial Reports under the UNFCCC. Finland will submit its first Biennial Transparency Report (BTR) at the latest by 31 December 2024.

Under the EU and UNFCCC and the Paris Agreement Finland is required to carry out annual greenhouse gas inventories covering emissions and removals of direct greenhouse gases from the five sectors (Energy, Industrial Processes and Product Use, Agriculture, Land Use, Land-Use Change and Forestry and Waste) and for all years from the base year to the most recent year. The preparation and reporting of the Finnish greenhouse gas inventory are guided by the modalities, guidelines and procedures (MPGs) adopted at COP 25 in Katowice

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[4] Decision 18/CMA.1
[5] Decision 24/CP.19
[6] Decision 5/CMA.3

(Decision 18/CMA.1[7])) and the guidance for operationalizing the MPGs (5/CMA.3[8]), as well as the methodological guidance in the 2006 IPCC Guidelines for National Greenhouse Gas inventories (hereafter referred to as *2006 IPCC Guidelines*).

1.2 A description of the national circumstances and institutional arrangements

The national inventory arrangements in Finland are described below. The descriptions take into account requirements for reporting requirements on national inventory arrangements under the MPGs of Paris Agreement (18/CMA.1) and relevant EU legislation, as well as for reporting on the national inventory arrangements consistent with paragraph 20 to 27 of the UNFCCC reporting guidelines.

1.2.1 National entity or national focal point

According to the Government resolution of 30 January 2003 on the organisation of climate policy activities of Government authorities, Statistics Finland[9] assumed the responsibilities of the national entity for Finland’s greenhouse gas inventory from the beginning of 2005. In 2015, the role of Statistics Finland as the national entity was enforced through the adoption of the Climate Change Act (609/2015 and 423/2022).

In Finland, the national inventory arrangements are established on a permanent footing to meet the requirements set in the UNFCCC reporting guidelines and in the MPGs referred to in Article 13 of Paris Agreement. The national inventory arrangements are based on laws and regulations concerning Statistics Finland, including Climate Change Act, on agreements between the inventory unit and expert organisations on the production of emission and removal estimates, as well as related documentation. Statistics Finland has also agreements on cooperation and support to the expert organisations participating in Finland’s national system with relevant ministries. The national inventory arrangements are designed and operated to ensure the transparency, consistency, comparability, completeness, accuracy and timeliness of greenhouse gas emission inventories. The quality requirements are fulfilled by implementing consistently the inventory quality management procedures (see Section 1.5.3). The national system of arrangements for the greenhouse gas inventory in Finland is presented in Figure 1.2-1 below. There have been no changes to the national inventory system since the previous submission (see Chapter 11).

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[7] Decision 18/CMA1 Modalities, procedures and guidelines for the transparency framework for action and support referred to in Article 13 of the Paris Agreement https://unfccc.int/sites/default/files/resource/CMA2018_03a02E.pdf

[8]: Decision 5/CMA.3 Guidance operationalizing the modalities, procedures and guidelines for the enhanced transparency framework referred to in Article 13 of the Paris Agreement https://unfccc.int/sites/default/files/resource/CMA2021_L10a2E.pdf

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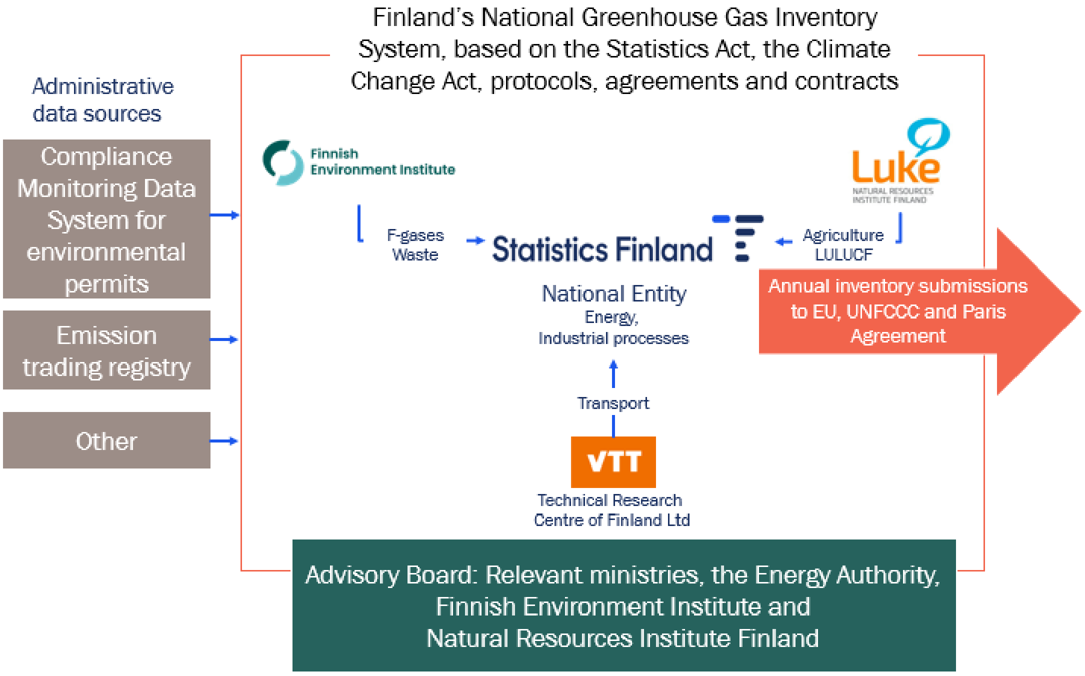

Figure 1.2-1. The National System of arrangements for the Greenhouse Gas Inventory in Finland (LULUCF = Land use, land-use change and forestry)

1.2.1.1 Statistics Finland as the national entity for the inventory

Statistics Finland is the general authority of the official statistics of Finland and is independently responsible for greenhouse gas emission inventory preparation, reporting and submission under the United Nations Framework Convention on Climate Change (UNFCCC) and the Paris Agreement.

In its activity as the national entity for the greenhouse gas inventory, the Statistics Finland Act (48/1992 and its amendment 901/2002) and the Statistics Act (280/2004 and its amendments 361/2013 and 146/2023) are applied.

Statistics Finland defines the placement of the inventory functions in its working order. The advisory board of the greenhouse gas inventory set up by Statistics Finland ensures collaboration and information exchange in issues related to the reporting of greenhouse gas emissions under the UNFCCC and the Paris Agreement. The advisory board reviews planned and implemented changes in the inventory and the achieved quality. It approves changes to the division of tasks between the expert organisations preparing the inventory. In addition, the advisory board promotes research and review projects related to the development of the inventory and reporting, as well as gives recommendations on participation in international cooperation in this area (UNFCCC, IPCC and EU). The advisory board is composed of representatives from the expert organisations and the responsible Government ministries.

Statistics Finland is in charge of the compilation of the national emission inventory and its quality management in the manner intended in the UNFCCC inventory reporting guidelines and the Paris Agreement as well as the relevant EU regulations. As the national entity, Statistics Finland also bears the responsibility for the general administration of the inventory and communication with the UNFCCC and the EU Commission, coordinates participation in the review of the inventory, and publishes and archives the inventory results.

Statistics Finland has access to data collected for administrative purposes. Hence by law, Statistics Finland has access to data collected under the EU ETS, regulation on fluorinated gases, the European Pollutant Release and Transfer Register (E-PRTR) and energy statistics regulation. Access to EU ETS data is also ensured through the agreement between Statistics Finland and the Energy Authority. The EU ETS data and data collected under energy statistics regulation are significant data sources and used both directly and/or for verification in inventory compilation. The use of the E-PRTR and data collected under the regulation on fluorinated greenhouse gases have a limited role in the inventory preparation.

Statistics Finland approves the inventory before the submissions to the UNFCCC secretariat and EU. The draft inventory to the EU on 15 January is presented to the advisory board, and before submitting the final inventory to UNFCCC on 15 April, the national inventory document is sent to the inter-ministerial network on climate policy issues for comments.

1.2.1.2 Responsibilities of expert organisations

Finland's inventory system includes, in addition to Statistics Finland, the expert organisations the Finnish Environment Institute (Syke) and the Natural Resources Institute Finland (Luke). Statistics Finland also acquires parts of the inventory as purchased services from VTT (VTT Technical Research Centre of Finland Ltd).

Up to 2009, Finavia (formerly Civil Aviation Administration) provided emission data on aviation to the inventory. In 2010, Finavia's status in Finland's inventory system changed. Finavia is not performing the calculations and is not responsible for the related calculations anymore. Statistics Finland has overtaken this task and has been responsible for the calculations since 2010. Finavia continues to support Statistics Finland in the task by providing Statistics Finland with expert advice (the calculations are described in Section 3.2.5.3).

The agreements between Statistics Finland and the expert organisations define the division of responsibilities (sectors/categories covered) and tasks related to uncertainty and key category analysis, QA/QC and reviews. They also specify the procedures and schedules for the annual inventory process coordinated by Statistics Finland. The responsibilities to estimate and report emissions/removals from different sectors/categories of the different expert organisations are based on established practices for the preparation and compilation of the greenhouse gas emission inventory. The scope of these responsibilities by expert organisation is presented in Table 1.2-1.

Table 1.2-1 Responsibility areas by expert organisation

Area		Organisations
CRF 1.A.	Stationary sources - fuel combustion in point sources, such as power plants, heating boilers, industrial combustion plants and processes	Statistics Finland
CRF 1.A.	Mobile sources (transport and off-road machinery)	Statistics Finland, VTT Technical Research Centre of Finland Ltd (as a purchased service), Finavia (inventory years 1990 to 2010)
CRF 1.A.	Other fuel combustion (agriculture, households, services, public sector, etc.)	Statistics Finland
CRF 1.B.	Fugitive emissions from energy production and distribution	Statistics Finland
CRF 2.	Emissions from industrial processes and product use	Statistics Finland
CRF 2.	Emissions of F gases	Finnish Environment Institute (Syke)
CRF 3.	Emissions from agriculture	Natural Resources Institute Finland (Luke)
CRF 4.	Emissions from land use, land-use change and forestry	Natural Resources Institute Finland (Luke)
CRF 5.	Emissions from waste	Finnish Environment Institute (Syke)
Indirect CO_2	Non-methane volatile organic compounds, NMVOC	Finnish Environment Institute (Syke)

All the participating organisations are represented in the inventory working group set up to support the process of producing annual inventories and the fulfilment of reporting requirements. The working group advances collaboration and communication between the inventory unit and the experts producing the estimates for the different reporting sectors and ensures the implementation of the QA/QC and verification process of the inventory.

1.2.1.3 The role of responsible ministries and the Energy Authority in the national system

The resources of the national system for the participating expert organisations are channelled through the relevant ministries' performance management (Ministry of the Environment and Ministry of Agriculture and Forestry). In addition, other ministries participating in the preparation of the climate policy advance in their administrative branch that the data collected in the management of public administration duties can be used in the emission inventory.

In accordance with the Government resolution, the ministries produce the data needed for international reporting on the contents, enforcement and effects of the climate strategy. Statistics Finland assists in the technical preparation of the policy reporting. Statistics Finland also technically compiles the National Communications and the biennial reports under the UNFCCC. Separate agreements have been made on the division of responsibilities and cooperation between Statistics Finland and the ministries.

The Energy Authority is the National Emissions Trading Authority and the National Registry Administrator in Finland and supervises the monitoring and reporting of the emissions data under the European Emissions Trading System (EU ETS). Statistics Finland and the Energy Authority concluded an agreement in 2006 on collaboration between the national inventory system and registry[10], including a division of the responsibilities relating to reporting. The most recent update to the agreement was made in 2018.

1.2.2 Inventory preparation process

The UNFCCC and the EU Governance regulation and acts complementing this regulation require Finland to submit annually a National Inventory Document (NID) and inventory tables. The annual submission contains emission estimates for the second to last year, so that the 2024 submission contains estimates for the calendar year 2022.

The organisation of the preparation and reporting of Finland's greenhouse gas inventory and the duties of its different parties are detailed in the previous Section (1.2.1). The expert organisations acting as parties to the inventory system are responsible for the preparation of the inventory data of defined reporting areas. The expert organisations produce the emission estimates and related documentation as defined in the agreements with Statistics Finland (Table 1.2-1) and according to the UNFCCC reporting guidelines. Statistics Finland compiles national reporting from the data produced by expert organisations and submits them to the UNFCCC Secretariat and to the European Commission.

The preparation of the annual inventory follows the schedule of the reporting. Under the EU Governance Regulation and its implementing Regulation (2020/1208), the Member State shall determine and report to the Commission final greenhouse gas inventory data by 15 March each year and preliminary data by 15 January each year. The greenhouse gas inventory is submitted to the UNFCCC Secretariat by 15 April. The joint EU inventory is compiled from the Member States' submissions and it is also supplied to the UNFCCC Secretariat by 15 April. The Commission uses the inventory data submitted annually by Member States also when evaluating the progress of the Community and its Member States towards the set greenhouse gas emission objectives and commitments.

Data collection and processing of each category are described in category-specific chapters. In addition, data sources used are described in Section 1.3.

Inventory documentation consists of inventory data and metadata (data explaining the calculated estimates). Documentation has a key role in inventory quality management. Meeting the requirement of transparency requires systematic documentation. Careful documentation also facilitates external evaluation of the inventory. The goal is to make replication of the inventory possible for the expert reviewers, should it be necessary. Due to the complexity of some of the methods used in the inventory preparation, the replication of inventory calculations will in some cases require, in addition to the documentation, access to the model and support by

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[10] Finland's National Kyoto Protocol Registry is briefly described in Finland's Eight National Communication, Section 3.4, submitted to the UNFCCC in December 2022.

experts familiar with their use. Documentation also stands as evidence of the compliance and functionality of the national system. Continuous, fact-based improvement of the inventory is steered by an analysis of the materials accumulated during the inventory process.

The inventory documentation system consists of the following document types:

1. Basic documents of the national system that are produced, updated and archived by Statistics Finland according to its archiving system (the system is described below):
    - The description of Finland’s national system
    - Agreements with expert organisations participating in the inventory preparation
    - Other agreements
    - Quality plan and related documents, e.g., documentation of the annual bilateral quality meetings or the quality desk review.

2. Annual inventory process documents by reporting sector, which are produced, updated and archived in the expert organisations responsible for the sectors, such as:
    - Primary material for the calculation
    - Internal documents for the calculation.

3. Inventory level documents of the annual inventory process, which are produced, updated and archived in the inventory unit according to Statistics Finland’s archiving system:
    - The general plan for compiling the inventory
    - Internal documents for compiling the inventory
    - Reference for country-specific data and methods
    - The set of CRF tables and CRF xml-files and the National Inventory Document (NID)
    - Review reports and other relevant material related to the review
    - The inventory improvement plan.

1.2.3 Archiving information

The main archives of the greenhouse gas inventory unit are at Statistics Finland. The main archive’s purpose is to fill the specific function mandated in the guidelines for national systems (UNFCCC Decision 20/CP.7, paragraphs 16 and 17): it holds all the important data, models and documentation needed in inventory development. It aims to facilitate efficient review of the inventory and provide fast responses to questions posed by expert review teams during reviews. The greenhouse gas inventory unit has prepared a working instruction for archiving, which also works as a plan for archive creation, that describes how and which records are being archived and the manner they are preserved. According to the working instructions, the archiving takes place between January and May each year, after submission of the inventory to the EU or UNFCCC. The main archive of the inventory is located on a server in Statistics Finland’s local area network. This archive has restricted writing privileges and daily back-up copies are created. In addition, Statistics Finland has a system for archiving data and metadata electronically in the national archives of Finland. The CRF data and SAS data sets of the Energy and IPPU (excl. F gases) sector are also archived in with this electronic archiving system. In addition to the guidelines for national systems, Statistics Finland needs to comply with the general record management duties laid down in Finnish legislation (for instance, the Archives Act 831/1994).

In addition to the main archive, the expert organisations have archives located in their own facilities. Typically, these organisations keep records of their work on the hard disks of individual experts’ workstations, with copies on backed-up network servers. Electronic copies on CD-ROMs, portable external hard drives or USB memory sticks are also produced. The expert organisations have implemented their archival procedures according to their own plans of archive creation, with systems for electronic storage and retrieval of records.

Energy and Industrial Processes and Product Use

The Energy (except transportation) and Industrial Processes and Product Use sector (except F gases) documentation and annual inventory records are archived according to working instructions (see above). The archiving of inventory records for these categories takes place as follows:

1. All data, models used at Statistics Finland and documentation needed in inventory preparation are preserved in an archive located on a server in Statistics Finland's local area network, which is backed-up daily. This archive has restricted writing privileges. These servers are physically located in the premises of Government ICT Centre.
2. The CRF data and SAS data sets of the Energy and IPPU (excl. F gases) sector are also archived electronically in the national archives of Finland (see above).

The archiving of inventory records for the transport category takes place as follows:

1. All calculation models (LIISA, RAILI, MEERI, and TYKO) including the calculation results and time series are annually filed. One copy to the official archive of VTT Technical Research Centre of Finland Ltd and one copy to the responsible person (presently Arttu Lauhkonen). All models and their documentation for all years are also stored in a SharePoint system at VTT.
2. All information produced during the calculation process is included in VTT's official back-up-system.

The archiving of inventory records for the civil aviation category has been as follows (Finavia will keep the records in their archives for 10 years):

1. Calculation results and ILMI model documents are filed as a paper copy to the archive of Finavia's Environmental unit
2. The ILMI model, including the calculation results and time series and all information produced during the calculation process are annually stored in a specific folder on a server maintained by the Information and Communication Technology unit of Finavia.

The archiving of inventory records for the F gases category takes place as follows:

1. Original survey responses in paper form of the sectoral inventory are archived in the archival room 214 at the Finnish Environment Institute (Syke).
2. The survey responses received from the web-based data collection system and e-mail are archived in Syke's servers.
3. In addition to the original survey responses, the material archived in the sectoral expert's office consists of hand-written notes, printed copies of survey questionnaires and mailing lists. Incoming survey responses are entered into an electric database in chronological order and the original paper copies are filed in dated folders (see point 1). The F gas archive at Syke also include printouts of data analysing spreadsheets, final CRF tables, quality assurance plans for each year and the references used in the inventory. Since submission 2021, all archiving of the F gas inventory has taken place in electronic format.
4. All material, except handwritten notes, is archived in electric files. Electronic files are saved on Syke's servers, which are back-up copied regularly, and on CD-ROMs or portable external hard drive, which are kept in the archive among the registry of paper copies. The archived electronic files contain the following information:
   - Survey data in a matrix database
     - All activity data is entered in an electronic database
     - Chronological listing and recording of responses enable easy access to the original copies of survey responses
   - Spreadsheet applications used for data analysing and calculation
     - Used methods, emission factors and parameters are displayed on worksheets
     - Estimates are presented for different gases at subcategory level, as well as at aggregated category level
     - Estimates of activity data and emission factor uncertainty
   - Submitted CRF data
   - Final version of the inventory document (NID)
   - Annual QA/QC plans

The archiving of inventory records for the indirect CO_2 emissions from NMVOCs category takes place as follows:

1. The calculation sheets of NMVOC emissions are stored in electronic form and saved on Syke's servers. Back-up tapes are created automatically every day.
2. The calculation model includes calculation results and time series.
3. Activity data, including questionnaires to industry, and information on emission factors are stored at least in paper form at the Finnish Environment Institute (Syke) in room 210 and in electronic form if available.
4. All electronic files created during the calculation process are backed-up regularly on a portable USB flash drive and kept in the archive of the sectoral expert.

Agriculture

During the inventory compilation, the calculation sheets and data documents related to inventory are stored in the server maintained by the information services of the Natural Resources Institute Finland (Luke). The folder structure is similar for each inventory year, which makes data management easier. A limited group of persons have access rights to the files. After the compilation, the results and relevant data are archived in Luke's electronic archive VIRTA. The files are write-protected to prevent accidental modification or erasure.

LULUCF

The archiving of LULUCF sector:

1. Original National Forest Inventory data (NFI) are archived at the Natural Resources Institute Finland (Luke). Database comprise of ASCII-files stored in a LINUX operating system.
2. Luke's statistics on forestry and agriculture and the quality descriptions of statistics are published on the Internet https://www.luke.fi/en/statistics. Descriptions of each statistics are available in English. Data collected for statistics are stored at Luke according to the Statistics Act (280/2004).
3. All activity data, calculation procedures and internal documentation, results and reports are archived in Luke's case processing system VIRTA after each submission. The files are write-protected to prevent accidental modification or erasure.

Waste

All electronic data (mainly Excel, Word or Access files) on the annual waste inventory including databases, models and documentation are collected in two separate places: the folder of the hard disk of the computer used in the inventory, the outer back-up hard disk of the computer. In addition to this, common network disk drive for sharing data also acts as a backup for essential files. Annual information on paper is collected at the Finnish Environment Institute (Syke) in the room 208 and in the archival room 214.

1.2.4 Process for official consideration and approval of inventory

Statistics Finland is the national entity with the overall responsibility for the compilation and finalisation of inventory reports and their submission to the UNFCCC Secretariat and the European Commission. Statistics Finland approves the inventory submissions to the EU and UNFCCC independently.

Before the finalisation of the inventory report, the draft inventory to the EU on 15 January is presented to the advisory board of the greenhouse gas inventory (see Section 1.2.1.1 on the role of the advisory board). Before submission of the final inventory to UNFCCC on 15 April, the national inventory document is sent to the inter-ministerial network on climate policy issues for comments.

1.3 Brief general description of the methodologies (including tiers used) and data sources used

The methodologies used for the Finnish greenhouse gas inventory are consistent with 2006 IPCC Guidelines. Methods and emission factors by category are presented in Table 1.3-1. This table is not fully consistent with the CRF tables. CRF Reporter is programmed in a way that method and emission factor information changes automatically to NA for subcategories with no emissions data (notation keys IE or C are used in the respective cells in the Reporter). The NID includes the correct method and emission factor information for these subcategories. Detailed descriptions of the methodologies used by sector are found in Chapters 3 to 9.

Table 1.3-1 Reported emissions, calculation methods and type of emission factors used in the Finnish inventory in 2021 (CS = country-specific, CR = Corinair, D= default, PS= plant-specific, M= model, OTH= other)

CRF	Source	Stock change reported	Emissions reported	Method	Emission factor
1. Energy					
1.A Fuel combustion					
1.A.1	Energy Industries		CO_2 CH_4 N_2O	Tier 3 Tier 3 Tier 3	CS, D, PS CS CS
1.A.2	Manufacturing industries and construction (stationary sources)		CO_2 CH_4 N_2O	Tier 3 Tier 3 Tier 3	CS, PS CS CS
1.A.2	Manufacturing industries and construction (mobile sources)		CO_2 CH_4 N_2O	Tier 3 Tier 3 Tier 3	CS CR CR, D
1.A.3	Transport		CO_2 CH_4 N_2O	Tier 2, Tier 1 Tier 3, Tier 1 Tier 3, Tier 1	CS CR, CS, D, OTH CR, CS, D, OTH
1.A.4	Other Sectors (stationary sources)		CO_2 CH_4 N_2O	Tier 3, Tier 2, Tier 1 Tier 3, Tier 2, Tier 1 Tier 3, Tier 2, Tier 1	CS, D CS, D CS, D
1.A.4	Other Sectors (mobile sources)		CO_2 CH_4 N_2O	Tier 3, Tier 2 Tier 3, Tier 1 Tier 3, Tier 1	CS CR, OTH CR, OTH, D
1.A.5	Other		CO_2 CH_4 N_2O	Tier 2 Tier 2 Tier 2	CS CS CS
1.B Fugitive emissions from fuels					
1.B.2	Oil and natural gas and other emissions from energy production		CO_2 CH_4 N_2O	CS Tier 1, Tier 2, CS CS	CS CS, PS, D CS
1.C CO_2 transport and storage					
1.C.1	Transport of CO_2, pipelines		CO_2	IE[11]	NA

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[11] CO_2 emissions are calculated from the amount of PCC produced from captured CO_2. Therefore, no losses during the capture, transfer and production are reported separately.

CRF	Source	Stock change reported	Emissions reported	Method	Emission factor
2. Industrial processes and product use					
2.A Mineral industry					
2.A.1	Cement production		CO_2	Tier 3	PS
2.A.2	Lime production		CO_2	Tier 3	CS
2.A.3	Glass production		CO_2	Tier 3	CS
2.A.4	Other process uses of carbonates				
	- Ceramics		CO_2	Tier 3	CS
	- Other uses of Soda Ash		CO_2	Tier 1	D
	- Other		CO_2	Tier 3	CS
2.B Chemical industry					
2.B.1	Ammonia Production		CO_2	Tier 1	D
2.B.2	Nitric acid Production		N_2O	Tier 3	PS
2.B.6	Titanium Dioxide Production		NO		
2.B.8	Petrochemical and carbon black production; ethylene		CO_2 CH_4 (fugitive)	IE (1.A.2c) Tier 2	 PS
2.B.10	Other				
	- Phosphoric acid Production		CO_2	CS	PS
	- Hydrogen Production		CO_2	Tier 2	CS
	- Formalin Production		CO_2	Tier 3	CS
	- Limestone and dolomite use		CO_2	Tier 3	CS
2.C Metal industry					
2.C.1	Iron and Steel Production				
	- Steel		CO_2	Tier 3, CS	CS
	- Limestone and dolomite use		CO_2	Tier 3	CS
	- Pig iron		IE (Steel)	Tier 3, CS	CS
	- Sinter		IE (Steel)	Tier 3, CS	CS
	- Other: Coke		CH_4	Tier 1	D
2.C.2	Ferroalloys Production		IE (2.C.1)	Tier 3, CS	CS
2.C.4	Magnesium production		CO_2 SF_6 IE (2.H.3)	NA Tier 2	NA NA
2.C.6	Zinc Production		IE (2.C.7)	Tier 2	CS
2.C.7	Other				
	- Zinc, copper and nickel production		CO_2	Tier 2	CS
2.D Non-energy products from fuels and solvent use					
2.D.1	Lubricant use		CO_2 CH_4, N_2O	Tier 1 Tier 1	D CS
2.D.2	Paraffin wax use		CO_2	Tier 1	D
2.D.3	Other				
	- Other; Use of urea-based catalysts		CO_2	Tier 1	D

CRF	Source	Stock change reported	Emissions reported	Method	Emission factor
	- Other, Use of urea in Nox control in the energy industry		CO_2	Tier 2	D
2.E Electronics industry					
2.E.1	Integrated circuit or semiconductor		HFC, PFC, SF_6 IE (2.H.3)	OTH, Tier 2a	CS, D
2.F Product uses as substitutes for ODS					
2.F.1	Refrigeration and air conditioning equipment		HFC, PFC	Tier 2	CS, D
2.F.2	Foam blowing and use of foam products		HFC	Tier 2	D
2.F.3	Fire protection		HFC IE (2.H.3)	OTH	NA
2.F.4	Aerosols		HFC	Tier 2	D
2.G Other product manufacture and use					
2.G.1	Electrical Equipment		SF_6, PFC (IE 2.H.3)	Tier 2	CS
2.G.2	SF_6 and PFCs from other product use		SF_6 (IE 2.H.3)	OTH	NA
2.G.3	N_2O from Product uses		N_2O	CS, Tier 1	CS
2.H Other					
2.H.3	Grouped confidential data of halocarbons and SF_6		SF_6 HFCs PFCs	OTH, Tier 2 OTH, Tier 2, OTH, Tier 2	CS, D, NA CS, D CS, D

CRF	Source	Stock change reported	Emissions reported	Method	Emission factor
3. Agriculture					
3.A Enteric fermentation					
3.A.1	Cattle				
	- Dairy Cattle		CH_4	Tier 2	CS
	- Non-Dairy Cattle		CH_4	Tier 2	CS
3.A.2	Sheep		CH_4	CS	CS
3.A.3	Swine		CH_4	CS	CS
3.A.4	Other livestock				
	- Goats		CH_4	Tier 1	D
	- Horses		CH_4	Tier 1	D
	- Poultry		NE1)	NA	NA
	- Reindeer		CH_4	CS	CS
	- Fur-bearing animals		CH_4	OTH	OTH
3.B Manure management					
3.B.1	Cattle				
	- Dairy Cattle		CH_4	Tier 2	CS
			N_2O	Tier 2	D
	- Non-Dairy Cattle		CH_4	Tier 2	CS
			N_2O	Tier 2	D
3.B.2	Sheep		CH_4	Tier 2	CS
			N_2O	Tier 2	D
3.B.3	Swine		CH_4	Tier 2	CS
			N_2O	Tier 2	D
3.B.4	Other livestock				
	- Poultry		CH_4	Tier 2	CS
			N_2O	Tier 2	D
	- Horses		CH_4	Tier 2	CS
			N_2O	Tier 2	D
	- Goats		CH_4	Tier 2	CS
			N_2O	Tier 2	D
	- Fur-bearing animals		CH_4	Tier 2	OTH
			N_2O	Tier 2	D
	- Reindeer		CH_4	Tier 2	CS
			N_2O	Tier 2	D
	Liquid system		N_2O	Tier 2	D
	Solid storage and dry lot		N_2O	Tier 2	D
	Pasture, range, and paddock		IE (3.D.3)	Tier 1	D
	Other[12]		N_2O	Tier 2	D
3.D Agricultural soils					
3.D.a	Direct Soil Emissions				
	- Synthetic Fertilisers		N_2O	Tier 1	D
	- Animal Manure Applied to Soils		N_2O	Tier 1	D
	- Municipal Sewage Sludge Applied to Soils		N_2O	Tier 1	D
	- Other Organic Fertilizers Applied to soils		N_2O	Tier 1	D
	- Pasture, Range and Paddock Manure		N_2O	Tier 1	D
	- Crop Residues		N_2O	Tier 1	D

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[12] Other AWMS (animal waste management system) is deep litter

CRF	Source	Stock change reported	Emissions reported	Method	Emission factor
	- Mineralisation associated with loss of soil organic matter (mineral soils)		N_2O	Tier 2	D
	- Cultivation of Histosols		N_2O	Tier 2	D, CS
3.D.b	Indirect Emissions				
	- Atmospheric Deposition		N_2O	Tier 2	D
	- Nitrogen Leaching and Run-off		N_2O	Tier 2	D
3.F Field burning of agricultural residues					
3.F.1	Cereals		NO	NA	NA
3.F.2	Pulses		NO	NA	NA
3.F.3	Tubers and roots		NO	NA	NA
3.F.4	Sugar cane		NO	NA	NA
3.F.5	Other		NO	NA	NA
3.G Liming					
3.G.1	Liming		CO_2	Tier 1	D
3.H Urea application					
3.H.1	Urea application		CO_2	Tier 1	D

CRF	Source	Stock change reported	Emissions reported	Method	Emission factor
4. Land use, land-use change and forestry					
4.A Forest land (remaining, converted)					
	Living biomass	carbon/ CO_2		Tier 3	CS
	DOM, SOM (mineral and organic soils)	carbon/ CO_2		Tier 2, Tier 3	CS
4.B Cropland (remaining, converted)					
	Living biomass	carbon/ CO_2		Tier 2, Tier 3	CS, D
	DOM, SOM (mineral and organic soils)	carbon/ CO_2		Tier 1, Tier 2, Tier 3	CS, D
4.C Grassland (remaining, converted)					
	Living biomass	carbon/ CO_2		Tier 3, Tier 2	CS, D
	DOM, SOM (mineral and organic soils)	carbon/ CO_2		Tier 1, Tier 2, Tier 3	CS, D
4.D Wetlands (remaining, converted)					
	Peat extraction areas: living biomass	carbon/ CO_2		Tier 3	CS
	Peat extraction areas: DOM, SOM	carbon/ CO_2		Tier 2	CS
	Flooded land: living biomass	carbon/ CO_2		Tier 3	CS
	Flooded land: DOM, SOM	carbon/ CO_2		Tier 1	CS, D
	Other wetlands: SOM	carbon/ CO_2		Tier 2	CS
4.E Settlements (converted)					
	Living biomass	carbon/ CO_2		Tier 3	CS
	DOM, SOM	carbon/ CO_2		Tier 2	CS
4.F Other land (converted)					
	Living biomass	carbon/ CO_2		Tier 1	D
	DOM, SOM	carbon/ CO_2		Tier 1	D
4.G Harvested Wood Products		carbon/ CO_2		Tier 2	CS, D
4.(I) Direct N_2O emissions from fertilisation					
	Forest land		N_2O	Tier 1	D
4.(II) Non-CO_2 emissions from drainage and rewetting and other management of organic and mineral soils					
	Wetlands: Peat extraction areas		CH_4, N_2O	Tier 2	CS
	Wetlands: Flooded land		CH_4	Tier 1	D
	Other Wetlands		CH_4, N_2O	Tier 2	CS
	Forest land: Drained organic forest soils		CH_4, N_2O	Tier 1, Tier 2	CS, D
4.(III) Direct non-CO_2 emissions from N mineralisation/immobilisation					
	Forest land, Settlements, Cropland, Grassland		N_2O	Tier 1	CS, D
4.(IV) N_2O emissions from N leaching and runoff					
	Land converted to Cropland and Grassland		N_2O	Tier 1, Tier 2	CS, D
4.(V) Biomass burning					
	Forest land, Grassland		CO_2, CH_4, NO_2	Tier 2	D

CRF	Source	Stock change reported	Emissions reported	Method	Emission factor
5.Waste					
5.A Solid waste disposal					
5.A.1	Managed Waste Disposal		CH_4	Tier 2	CS, D
5.A.2	Unmanaged Waste Disposal Sites		CH_4 NO CO_2 NO	NA NA	NA NA
5.B Biological treatment of solid waste					
5.B.1	Composting				
	- Municipal solid waste		CH_4, N_2O	Tier 1	D
	- Municipal sludge		CH_4, N_2O	Tier 1	D
	- Industrial sludge		CH_4, N_2O	Tier 1	D
	- Industrial solid waste, constr. waste		CH_4, N_2O	Tier 1	D
5.B.2	Anaerobic digestation at biogas facilities				
	- Municipal solid waste		CH_4	Tier 1	D
	- Municipal sludge		CH_4	Tier 1	D
	- Industrial sludge		CH_4	Tier 1	D
	- Industrial solid waste, constr. waste		CH_4	Tier 1	D
5.D Wastewater treatment and discharge					
5.D.1	Domestic Wastewater		CH_4 N_2O	Tier 2, CS Tier 1, CS	CS, D D
5.D.2	Industrial Wastewater		CH_4 N_2O	Tier 2, CS CS	CS, D D
5.D.3	Other (Fish Farming)		N_2O	CS	D

A specific feature of the Finnish system is its extensive use of bottom-up data. This is especially true in the case of the Energy (excluding transport) and Industrial Processes and Product Use sectors, where emissions originate from point sources. For these sources, simple equations that combine activity data with emission factors are used. Also, in the waste sector, bottom-up data from solid waste disposal sites and other treatment facilities form the basic activity data. Different sources in the transport categories, Agriculture and LULUCF sectors necessitate the use of more complicated equations and models. Table 1.3-2 summarises the most important data sources used in the inventory.

Table 1.3-2 Main data sources used in the Finnish greenhouse gas inventory

Sector	Main data sources
1.A Energy: Fuel Combustion	YLVA (formerly VAHTI) system Energy Statistics (Statistics Finland) Surveys: electricity production, district heating plants, energy consumption of the manufacturing industry LIPASTO and TYKO models of VTT, Finavia, Eurocontrol Energy Authority (ETS fuel and emission data) Other data (e.g. wood consumption data collected by Natural Resources Institute Finland)
1.B Fugitive Emissions	YLVA system Energy Statistics (Statistics Finland) Individual companies
2. (I) Industrial Processes and Product Use	Energy Authority (ETS emission data) Industrial statistics database YLVA system Individual production plants
2. (II) Industrial Processes and Product Use (F gases)	Surveys of Syke Several statistics (see 4.7.2)

Sector	Main data sources
3. Agriculture	Yearbook of Farm Statistics Finnish Trotting and Breeding Association Finnish Fur Breeders' Association Natural Resources Institute Finland (Luke) Finnish Environment Institute (Syke) Published literature Finnish Food Authority
4. LULUCF	NFI (National Forest Inventory) Finnish Statistical Yearbook of Forestry (data source until 2014) Natural Resources Institute Finland (Luke), Statistics service Published literature National Land Survey of Finland Finnish Food Authority
5. Waste	YLVA system The Finnish Biogas Plant Register and Biogas survey of Statistics Finland Water and Sewage Works Register Register for Industrial Water Pollution Control
Indirect CO_2 emissions	YLVA system ULTIKA/ULJAS, import statistics of Finland Association of Finnish Paint Industry Individual companies Published literature

The YLVA (formerly VAHTI) system of Finland's environmental administration is one of the main data sources used in the inventory (especially in the Energy and Waste sectors). The YLVA system functions as a tool for the 15 Centres for Economic Development, Transport and the Environment in their work on processing and monitoring environmental permits. The data system contains information required by the environmental permits concerning the clients (more than 31,000), such as:

- Identification
- Contact persons
- Respective authorities
- Licence conditions
- Environmental insurance
- Discharge points, such as stacks and sewers
- Emissions control equipment
- Treatment plans
- Boilers and fuels used
- Landfills
- Emissions to air, discharges to water and waste
- Energy production
- Raw materials.

The range of facilities that have requirements to report information of their emissions to the environment to supervising authorities (e.g. according to their environmental permit/emission monitoring programme) is much wider than the IPCC activities in Finland, and also includes fish farms regarding wastewater issues. The installations report annually emission data to the supervising authority. Monitoring of releases is carried out according to the requirements in the monitoring programme (e.g., measurement methods are determined there).

The authorities check the quality of these data before accepting them to the YLVA system. The checks include an overview if the requirements in the permit/programme have been met and of the submitted data. In case the authorities find inconsistencies, the facilities are required to correct the data and resubmit it. The authorities carry out regular visits to supervise the activities at a plant and check issues related to emission monitoring during these visits. Data reported by the plants are also checked (level of emissions, completeness of emissions and activity data reported etc.) by the inventory preparers (Statistics Finland, Syke). If inconsistencies are found, questions are sent to the facilities, which check their data and resubmit the corrected data to the authorities. A more detailed description of YLVA is included in Annex 6.

The EU ETS data obtained from the Energy Authority have become an increasingly important source of activity and emission data for the inventory. It has been used as prime source of activity data (especially for emissions in the Industrial Processes and Product Use sector) and for comparison of fuel consumption and CO_2 emissions of specific installations (mainly energy emissions). Quality assurance of EU ETS data have been reported in the Appendix_3e of Energy.

During 2005 to 2007, Finland implemented the Directive 2003/87/EC of the European Parliament and of the Council establishing a scheme for greenhouse gas emission allowance trading within the Community with the Emissions Trading Act. The Emissions Trading Act was applied to CO_2 emissions from combustion installations with a rated thermal input of more than 20 MW, smaller combustion installations connected to the same district heating network, mineral oil refineries and coke ovens, as well as of certain installations and processes of the steel, mineral and forest industries. An installation belonging to the emissions trading system needs an emissions permit, pursuant to which it has the right to emit CO_2 into the atmosphere. The issuance of permits lies with the Energy Authority. In Finland, the number of installations needing a permit has been around 530 during the first period of the EU ETS.

During the period 2008 to 2012, the EU ETS was linked to the international emissions trading under the Kyoto Protocol. Also, the scope of installations included in the emissions trading was expanded to involve petrochemical cracking installations and mineral wool production, as well as carbon black production.

In 2012, the EU ETS was extended to cover emissions from aviation including internal flights within the EU. Finnish Transport and Communications Agency, Traficom[13] is the national authority for emissions trading in aviation in Finland.

For the period 2013 to 2020, the EU ETS was again extended to cover all installations (not only combustion installations) with thermal input of more than 20 MW and some new industrial sources, such as N_2O emissions nitric acid production. During this period, the emission allowances were mainly auctioned. An EU ETS operator could have also applied for free emission allowances from the Ministry of Economic Affairs and Employment depending on their industrial branch consistent with the decision 2011/278/EU. During the period 2013 to 2020, the EU ETS was still linked to the international emissions trading under the Kyoto Protocol.

The fourth emissions trading period began in 2021. This time the scope was not extended as it was in the beginning of the previous trading periods. At the moment, there are about 500 installations, which need a permit. During this period, the emission allowances are mainly auctioned. An EU ETS operator can apply for free emission allowances from the Energy Authority according to the rules laid down in the delegated regulation (EU) 2019/331.

1.3.1 Changes in the national inventory arrangements since the previous annual greenhouse gas inventory submission

There were no changes in national inventory arrangements i.e. national system since the previous annual inventory submission (see Chapter 11).

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[13] The Finnish Transport Safety Agency (Trafi), the Finnish Communications Regulatory Authority (FICORA) and certain functions of the Finnish Transport Agency merged to form the Finnish Transport and Communications Agency Traficom on 1 January 2019

1.4 Brief description of the key categories

1.4.1 GHG inventory

This section provides a summary of the key categories identified (Table 1.4-1). Finland's key category analysis differs from information reported in CRF Table 7, since it includes Approach 2 analysis and a bit different aggregation level of subcategories than suggested in the 2006 IPCC Guidelines. Annex 1 provides detailed information on the identification of the key categories.

The national key categories for the base year and the latest reported inventory year are identified using Approach 1 and Approach 2, the key categories of Approach 2 are added to the key categories of Approach 1. The key categories listed here were analysed with a national procedure. The aggregation level of subcategories used in the analysis is based on the suggested aggregation level in the 2006 IPCC Guidelines (Vol. 1, Table 4.1) with following disaggregation:

i) Category *1.A.3b Road Transportation* is subdivided to main fuel types,
ii) Category *2.B.10 Other* is subdivided to the 4th CRF category level,
iii) Category *2.D Non-energy Products from Fuels and Solvent Use* is subdivided to the 3rd CRF category level.

These disaggregated subcategories have clearly distinguishable activity data and cross correlation between them is minimal.

The categories *4.D.1 Wetlands remaining wetlands* and *4.D.2 Land converted to wetlands* are kept in the 3rd CRF category level. Here the peat extraction area is the main activity area and the other subcategories have a minor role. Subdivision of this category would increase uncertainties since cross correlations between the subcategories are poorly known.

Indirect CO_2 emissions are included in the key category analysis.

Results of the key category analysis are important because they guide decisions on methodological choice (together with uncertainty analysis, see Section 1.6). The goal is to screen the long list of category-gas combinations (over 200 categories) and find those that are the most important in terms of the emissions level and the trend. This short list (Table 1.4-1) forms the basis of discussions with the sectoral experts on the quality of the estimates and possible need for improvement. The key categories are also subject to more detailed documentation and quality control.

Table 1.4-1 Key categories identified using Approach 1 and Approach 2 level and trend assessment

Category		**Gas**	**Level**		**Trend**
			Base year	Year 2022	
1.A.1. Energy Industries	Liquid	CO_2	Yes	Yes	Yes
1.A.1. Energy Industries	Solid	CO_2	Yes	Yes	Yes
1.A.1. Energy Industries	Gaseous	CO_2	Yes	Yes	Yes
1.A.1. Energy Industries	Other fossil	CO_2		Yes	Yes
1.A.1. Energy Industries	Peat	CO_2	Yes	Yes	Yes
1.A.1. Energy Industries	Biomass	N_2O		Yes	Yes
1.A.2. Manufacturing Industries and Construction	Liquid	CO_2	Yes	Yes	Yes
1.A.2. Manufacturing Industries and Construction	Solid	CO_2	Yes	Yes	Yes
1.A.2. Manufacturing Industries and Construction	Gaseous	CO_2	Yes	Yes	Yes
1.A.2. Manufacturing Industries and Construction	Other fossil	CO_2		Yes	Yes
1.A.2. Manufacturing Industries and Construction	Peat	CO_2	Yes	Yes	Yes
1.A.3.a. Domestic Aviation	Liquid	CO_2	Yes		Yes
1.A.3.b. Road Transportation	Diesel oil	CO_2	Yes	Yes	Yes
1.A.3.b. Road Transportation	Diesel oil	N_2O		Yes	Yes
1.A.3.b. Road Transportation	Motor gasoline	CO_2	Yes	Yes	Yes
1.A.3.b. Road Transportation	Motor gasoline	CH_4			Yes
1.A.3.b. Road Transportation	Motor gasoline	N_2O			Yes
1.A.3.c. Railways	Liquid	CO_2			Yes
1.A.3.d. Domestic Navigation	Liquid	CO_2	Yes	Yes	
1.A.4. Other Sectors	Liquid	CO_2	Yes	Yes	Yes
1.A.4. Other Sectors	Peat	CO_2			Yes
1.A.4. Other Sectors	Biomass	CH_4	Yes	Yes	Yes
1.A.4. Other Sectors	Biomass	N_2O		Yes	Yes
1.A.5. Other	Liquid	CO_2	Yes	Yes	Yes
1.A.5. Other	Gaseous	CO_2			Yes
1.B.2. Oil and Natural gas and other emissions from energy		CH4			Yes
2.A.1. Cement Production		CO_2	Yes	Yes	Yes
2.A.2. Lime Production		CO_2	Yes	Yes	
2.B.2. Nitric Acid Production		N_2O	Yes		Yes
2.B.10.b. Hydrogen Production		CO_2		Yes	Yes
2.C.1. Iron and Steel Production		CO_2	Yes	Yes	Yes
2.C.7. Other metal industry		CO_2	Yes		
2.D.1. Lubricant use		CO_2	Yes		
2.F.1. Refrigeration and Air Conditioning		HFCs		Yes	Yes
3.A. Enteric Fermentation		CH_4	Yes	Yes	Yes
3.B. Manure Management		CH_4	Yes	Yes	Yes
3.B. Manure Management		N_2O	Yes	Yes	Yes
3.D.1. Direct N2O Emissions From Managed Soils		N_2O	Yes	Yes	Yes
3.D.2. Indirect N2O Emissions From Managed Soils		N_2O	Yes	Yes	Yes
3.G. Liming		CO_2	Yes	Yes	Yes
4.A.1. Forest Land Remaining Forest Land		CO_2	Yes	Yes	Yes
4.A.2. Land Converted to Forest Land		CO_2	Yes		
4.B.1. Cropland Remaining Cropland		CO_2	Yes	Yes	Yes
4.B.2. Land Converted to Cropland		CO_2	Yes	Yes	Yes
4.C.1. Grassland Remaining Grassland		CO_2	Yes	Yes	Yes
4.D.1. Wetlands Remaining Wetlands		CO_2	Yes	Yes	Yes
4.E.2. Land converted to Settlements		CO_2	Yes	Yes	
4.G. Harvested Wood Products		CO_2	Yes	Yes	Yes
4(II). Drainage and Rewetting and Other Management of Soils		CH_4	Yes	Yes	Yes
4(II). Drainage and Rewetting and Other Management of Soils		N_2O	Yes	Yes	
5.A. Solid Waste Disposal		CH_4	Yes	Yes	Yes
5.B. Biological Treatment of Solid Waste		CH_4			Yes
5.B. Biological Treatment of Solid Waste		N_2O	Yes		Yes
5.D. Wastewater Treatment and Discharge		CH_4	Yes	Yes	
5.D. Wastewater Treatment and Discharge		N_2O	Yes	Yes	Yes

1.5 Brief general description on QA/QC plan and implementation

This section presents the quality management including quality objectives and the QA/QC and verification plan for the Finnish greenhouse gas inventory at the national inventory level. Category-specific QA/QC details are discussed in the relevant sections of this NID.

1.5.1 Quality management

The objective of Finland's GHG inventory system is to produce high-quality GHG inventories, which means that the structure of the national system (i.e. all institutional, legal and procedural arrangements) for estimating greenhouse gas emissions and removals and the content of the inventory submissions (i.e. outputs, products) comply with the requirements and principles.

The starting point for accomplishing a high-quality GHG inventory is consideration of the expectations and requirements directed at the inventory. The quality requirements set for the annual inventories – transparency, consistency, comparability, completeness, accuracy, timeliness and continuous improvement – are fulfilled by implementing the QA/QC process consistently in conjunction with the inventory process (Figure 1.5-1). The quality control and quality assurance elements are integrated into the inventory production system, which means that each stage of the inventory process includes relevant procedures for quality management.

The inventory process consists of four main stages: planning, preparation, evaluation and improvement (PDCA cycle) and aims at continuous improvement. A clear set of documents is produced on the different work phases of the inventory. The documentation ensures the transparency of the inventory: it enables external evaluation of the inventory and, where necessary, its replication.

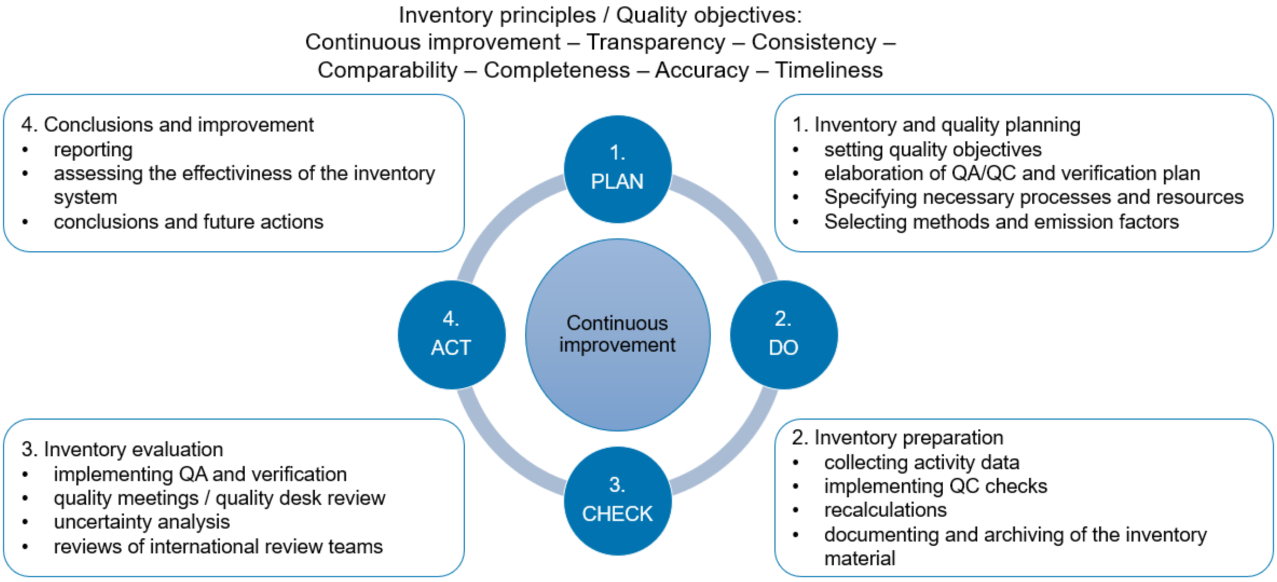

Figure 1.5-1 Inventory and QA/QC process of the inventory

Statistics Finland has the overall responsibility for the GHG inventory in Finland, including the responsibility for coordinating the quality management measures at the national level. The quality coordinator steers and facilitates the quality assurance and quality control (QA/QC) and verification process and elaborates the QA/QC and verification plan (Section 1.5.2). The expert organisations contributing to the production of emission or removal estimates are responsible for the quality of their own inventory calculations. Experts on each inventory sector implement and document the QA/QC and verification procedures.

Issues related to QA/QC and verification are discussed at the meetings of the inventory working group (three to five meetings per year) and at the bilateral quality meetings or in conjunction with the quality desk reviews between the inventory unit and the expert organisations (once a year). The main findings and conclusions concerning the inventory's quality and improvement needs are communicated to the advisory board. A shared workspace including, e.g., guidelines, plans, templates and checklists is in place and available to all parties of the national inventory system via the Internet.

Statistics Finland bears the responsibility for archiving the basic documents of the national system and the submissions of annual inventories (CRF tables and NID). Expert organisations contributing to the sectoral calculations archive the primary data used, internal documentation of calculations and sectoral CRF tables (See Section 1.2.3).

In addition to consideration of the specific requirements in the guidelines for greenhouse gas inventories, the development of the inventory quality management system followed the principles and requirements of the ISO 9001 standard. The advantages (e.g. the perspective of a third-party assessment) and costs (e.g. the amount of resources required for registration) of certification were evaluated in conjunction with the development of the inventory quality management system, and Statistics Finland has decided not to apply for the ISO 9001 compliance certification.

Also, as a national statistical office, Statistics Finland and its Greenhouse Gas Inventory Unit are committed to quality. The principles of the European Foundation for Quality Management (EFQM principles) are employed by Statistics Finland as it is the overall framework for quality management. The quality management framework of the field of statistics is the European Statistics Code of Practice (CoP). The frameworks complement each other and supports the GHG inventory quality management (http://www.tilastokeskus.fi/org/periaatteet/laadunhallinta_en.html).

1.5.2 QA/QC and verification plan and quality objectives (Plan)

The inventory planning stage includes the setting of quality objectives and elaboration of the QA/QC and verification plan for the coming inventory preparation, compilation and reporting work. In addition, a schedule of the coming inventory round is prepared and presented to the expert organisations. The timetable includes, for example, deadlines for QC checks of the inventory compilation and draft meeting schedules of the inventory working group and advisory board.

The setting of quality objectives is based on the inventory principles. Quality objectives (Table 1.5-1) are specified statements about the quality level that is aimed at the inventory preparation with regard to the inventory principles. The objectives aim to be appropriate and realistic while taking into account the available resources and other conditions in the operating environment.

Table 1.5-1. The quality objectives regarding all calculation sectors for the inventory

Quality objectives
1. Continuous improvement
1.1. Treatment of review feedback is systematic
1.2. Improvements promised in the National Inventory Document (NID) are carried out
1.3. Improvement of the inventory is systematic
1.4. Inventory quality control (QC) procedures meet the requirements
1.5. Inventory quality assurance (QA) is appropriate and sufficient
1.6. Verification of the inventory meet the requirements
1.7. Known uncertainties of the inventory are taken into consideration when planning the improvement needs
2. Transparency
2.1. Archiving of the inventory is systematic and complete
2.2. Internal documentation of calculations supports emission and removal estimates
2.3. CRF tables and the National Inventory Document (NID) include transparent and appropriate descriptions of emission and removal estimates and of their preparation
3. Consistency
3.1. The time series are consistent
3.2. Data have been used in a consistent manner in the inventory
4. Comparability
4.1. The methodologies and formats used in the inventory meet comparability requirements
5. Completeness
5.1. The inventory covers all the emission sources, sinks, gases and geographic areas
6. Accuracy
6.1. Estimates are systematically neither higher nor lower than the true emissions or removals
6.2. Calculation is correct
6.3. Inventory uncertainties are estimated
7. Timeliness
7.1. High-quality inventory documents reach their receivers (EU/UNFCCC) within the set time

The quality objectives and the planned general and category-specific QA/QC and verification procedures regarding all sectors are set in the QA/QC plan. This is a document that specifies the actions, schedules and responsibilities in order to attain the quality objectives and to provide confidence in the Finnish national system's capability to deliver high-quality inventories. The QA/QC plan is written in Finnish, updated annually, and consists of instructions and a QA/QC form. Instructions include descriptions of, e.g., quality objectives, general and category-specific inventory QC checks, information on quality assurance and verification, schedules, and responsible parties. The QA/QC form addresses the actions to be taken in each stage of the inventory preparation. Sectoral experts fill in the form the QA/QC and verification procedures performed, and the results of the procedures. Discussions in the bilateral quality meetings or feedback given during the quality desk reviews are based on information documented on these forms. The QA/QC plan is available in the shared workspace of the inventory and archived according to the inventory unit's archive formation plan.

In addition to the general QA/QC plan, the expert organisations may use category-specific QC checklists. These lists are included in the internal documentation of the calculations.

1.5.3 Quality control procedures (Do)

The general and category-specific QC procedures are performed by the experts during inventory calculation and compilation according to the QA/QC and verification plan.

The QC procedures used in Finland's GHG inventory comply with the 2006 IPCC Guidelines. General inventory QC checks (2006 IPCC Guidelines, Vol 1, Chapter 6, Table 6.1) include routine checks of the integrity, correctness and completeness of the data, identification of errors and deficiencies, and documentation and archiving of the inventory data and quality control actions. Category-specific QC checks including reviews of the activity data, emission factors and methods are applied on a case-by-case basis focusing on key categories and on categories where significant methodological changes or data revisions have taken place.

Once the experts have implemented the QC procedures, they complete the QA/QC and verification form for each category, which provides a record of the procedures performed. Results of the completed QC checks are recorded in the internal documents of the calculations and archived in the expert organisations. Key findings are summarised in the category-specific chapters of this NID.

Several QC checks are implemented at Statistics Finland during the compilation of the CRF Tables and the NID. A specific excel workbook is established to improve the assessment of results, emission trends and to ease the detection of errors and inconsistencies. Also, the NID tables and figures are produced based on CRF data as much as possible to ensure consistency between CRF Tables and the NID. This is continuously improved in order to avoid any discrepancies.

1.5.4 Quality assurance (Check)

The QA reviews are performed after the implementation of QC procedures concerning the finalised inventory. The QA system comprises reviews and audits to assess the quality of the inventory and the inventory preparation and reporting process, to determine the conformity of the procedures taken and to identify areas where improvements could be made.

Specific QA actions differ in their viewpoints and timing. The actions include basic reviews of the draft report, quality meetings or quality desk reviews, internal and external audits, peer reviews, comparisons under the EU Governance Regulation and UNFCCC and EU inventory reviews.

EU Governance Regulation

Under the EU Governance Regulation, Finland annually compares greenhouse gas inventory data with data reported under the UN ECE (air pollutant data), the EU ETS and energy statistics. At present, the European environmental Agency (EEA) performs QA/QC of EU Member States' submissions under the EU Governance Regulation and acts complementing it (e.g. annual initial checks, comprehensive reviews in 2025 and 2027, compliance checks in 2027 and 2032 and comparisons across Member States). These checks and comparisons produce valuable information for correction of potential errors and deficiencies. The information is taken into account before Finland submits its final annual inventory to the EU and the UNFCCC.

Basic review of the draft submission

A basic review of the draft GHG emission and removal estimates and the draft report takes place before the initial submission to the EU (in November to December) and again before the final submissions to the EU and UNFCCC (January to March) by the inventory experts and the inventory unit. The basic review includes for example analyses of emission and removal trends and recalculations, checks of NID and CFR tables. These analyses and checks are performed by sectoral experts and by the inventory unit. Final official consideration, which includes review and approval of the submission, is done by Statistics Finland after the annual quality meetings or quality desk reviews and after the EU initial check.

Internal and external audits

An annual in-depth-review of the inventory by sector or responsibility area is done mainly in conjunction with the bilateral quality meetings or the quality desk review. The bilateral quality meetings are held annually between the inventory unit (the compiler) and the expert organisations (producing the inventory estimates and descriptions) in January to February. For sectors and responsibility areas, where no significant changes in the inventory calculations have been made, quality desk reviews are performed by the quality coordinator. During this review, issues concerning quality are discussed by e-mail or phone. In 2024 (inventory 2022) bilateral quality meetings were held for every sector.

The main objective of the quality meetings and quality desk review is to ensure that the experts have implemented the QC checks and required QA and verification procedures according to the QA/QC and verification plan and to evaluate the results and documentation of the procedures (Figure 1.5-2). Quality meetings and desk reviews follow a fixed agenda that include the following items: Implementation of the QA/QC plan, category-specific QA/QC and verification actions if relevant, review feedback, structure and transparency of the reporting (NID and CRF tables), improvement needs and plans, and functioning of the national inventory system (e.g. resources for inventory preparation). The main findings and conclusions concerning the inventory's quality and improvement needs are considered by the advisory board and communicated to the parties to Finland's GHG inventory system. These conclusions concerning the 2022 quality meetings were for example that all sectors perform QA/QC and verification procedures and aim towards continuous improvement, and every sector should have substitute experts.

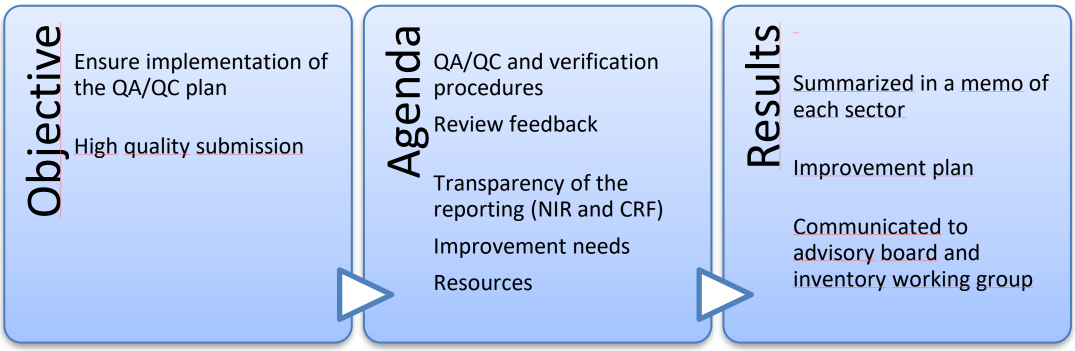

Figure 1.5-2 Objective, agenda and results of the quality meetings and desk reviews

Category-specific internal audits have a specific viewpoint and timing in the QA system. They are extensive QA assessments that are focused on topical or otherwise important factors in one specific sector (not a submission) at a time, e.g., implementation of general and category-specific QC checks, QA and verification procedures, internal documentation or recalculations. In internal audits, representatives of the inventory unit visit the expert organisation to evaluate how effectively the actual activity and the results attained in the specific calculation sectors comply with the requirements. Internal audits provide an in-depth analysis of the respective procedures taken to develop the inventory, and of the available documentation. Above all, the basic task of internal audits is to contribute to the improvement of an inventory in a longer term. Internal audits also contribute to learning and sharing of knowledge and good practices among the actors in the national system. The timing of internal audits is not dependent on the timing of the annual submissions: they are carried out throughout the year within the available resources. The need and focus of internal audits are identified in the bilateral quality meetings or in the quality desk reviews. The audit findings and conclusions are documented in audit reports (in Finnish).

The first internal audit took place in the Agriculture sector in November 2009. The audit covered issues related to the management of review feedback, recalculations and institutional arrangements for inventory preparation. In general, the audit findings and conclusions indicated conformance with the requirements. Some minor improvement needs were identified.

The second internal audit was conducted in the LULUCF sector in October 2010. The audit focused on institutional arrangements for inventory preparation and documentation of the general and sector-specific QA/QC procedures. Non-conformities with the requirements were not found. The audit concluded that the inventory QA/QC system in the sector is effectively implemented and continually improved.

In 2011, two internal audits were carried out, one in mobile sources and another in the Waste sector. The aim of the audits was to ensure the adequacy of the working instructions and other internal documentation for the calculation. In addition, the archiving procedures were reviewed. The audit findings indicated that the internal documents and archiving procedures were in line with the requirements.

In 2013 and 2021, the working instructions of the industrial processes were audited in order to assess the transparency of the instructions. The audit confirmed that the instructions were adequate for the inventory preparation, but few improvement suggestions were made in order to ease the work of new or substitute experts in future.

The documentation of energy sector calculations in the NID were audited in 2017 by an independent expert who is not involved in the Finnish inventory but have some knowledge of Finland‘s energy sector and in-depth knowledge of the greenhouse gas inventory and calculation methodologies. The objective of this audit was to improve the transparency of the NID. In the audit report, it was concluded that in general the quality of the

Finnish NID is high, but some improvements could be made to improve the transparency. For example, some significant changes in the time series should be explained and more comparisons could be presented at aggregate level (Nielsen, 2017). Results of the audit were taken into account in the 2018 and 2019 submissions.

Statistics Finland has had its own internal quality audit system (statistical auditing). The objectives of this quality audit were, for example, to evaluate and question ways of working, methods and techniques, and to identify and search for good practices (Piela, 2011). The auditing examined the production process of an individual set of statistics step by step, analysing the employed procedures and imposed demands, and their realisation. The internal quality auditing of the greenhouse gas statistics was performed in autumn 2020. The focus of the internal statistical audit was on greenhouse gas statistics not the entire inventory, meaning that only energy and IPPU (excl. F gases) calculation processes were audited. During the audit, the basic information form was filled and interviews were performed by a team of three experts. These experts summarised the results including improvement needs of this audit in a final report (Statistics Finland, 2020). These included for example suggestions to reduce manual work during data checks and to increase and simplify communication to users.

Peer reviews

Peer reviews are sector or category-specific projects that are performed by external experts or expert groups. The reviewers should preferably be external experts who are independent of the inventory preparation. The reviewers may also be experts in other calculation sectors of the GHG inventory system. The objective of the peer review is to ensure that the inventory's results, assumptions and methods are reasonable, as judged by those knowledgeable in the specific field. More information on peer review activities that have been undertaken are described in the category-specific chapters.

GHG inventory teams of the Nordic counties have met periodically to exchange information, experiences and views relating to the preparation on the national GHG inventories. The Nordic greenhouse gas inventory expert meetings, which include participants from Finland, Sweden, Norway, Denmark and Iceland, have been organised annually from 2015 on. In 2020, the meeting was exceptionally cancelled due to the COVID-19 pandemic. In 2023 the meeting was organized in Norway (a hybrid meeting). In these meetings, several issues concerning the inventory are discussed. Experts have decided to further continue cooperation in order to get input to the QA and verification of inventory data and to create a network for sharing information.

This collaboration also provides opportunities for bilateral peer reviews. For example, in 2011 the Finnish and Swedish LULUCF teams decided to launch a joint project to verify reported carbon stock changes in dead organic matter and soil carbon. The project results have increased confidence in the reported carbon stock changes. From 2012 on annual collaboration meetings (Finland, Sweden, Norway and Denmark) have been organised on the LULUCF sector. Special focus has been given to several topics such as adaptation of the 2006 IPCC Guidelines and the related CRF tables, methods on land area identification and reporting, comparison of emission factors and other parameters, ongoing methodological developments.

A project called 'Nordic policy cluster for F gases' started in 2017. The project includes all the Nordic countries (Finland, Denmark, Iceland, Norway and Sweden) and is funded by the Nordic council of ministers. The aim of the project has been to compare the Nordic F gas emission inventories. Variations and similarities in the total emissions and consumption figures, data sources, emission estimation methodologies and emission factors have been identified during the project and results so far have been summarized in the two published project reports (http://norden.diva-portal.org/smash/record.jsf?pid=diva2%3A1344817&dswid=-2943 and https://norden.diva-portal.org/smash/record.jsf?pid=diva2%3A1691867&dswid=5007).

The UNFCCC inventory review teams coordinated by the UNFCCC Secretariat carry out international reviews of the inventory according to the annual schedule after the submission of the annual inventory report. The expert review teams produce annually an independent review report on Finland's GHG inventory.

In 2012, the EU implemented an internal technical review of its Member States' greenhouse gas inventory as part of the implementation of the EU Effort Sharing Decision (ESD). This technical review of the 2012 greenhouse gas inventory submission had focus on the estimates for the years 2005, 2008, 2009 and 2010 and was performed by a Technical Expert Review Team (TERT). The European Commission determined the annual emission allocations of Finland for the period from 2013 to 2020 using this reviewed and verified emission data. Technical reviews to verify the annual emissions under the ESD were conducted under the EU MMR also for the inventory submissions annually since 2015. The 2020 review was carried out as a comprehensive review. The reviewers carried out checks to verify the transparency, accuracy, consistency, comparability and completeness of the national GHG inventory for the years 2005, 2016, 2017 and 2018 submitted in 2020 by Finland pursuant to Article 7 of the MMR. The European Commission has determined Finland's annual emission allocations (AEAs) for the years from 2021 to 2030 using this data[14].

1.5.5 Verification (Check)

Emission and activity data are verified by comparing them with other available data compiled independently of the GHG inventory system. These include measurement and research projects and programmes initiated to support the inventory system, or for other purposes but producing information relevant to the inventory preparation. Verification activities that have been undertaken are described in the category-specific chapters.

In addition, Finland annually compares greenhouse gas inventory data with, for example, data reported under the EU ETS, energy statistics and under the CLRTAP.

1.5.6 Improvement of the inventory, including the process for recalculations (Act)

The ultimate aim of the QA/QC process is to ensure the quality of the inventory and to contribute to the improvement of the inventory. At the improvement stage of the QA/QC process, conclusions are made based on the realised QA/QC measures taken and their results, as well as UNFCCC and EU review feedback and uncertainty analysis where relevant. In addition, the inventory unit and experts performing the inventory calculations follow the development of the sector. When technologies and practices change, or recent activity or research data become available, they evaluate the need for improvements and recalculations to improve the inventory.

Finland's inventory system has a special procedure for the consideration and approval of the recalculations (Figure 1.5-3). If sectoral experts identify any needs for recalculations, they contact the inventory unit and provide comparison calculations and solid justification for the recalculation. The methodological changes are then communicated to the advisory board for evaluation and approved by the inventory unit before adopted into production.

As a part of the inventory improvement, also the QA/QC and verification plan is checked and updated annually based on results received from the previous inventory round. In the implementation of the improvements, resources are prioritised based on the significance of the sources where needed. The results of the key category analysis are taken into account in assessing the significance.

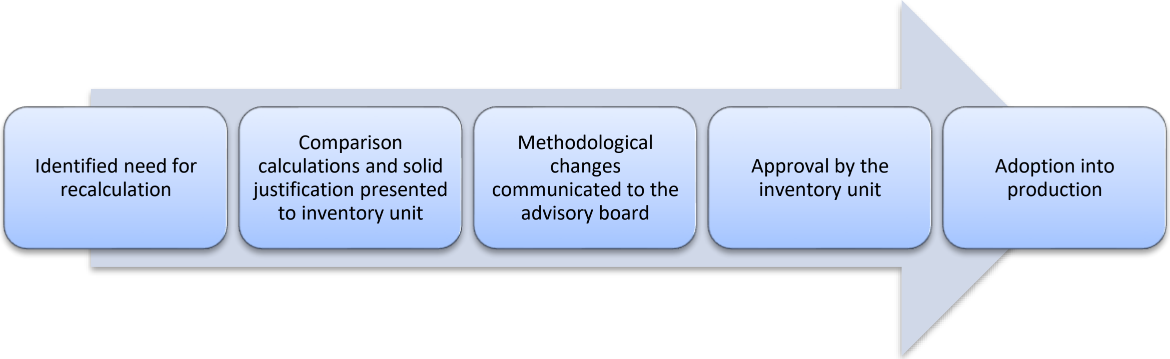

Figure 1.5-3 Procedure for the consideration and approval of the recalculations

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[14] Commission implementing decision (EU) 2020/2126 on setting out the annual emission allocations of the Member States for the period from 2021 to 2030 pursuant to Regulation (EU) 2018/842 of the European Parliament and of the Council

1.5.7 Treatment of confidentiality issues

The treatment of confidential information in the GHG inventory is based on national[15] and international[16] legislation on statistical confidentiality, as well as on internal guidelines and regulations. Statistics Finland does not, by rule, disclose data related to single statistical units. The main principle in publishing aggregated data is that data from a single unit cannot be identified based on the published information. In practise, this means that data from at least three units are needed for disclosing the aggregate value. If one unit is very dominant in a specific category, this can also lead to treating the whole category as confidential. In case Statistics Finland has an agreement with the data producer, the information can be made public.

Finland has made efforts to report confidential data, e.g. through agreements with companies to allow publication or their data. At present, only insignificant or small emissions are reported as confidential in the CRF tables. In many cases, the confidential activity data is received from small companies and these data providers change over time. In addition, some companies are unwilling to allow publication of their confidential data. Therefore, in many cases it would not be possible to change the reporting or the efforts would be disproportionate compared with the potential improvements in transparency.

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[15] Statistics Act 280/2004 and its amendments

[16] Regulation (EC) No 223/2009 of the European Parliament and of the Council of 11 March 2009 on European statistics and repealing Regulation (EC, Euratom) No 1101/2008 of the European Parliament and of the Council on the transmission of data subject to statistical confidentiality to the Statistical Office of the European Communities, Council Regulation (EC) No 322/97 on Community Statistics, and Council Decision 89/382/EEC, Euratom establishing a Committee on the Statistical Programmes of the European Communities

1.6 General uncertainty assessment, including data pertaining to the overall uncertainty of inventory totals

The detailed reporting tables of the analysis are in Annex 2.

Finland carries out both Approach 1 and Approach 2 uncertainty analysis annually. The Approach 2 analysis is based on the Monte Carlo simulation, and it is prepared in accordance with IPCC methodology (2006 IPCC Guidelines). The uncertainty analysis includes all categories of emissions and removals.

The results of the uncertainty analysis are used to prioritise inventory improvement by using them in association with the key category analysis.

The main methodologies used by sector and changes are summarised below. More information on the uncertainty assessment by category is given in sector-specific chapters.

The uncertainty analysis in the energy sector was carried out on a detailed level, covering more than 30 fuel types mainly at the 4th CRF category level (e.g. 1.A.1a). The disaggregation level was such that uncertainties of activity data (AD) and emission factors (EFs) (within the same year) could be considered independent. For the calculation of different greenhouse gas emissions from the same fuel and category combination, the same AD distribution was used.

In the industrial processes and product use sector, most uncertainties were determined at 3rd CRF category level (e.g. 2.A.1) and by greenhouse gas. Uncertainties in indirect CO_2 emissions were estimated separately from direct CO_2. The uncertainties in process emissions from iron and steel (CO_2 from 2.C.1) were estimated based on uncertainty in total CO_2 emissions from iron and steel production (2.C.1 +1.A.2a) and uncertainties in related emissions in the energy sector (1.A.2a). The uncertainties in emissions from F gases were calculated by the Finnish Environment Institute (Syke) using the Monte Carlo analysis directly in the calculation sheets. Uncertainty distributions were fitted to results and included in the overall inventory uncertainty model.

In the agriculture sector, the Monte Carlo simulation was applied directly to the calculation parameters of emission calculation models (LUKEagri calculation model and Nitrogen Mass Flow model). The calculated uncertainties by category and GHG were included in the overall uncertainty model of the inventory.

In the LULUCF sector, most of the uncertainties were based on uncertainty analyses carried out by Luke (for example for Forest land remaining forest land, separately for biomass, mineral and organic soils), in these cases emission uncertainties were used in the overall inventory uncertainty model. The uncertainty of wetlands remaining wetlands constitutes that of peat extraction, while uncertainties of other subcategories were excluded due to their minor role. Whereas for the remaining categories, uncertainties were estimated based on AD and EF/implied emission factor (IEF) uncertainties.

In the waste sector, the uncertainties in CH_4 emissions from landfills were estimated by applying the Monte Carlo simulation to the SWDS model. Other categories uncertainties were estimated based on AD and EF/IEF uncertainties in the overall inventory uncertainty model.

The uncertainties estimated at a detailed level were aggregated (with the Monte Carlo simulation) to the level used in the key category analysis (see Annex 2). In addition to uncertainties in emissions, also uncertainties in aggregated AD and IEFs (in some cases the same as EFs) were estimated with the Monte Carlo simulation. The higher uncertainty values (usually the upper bound of uncertainty range) of simulated AD and IEFs were used as AD and EF uncertainties in the Approach 1 method (also in Annex 2). In the cases in which uncertainty estimates could not be divided between AD and IEF/EF, only emission uncertainty was presented in the Approach 2 Table in Annex 2. Similarly, the emission uncertainty was used in those cases in the Approach 1 calculation following 2006 IPCC Guidelines.

Table 1.6-1 shows the uncertainties (for CO_2 eq. emissions/removals) for the 2022 level and trend (percentage change from 1990) estimated with Approach 1 and Approach 2 methods for this submission. Both uncertainties for UNFCCC sectors are shown. For UNFCCC sectors, Approach 1 and 2 gave quite similar results for 2022, owing to the use of the same input data. Small differences were caused by the fact that asymmetry of uncertainties cannot be taken into account in Approach 1; however, as the majority of emissions is from sources with symmetrical distributions, the results of Approach 1 and 2 are quite close to each other. The similarity of results of Approach 1 and 2 confirm that both methods to combine uncertainties were applied correctly. The differences of Approach 1 and 2 estimates of trend uncertainty were larger. This is due to the fact that in the Approach 1 method, when uncertainties are available only for emissions (not for AD and EF separately), the estimates of 1990 and 2022 have to be expressed either as "correlated" or "not correlated". In particular in the agriculture sector, partial correlation occurs, and the trend uncertainty is highly sensitive to whether partial correlation is treated as "correlated" or "not correlated". In the current approach, uncertainties in most agriculture categories were treated as "not correlated", and, therefore, the trend uncertainty estimated with Approach 1 is somewhat overestimated.

Table 1.6-1 Inventory uncertainties for level and trend (percentage change from 1990)

Emission, trend and uncertainty estimates	**2022**		**Level uncertainty 2022**		**Trend uncertainty 2022**	
	Emission	***Trend***	*Approach 2*	*Approach 1*	*Approach 2*	*Approach 1*
	kt CO_2 eq.	%	%	%	%	%
Total UNFCCC, without LULUCF	45 700	-36	-3 .. +4	±4	-3 .. +3	±4
Total UNFCCC, with LULUCF	50 143	4	-20 .. +33	±32	-24 .. +38	±47
Indirect CO_2	51	-69	-18 .. +18	±18	-7 .. +9	±8
1. Energy	32 868	-38	-1 .. +1	±1	-1 .. +1	±1
2. Industrial processes and product use	4 979	-5	-5 .. +5	±7	-22 .. +41	±9
3. Agriculture	6 075	-17	-21 .. +29	±29	-21 .. +22	±34
4. LULUCF	4 443	-119	-213 .. +357	±354	-75 .. +41	±96
5. Waste	1 727	-67	-29 .. +31	±31	-6 .. +7	±13

Quantitative estimates of uncertainty for the Finnish greenhouse gas inventory were published for the first time in 2001, starting from the inventory year 1999. This was immediately after the publishing of IPCC good practice guidance with its methodologies for uncertainty analysis. Table 1.6-2 summarises the estimates over time. The changes in the uncertainty estimates over time are due to improvements in the inventory methodologies, changes in the share of different categories in the annual inventories and improvements in the uncertainty analysis.

Both the level and trend uncertainty estimates of the total emissions without the LULUCF sector have remained quite stable in the reporting during the past decade. The emissions in the LULUCF sector can fluctuate significantly between years depending mostly on the changes in the amount of domestic commercial roundwood fellings. This fluctuation produces variation over time to the uncertainty results of the total inventory including the LULUCF sector.

Table 1.6-2 Uncertainties analysed since inventory year 1999

Uncertainty estimates			Method and documentation		
year 1990	*year t*	*trend*	*method*	*source*	*notes*
	7 %	10 %	Tier 1	Pipatti 2001	Preliminary analysis for 1999, based entirely on expert judgement
	-5 … +6%	(6 ± 5)%	Tier 2	Monni & Syri 2003	Analysis for year 2001 LULUCF not included.
-6 … +7%	-5 … +6%	(8 ± 5)%	Tier 2	Monni 2004	Analysis for years 1990 and 2002 LULUCF not included
	-4 … +8%	-6 … +4%	Tier 2	NIR 2005	Without LULUCF
	-14 … +15%	-18 … +23%			With LULUCF
-6 … +13%	-5 … +6%	-2 … +25%	Tier 2	NIR 2006	Without LULUCF
±50%	±30%	-20 … +130%			With LULUCF
-7 … +13%	-4 … +7%	-14 … +6%	Tier 2	NIR 2007	Without LULUCF
±50%	±50%	-65 … +45%			With LULUCF
	±5%	±6%	Tier 1	NIR 2008	Without LULUCF
	±29%	±36%			With LULUCF
	±5%	±6%	Tier 1	NIR 2009	Without LULUCF
	±22%	±31%			With LULUCF
	±5%	±6%	Tier 1	NIR 2010	Without LULUCF
	±40%	±36%			With LULUCF
	±5%	±6%	Tier 1	NIR 2011	Without LULUCF
	±60%	±39%			With LULUCF
	±5%	±6%	Tier 1	NIR 2012	Without LULUCF
	±24%	±32%			With LULUCF
	-4 … +7%	-5 … +5%	Tier 2	NIR 2013	Without LULUCF
	-25 … +34%	-25 … +32%			With LULUCF
	-5 … +7%	-5 … +5%	Tier 2	NIR 2014	Without LULUCF
	-33 … +33%	-22 … +28%			With LULUCF
	-4 … +7%	-6 … +7%	Approach 2	NIR 2015	Without LULUCF
	-26 … +34%	-23 … +30%			With LULUCF
	-3 … +5%	-5 … +5%	Approach 2	NIR 2016	Without LULUCF
	-29 … +37%	-23 … +31%			With LULUCF
-4 … +5%	-3 … +4%	-3 … +4%	Approach 2	NIR 2017	Without LULUCF
-23 … +36%	-36 … +45%	-19 … +26%			With LULUCF
-4 … +5%	-3 … +4%	-4 … +4%	Approach 2	NIR 2018	Without LULUCF
-23 … +37%	-36 … +43%	-21 … +28%			With LULUCF
-4 … +5%	-3 … +4%	-4 … +4%	Approach 2	NIR 2019	Without LULUCF
-25 ... +39%	-28 … +35%	-21 … +29%			With LULUCF
-4 … +5%	-3 … +4%	-4 … +4%	Approach 2	NIR 2020	Without LULUCF
-25 ... +39%	-18 … +24%	-24 … +33%			With LULUCF
-5 … +5%	-3 … +4%	-4 … +4%	Approach 2	NIR 2021	Without LULUCF
-25 ... +39%	-31 … +37%	-24 … +33%			With LULUCF
-5 … +6%	-3 … +5%	-3 … +4%	Approach 2	NIR 2022	Without LULUCF
-24 ... +38%	-36 … +41%	-21 … +29%			With LULUCF
-4 ... +5%	-3 ... +5%	-3 ... +3%	Approach 2	NIR 2023	Without LULUCF
-20 ... +23%	-27 ... +38%	-34 ... +49%			With LULUCF
-4 ... +4%	-3 ... +4%	-3 ... +3%	Approach 2	NID 2024	Without LULUCF
-15 ... +15%	-20 ... +33%	-24 ... +38%			With LULUCF

1.7 General assessment of completeness

1.7.1 Information on completeness

Finland has provided estimates for all significant IPCC source and sink categories according to the detailed CRF classification. Estimates are provided for the following gases: CO_2, N_2O, CH_4, F gases (HFCs, PFCs, SF_6 and NF_3), NMVOC, NO_x, CO and SO_2.

In accordance with the IPCC Guidelines, international aviation and marine bunker fuel emissions are not included in national totals.

Assessment of completeness is included in Annex 5.

1.7.2 Completeness by geographical coverage

The geographical coverage of the inventory is complete. It includes emissions from the autonomic territory of Åland. The emissions for the territory of Åland are not reported separately.

1.7.3 Completeness by timely coverage

A complete set of CRF tables are provided for all years and the estimates are calculated in a consistent manner.

1.7.4 Total aggregate emissions considered insignificant

Finland provides a list of sources in Table 1.7-1 for which estimates are not provided because they are assessed as insignificant. . The individual sources for which estimates have not been provided are estimated to have emissions below the threshold of 0.05% of the national total emissions and the likely total aggregate estimate of these sources is below 0.1% of the national total emissions.

Emissions/removals from dead organic matter (DOM) in grassland remaining grassland are also considered insignificant. Quantitative estimate has not yet been made. DOM in grassland remaining grassland is likely a small sink because the areas where trees exist are on their way to slowly becoming forested and thus the biomass is increasing. The amount of tree biomass on grassland remaining grassland is however very small so it is justified to say that the increase in DOM is insignificant.

Finland’s total emissions in 2022 were 45.7 Mt CO_2 eq.

Table 1.7-1 Summary of insignificant sources

Greenhouse gas source and sink categories	CO_2	CH_4	N_2O	F gases	Likely emission level	Notes
Energy						
Fugitive emissions from fuels-Natural gas transmission, storage and distribution	NE				< 0.02 kt	See NID
Industrial processes and product use						
Use of NF_3 in production of semiconductors				C, NE	< 0.1 kt (2003)	NF_3 used only in 2003, See NID 4.6.2.1
Agriculture						
Composting	NO	NE	NE		< 7 kt CO_2 eq.[1]	See NID 5.3.2.2
Anaerobic digestion	NO	NE	NO		around 2 kt CO_2 eq.[1]	
LULUCF						
Biomass burning, wildfires on Wetlands	NE	NE	NE		around 0.9 kt CO_2 eq.	See NID 6.10.5.2
DOM on GL, WL and SE converted to CL	NE				< 0.4 kt CO_2	See NID 6.5.2.2
DOM on CL, WL and SE converted to GL	NE				< 0.07 kt CO_2	See NID 6.6.2.2

[10] The estimates reflect the likely level of emissions from composting and anaerobic digestion and do not take into account possible emission reductions/changes in other manure treatments or phases of manure management (due to this, the total emissions from manure management could also be smaller than reported presently).

1.7.5 Description of insignificant categories

Energy: Fugitive CO_2 emissions from natural gas transmission, storage and distribution are insignificant, according to Gasgrid Oy (one of Finnish natural gas providers), the composition of natural gas used in Finland has only 0.5% by volume CO_2.

Industrial processes and products use: A small amount of NF_3 was used in semiconductor manufacturing by one company in 2003. Use of NF_3 was tested by that company in 2003 but results of the tests did not lead to any further use of NF_3. The amount of NF_3 used was very small and the resulted emissions are considered insignificant. Therefore, the emissions of NF_3 are reported as not estimated in Finland. The potential use of NF_3 in Finland has been investigated and no other use, in addition to the reported use in 2003, has been found.

Agriculture: Estimates of composted manure currently rely on the 2013 questionnaire (Grönroos, 2014), which indicates that approximately 5% of all deep litter and solid manure is composted, primarily using passive windrow composting. This implies a maximum increase of 7 kt CO_2 equivalents in emissions for ''N_2O manure'' and a reduction in methane emissions from manure. In Finland, manure used in biogas production is predominantly slurry, and the proportion of biogas manure in total manure is currently small. It is estimated that the methane emissions from stored digestate could be around 2 kt CO_2-eq. However, slurry processing in biogas plants would also likely have a small decreasing impact on emissions from manure management, as the default methane emission factor will be smaller (ranging from 0.01 to 0.12 depending on plant quality) than the default for slurry (EF 0.17).

LULUCF: Biomass burning, wildfires on Wetlands: Applying Equation 2.8 in IPCC Wetlands Supplement refined with expert judgements showed that the expected value for emissions from wildfires on Wetlands (4.D.1, 4.D.2) were 0.9 kt CO_2 eq. on average in 1996 to 2016 and can be considered insignificant and is reported as 'NE'. For wildfires on Land Converted to Wetlands there is no method available in the 2006 IPCC Guidelines.

DOM on GL, WL and SE converted to CL: Grassland converted to Cropland consists mostly of abandoned cropland that is taken back to cultivation. The carbon stock change is considered insignificant. Wetlands converted to Cropland are mainly abandoned peat extraction areas where there is no dead organic matter. In the rest of the conversion area the CSC is considered insignificant due to small area. For Settlements converted to Cropland dead organic matter is not included in the soil, however the category is area-wise very small and the CSC is considered insignificant. The likely combined emission level for these insignificant categories is < 0.4 kt CO_2.

DOM on CL, WL and SE converted to GL: For organic soils the dead organic matter in Cropland converted to Grassland is considered to be a small sink due to the stopping of tilling and increasing mean biomass. Wetlands converted to Grassland are mainly abandoned peat extraction areas where there is no dead organic matter. In the rest of the conversion area the CSC is considered insignificant due to small area. For Settlements converted to Grasslands DOM is not included in soil. This category consists mostly of pulled down barns or other outbuildings. The area is very small and it is considered that no change in the surroundings occurs so this CSC is also considered insignificant. The likely combined emission level for these insignificant categories is < 0.07 kt CO_2.

Waste: Open burning of waste by households is illegal apart from garden waste in Finland. The total amount of emissions in this category, including those from open burning of garden waste and a marginal amount of illegal burning, are estimated to be insignificant (< 0.1 kt CO_2 eq./a). Furthermore, advanced centralized wastewater treatment plants with active nitrogen addition or removal cause direct emissions. These emissions can be estimated using Equation 6.9 in the IPCC Guidelines, and they are found to be insignificant compared to those from the effluent.

1.8 Metrics

The National Inventory Report of Finland has been prepared using the 100-year time-horizon global warming potential (GWP) values from the IPCC Fifth Assessment Report (IPCC, 2013) as agreed in paragraph 37 of the MPG (CMA, 2018).

2 TRENDS IN EMISSIONS

2.1 Description of emission and removal trends for aggregated greenhouse gas emissions and removals

In 2022, Finland’s greenhouse gas emissions totalled 45.7 million tonnes of carbon dioxide equivalent (Mt CO_2 eq.) without the LULUCF sector. The total emissions in 2022 were approximately 36% (25.6 Mt) below the 1990 emissions level. Emissions in 2022 were 4% lower than in 2021, they decreased 1.9 Mt CO_2 eq.

Figure 2.1-1 shows a time series of CO_2 equivalent emissions with and without the net removals in the LULUCF sector in Finland during 1990 to 2022. The total greenhouse gas emissions by gas as CO_2 equivalence and indexed emissions in relation to the 1990 level are presented in Table 2.1-1.

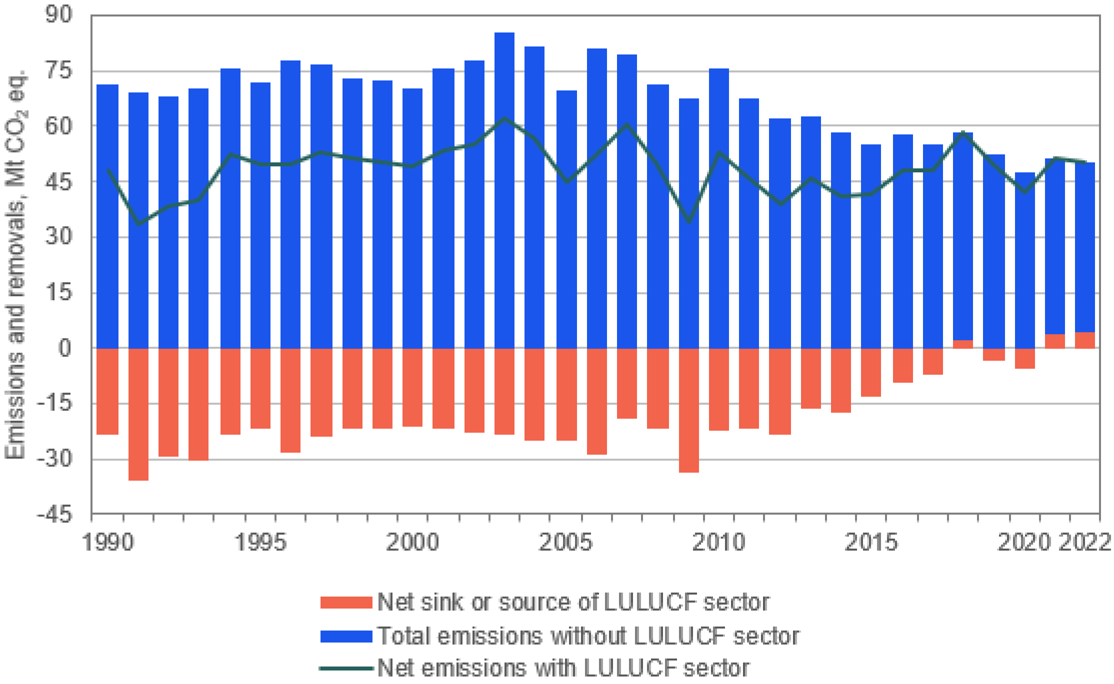
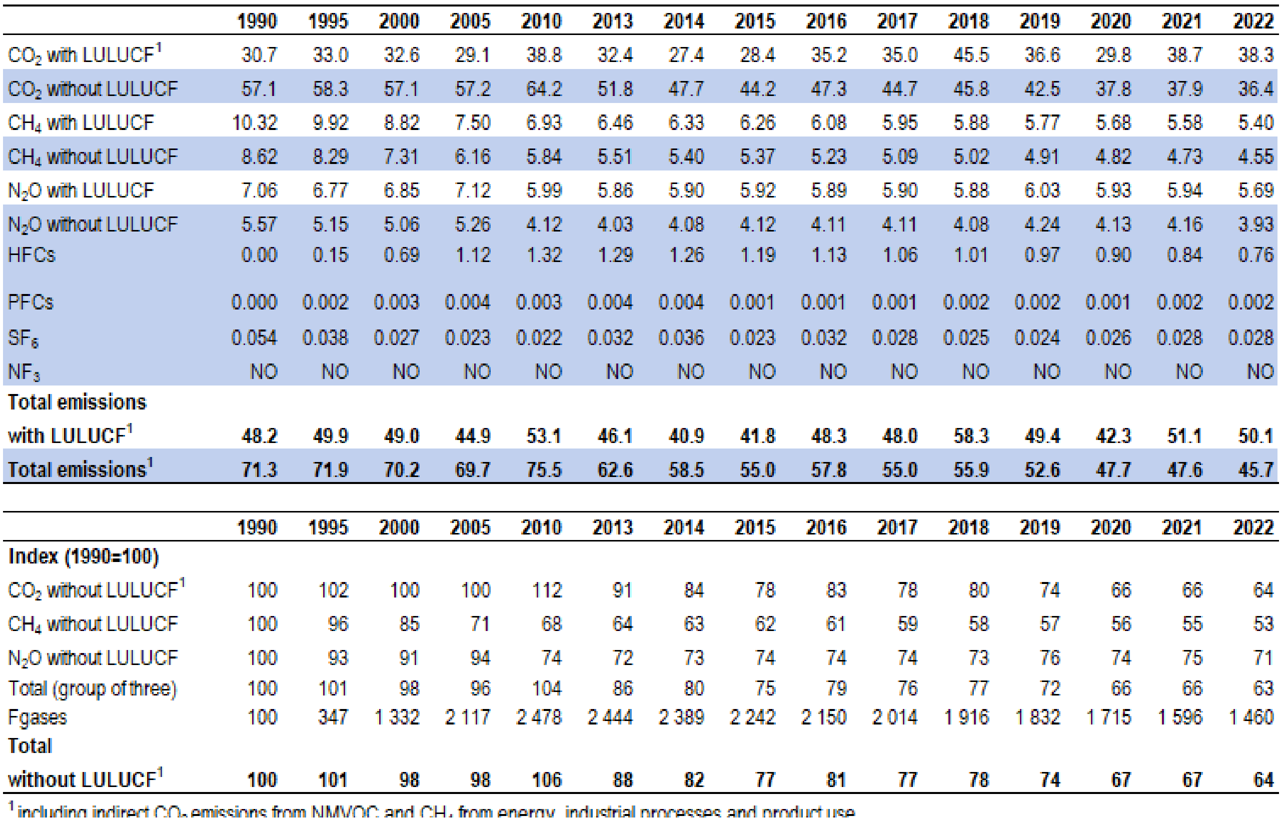


Figure 2.1-1 Total national CO_2 equivalent emissions with and without the net removals in the LULUCF sector in Finland (Mt CO_2 eq.)

Table 2.1-1 Total greenhouse gas emissions in Mt CO_2 eq. and indexed for the years 1990 to 2022 (index 1990=100)



	1990	1995	2000	2005	2010	2013	2014	2015	2016	2017	2018	2019	2020	2021	2022
CO_2 with LULUCF[1]	30.7	33.0	32.6	29.1	38.8	32.4	27.4	28.4	35.2	35.0	45.5	36.6	29.8	38.7	38.3
CO_2 without LULUCF	57.1	58.3	57.1	57.2	64.2	51.8	47.7	44.2	47.3	44.7	45.8	42.5	37.8	37.9	36.4
CH_4 with LULUCF	10.32	9.92	8.82	7.50	6.93	6.46	6.33	6.26	6.08	5.95	5.88	5.77	5.68	5.58	5.40
CH_4 without LULUCF	8.62	8.29	7.31	6.16	5.84	5.51	5.40	5.37	5.23	5.09	5.02	4.91	4.82	4.73	4.55
N_2O with LULUCF	7.06	6.77	6.85	7.12	5.99	5.86	5.90	5.92	5.89	5.90	5.88	6.03	5.93	5.94	5.69
N_2O without LULUCF	5.57	5.15	5.06	5.26	4.12	4.03	4.08	4.12	4.11	4.11	4.08	4.24	4.13	4.16	3.93
HFCs	0.00	0.15	0.69	1.12	1.32	1.29	1.26	1.19	1.13	1.06	1.01	0.97	0.90	0.84	0.76
PFCs	0.000	0.002	0.003	0.004	0.003	0.004	0.004	0.001	0.001	0.001	0.002	0.002	0.001	0.002	0.002
SF_6	0.054	0.038	0.027	0.023	0.022	0.032	0.036	0.023	0.032	0.028	0.025	0.024	0.026	0.028	0.028
NF_3	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO
Total emissions with LULUCF[1]	**48.2**	**49.9**	**49.0**	**44.9**	**53.1**	**46.1**	**40.9**	**41.8**	**48.3**	**48.0**	**58.3**	**49.4**	**42.3**	**51.1**	**50.1**
Total emissions[1]	**71.3**	**71.9**	**70.2**	**69.7**	**75.5**	**62.6**	**58.5**	**55.0**	**57.8**	**55.0**	**55.9**	**52.6**	**47.7**	**47.6**	**45.7**

	1990	1995	2000	2005	2010	2013	2014	2015	2016	2017	2018	2019	2020	2021	2022
Index (1990=100)															
CO_2 without LULUCF[1]	100	102	100	100	112	91	84	78	83	78	80	74	66	66	64
CH_4 without LULUCF	100	96	85	71	68	64	63	62	61	59	58	57	56	55	53
N_2O without LULUCF	100	93	91	94	74	72	73	74	74	74	73	76	74	75	71
Total (group of three)	100	101	98	96	104	86	80	75	79	76	77	72	66	66	63
Fgases	100	347	1 332	2 117	2 478	2 444	2 389	2 242	2 150	2 014	1 916	1 832	1 715	1 596	1 460
Total without LULUCF[1]	**100**	**101**	**98**	**98**	**106**	**88**	**82**	**77**	**81**	**77**	**78**	**74**	**67**	**67**	**64**

[1] including indirect CO_2 emissions from NMVOC and CH_4 from energy, industrial processes and product use

The most important greenhouse gas in Finland is carbon dioxide. The share of CO_2 emissions from the total greenhouse gas emissions has varied from 79% to 85%. In absolute terms, CO_2 emissions have decreased by 20.7 Mt (i.e. 36%) since 1990. Around 88% of all CO_2 emissions originated from the Energy sector in 2022. The amount of energy-related CO_2 emissions has fluctuated much during the time series 1990 to 2022 according to the economic trend, the energy supply structure (including electricity imports and exports) and climate conditions. Regarding the annual variations of total greenhouse gas emissions in the Finnish GHG inventory, CO_2 emissions from public power and heat production are dominant, as shown in Figure 3.1-2. The year 2009 shows a deviations from the previous trend. In 2009 there was a recession in Finland and the value of industrial output fell approximately one third from year before (Industrial output, 2010) resulting also 20% decline of emissions in manufacturing industries and construction. At the same time the weather was colder than in 2008 resulting higher emissions from public electricity and heat production. From 2010 on there has been an overall declining emission trend in the energy sector.

Methane emissions (CH_4) have decreased by 47% from the 1990 level. This is mainly due to the improvements in waste treatment and a contraction in animal husbandry in the Agriculture sector.

Correspondingly, emissions of nitrous oxide (N_2O) have also decreased by 29%; the biggest decline occurred in 2009 when the implementation of a N_2O abatement technology in nitric acid production reduced emissions significantly. Another reason for the decrease of the emission is the reduced nitrogen fertilisation of agricultural fields.

The development of emissions of greenhouse gases (CO_2, CH_4, N_2O and F gases) relative to the 1990 level is presented in Figure 2.1-3.

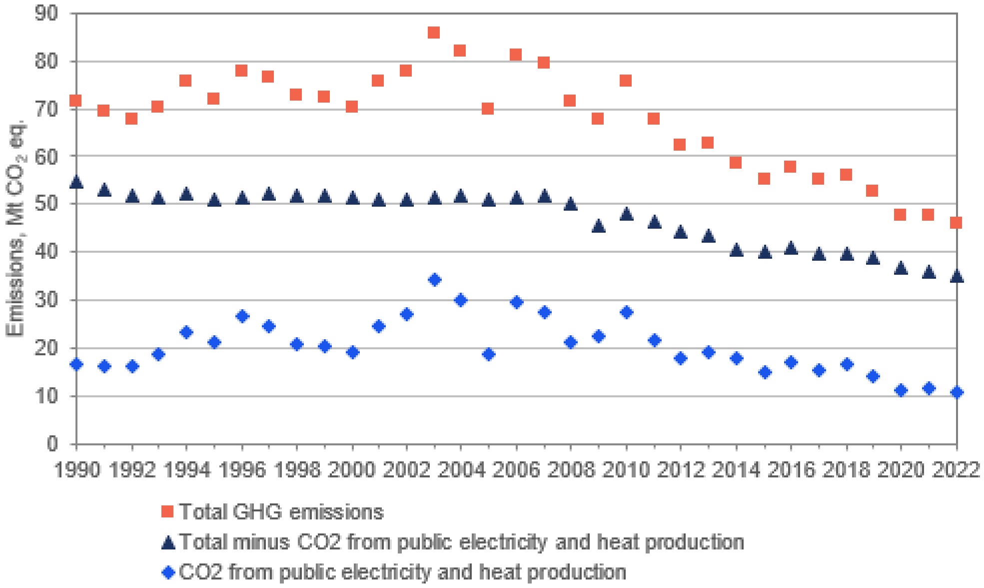


Figure 2.1-2 The effect of the CO_2 emissions of 1.A.1a Public Electricity and Heat Production to the total CO_2 equivalent emission trend

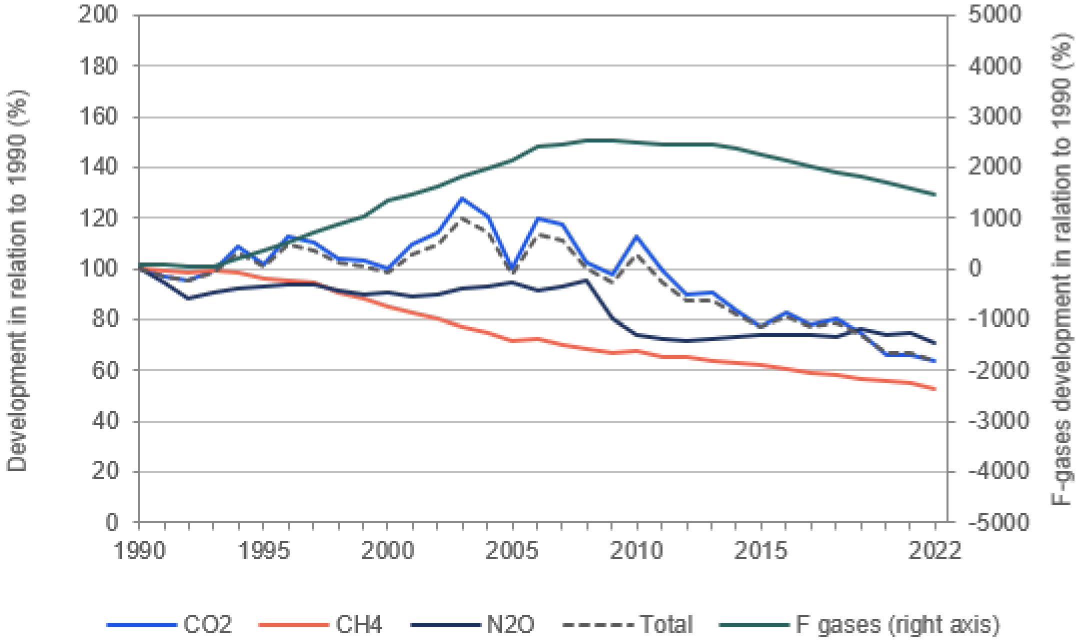


Figure 2.1-3 Relative development of CO_2, CH_4, N_2O and F gases without the LULUCF sector in time series relative to the 1990 level (%)

The emissions of F gases increased nearly 25-fold during 1990 to 2008. A key driver behind the trend has been the substitution of ozone depleting substances (ODS) by F gases in many applications. During 2010s F gas emissions have started to decline due to decreased leakage rates and replacement of high GWP HFC refrigerants with alternative low-GWP non-HFC refrigerants in many applications (See also Annex 7). Between 2021 and 2022, F gas emissions decreased by 8% being still 15-fold compared with the emissions in 1990. In Table 2.1-1, the development of emissions of F gases is presented by gas category and in Figure 2.1-4 by subcategory (Mt CO_2 eq.).

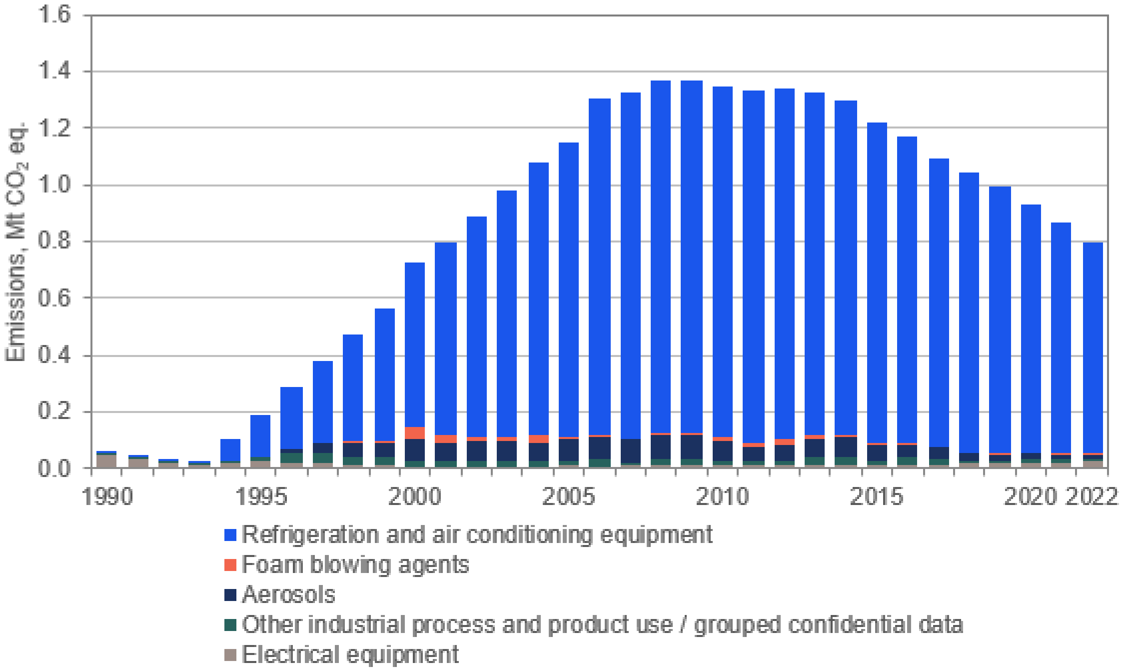


Figure 2.1-4 Emissions of F gases by subcategory (Mt CO_2 eq.)

2.2 Description of emission and removal trends by sector and by gas

The energy sector is the most significant source of greenhouse gas emissions in Finland and, therefore, the key driver behind the trend. Energy related emissions vary much in Finland, mainly according to the economic trend, the energy supply structure and climate conditions. Figure 2.2-1 and Table 2.2-1 provide an overview of the development of the CO_2 equivalent emissions by IPCC source sector.

In 2022, emissions from the energy sector totalled 32.9 Mt and were 38% (20.6 Mt CO_2 eq.) below the level in 1990 and the emissions decreased 4% since 2021.

Emissions of industrial processes and product use were 5.0 Mt in 2022 and were 5% lower than in 1990. Between 1993 and 2008, the sectors' emissions increased to a level almost 40% higher than in 1990 but decreased almost equally due to the economic downturn and technical abatement measures implemented to reduce N_2O emissions in nitric production in 2009.

Emissions in the Agriculture and Waste sectors have decreased since 1990. The decrease can largely be attributed to changes in waste legislation, implementation of the Landfill Directive (1999/31/EC), and changes in agricultural policy and farming subsidies.

The LULUCF sector in Finland has been a net sink until 2017, after which is has acted as both a net sink and a net source of emissions. Most of the removals in the LULUCF sector have come from tree biomass; that is to say the tree biomass growth in forest land has been higher than the removed biomass. The increment of the growing stock has increased in Finland since 1990 until 2013 after which it has been slightly declining. Annual variations in the total drain (consisted of roundwood removals, logging residues and natural losses) have been considerable. In addition, the aggregated dead organic matter and soil organic matter pool in mineral soils has been a significant sink during the reporting period. The largest emissions in the LULUCF sector came from changes in soil organic carbon in organic forest and agricultural soils.

Indirect CO_2 emissions have decreased by 69% since 1990, the main reason being reduced use of solvent chemicals in industry.

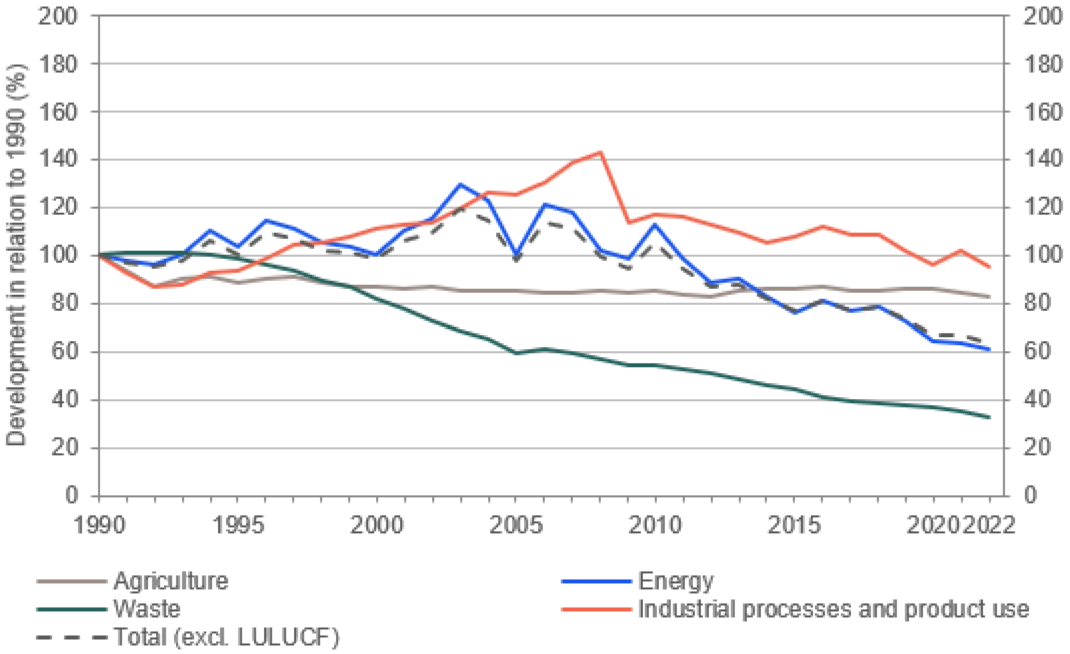
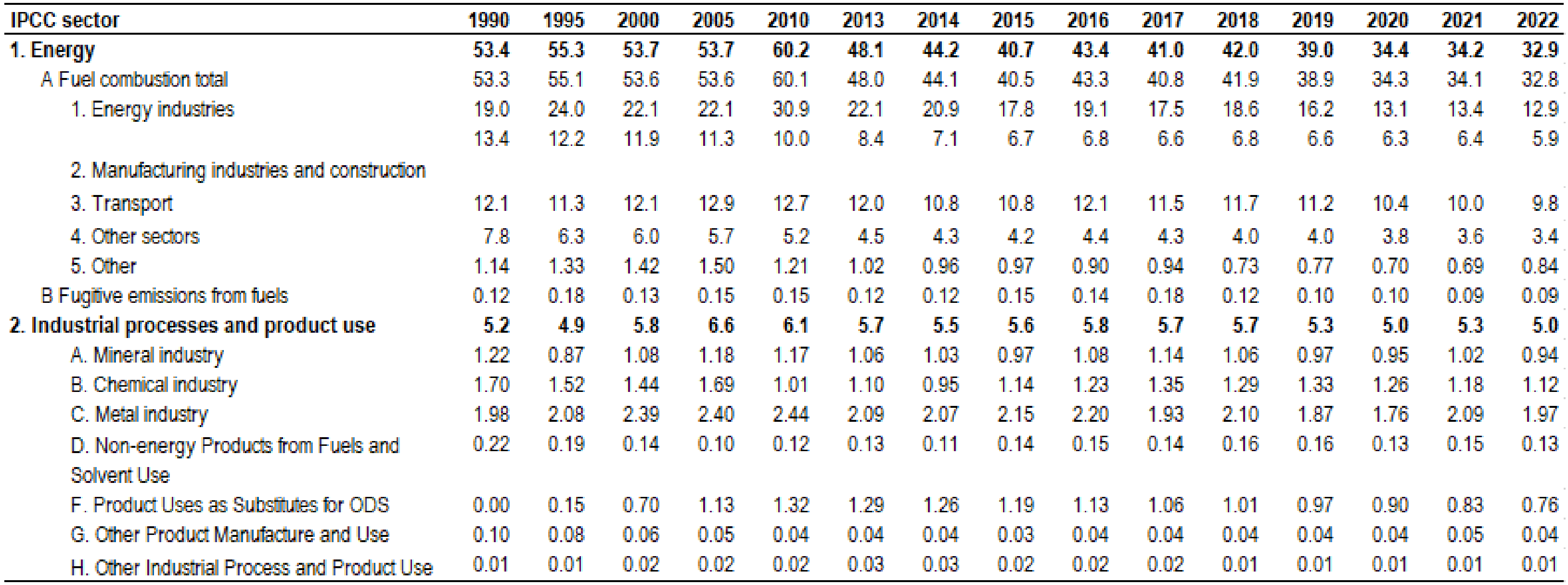


Figure 2.2-1 Relative development of greenhouse gas emissions by main category relative to the 1990 level (1990=100%)

Table 2.2-1 Summary of emission trend by category (unit Mt CO_2 eq.)



IPCC sector	1990	1995	2000	2005	2010	2013	2014	2015	2016	2017	2018	2019	2020	2021	2022
1. Energy	**53.4**	**55.3**	**53.7**	**53.7**	**60.2**	**48.1**	**44.2**	**40.7**	**43.4**	**41.0**	**42.0**	**39.0**	**34.4**	**34.2**	**32.9**
A Fuel combustion total	53.3	55.1	53.6	53.6	60.1	48.0	44.1	40.5	43.3	40.8	41.9	38.9	34.3	34.1	32.8
1. Energy industries	19.0	24.0	22.1	22.1	30.9	22.1	20.9	17.8	19.1	17.5	18.6	16.2	13.1	13.4	12.9
2. Manufacturing industries and construction	13.4	12.2	11.9	11.3	10.0	8.4	7.1	6.7	6.8	6.6	6.8	6.6	6.3	6.4	5.9
3. Transport	12.1	11.3	12.1	12.9	12.7	12.0	10.8	10.8	12.1	11.5	11.7	11.2	10.4	10.0	9.8
4. Other sectors	7.8	6.3	6.0	5.7	5.2	4.5	4.3	4.2	4.4	4.3	4.0	4.0	3.8	3.6	3.4
5. Other	1.14	1.33	1.42	1.50	1.21	1.02	0.96	0.97	0.90	0.94	0.73	0.77	0.70	0.69	0.84
B Fugitive emissions from fuels	0.12	0.18	0.13	0.15	0.15	0.12	0.12	0.15	0.14	0.18	0.12	0.10	0.10	0.09	0.09
2. Industrial processes and product use	**5.2**	**4.9**	**5.8**	**6.6**	**6.1**	**5.7**	**5.5**	**5.6**	**5.8**	**5.7**	**5.7**	**5.3**	**5.0**	**5.3**	**5.0**
A. Mineral industry	1.22	0.87	1.08	1.18	1.17	1.06	1.03	0.97	1.08	1.14	1.06	0.97	0.95	1.02	0.94
B. Chemical industry	1.70	1.52	1.44	1.69	1.01	1.10	0.95	1.14	1.23	1.35	1.29	1.33	1.26	1.18	1.12
C. Metal industry	1.98	2.08	2.39	2.40	2.44	2.09	2.07	2.15	2.20	1.93	2.10	1.87	1.76	2.09	1.97
D. Non-energy Products from Fuels and Solvent Use	0.22	0.19	0.14	0.10	0.12	0.13	0.11	0.14	0.15	0.14	0.16	0.16	0.13	0.15	0.13
F. Product Uses as Substitutes for ODS	0.00	0.15	0.70	1.13	1.32	1.29	1.26	1.19	1.13	1.06	1.01	0.97	0.90	0.83	0.76
G. Other Product Manufacture and Use	0.10	0.08	0.06	0.05	0.04	0.04	0.04	0.03	0.04	0.04	0.04	0.04	0.04	0.05	0.04
H. Other Industrial Process and Product Use	0.01	0.01	0.02	0.02	0.02	0.03	0.03	0.02	0.02	0.02	0.01	0.01	0.01	0.01	0.01

IPCC sector	1990	1995	2000	2005	2010	2013	2014	2015	2016	2017	2018	2019	2020	2021	2022
3. Agriculture	**7.3**	**6.5**	**6.4**	**6.2**	**6.3**	**6.2**	**6.3**	**6.3**	**6.4**	**6.3**	**6.2**	**6.3**	**6.3**	**6.2**	**6.1**
A. Enteric fermentation	2.72	2.37	2.31	2.22	2.22	2.21	2.25	2.29	2.29	2.27	2.26	2.21	2.23	2.21	2.18
B. Manure management	0.69	0.68	0.69	0.74	0.74	0.76	0.78	0.80	0.78	0.77	0.76	0.75	0.73	0.72	0.68
D. Agricultural soils	3.26	3.00	2.99	2.96	3.02	2.94	3.01	3.02	3.02	3.02	2.99	3.17	3.11	3.07	2.97
F. Field burning of agricultural residues	0.004	0.004	0.004	0.003	0.002	0.003	0.003	0.003	0.002	0.003	0.002	0.003	0.002	0.000	0.000
G. Liming	0.64	0.41	0.35	0.29	0.28	0.31	0.24	0.16	0.26	0.19	0.20	0.19	0.20	0.20	0.25
H. Urea application	0.005	0.001	0.001	0.001	0.002	0.001	0.002	0.002	0.003	0.002	0.001	0.002	0.002	0.001	0.008
4. Land-use, land-use change and forestry	**-23.2**	**-22.0**	**-21.3**	**-24.9**	**-22.4**	**-16.6**	**-17.5**	**-13.1**	**-9.5**	**-7.0**	**2.3**	**-3.2**	**-5.4**	**3.5**	**4.4**
A. Forest Land	-29.0	-26.4	-26.1	-35.1	-32.7	-26.2	-26.4	-21.9	-17.8	-14.4	-5.5	-12.4	-16.4	-5.0	-4.8
B. Cropland	5.39	5.66	7.48	7.56	7.70	7.43	7.42	7.45	7.99	7.82	8.21	8.63	8.53	8.27	8.83
C. Grassland	1.02	0.91	0.84	0.91	0.81	0.76	0.75	0.76	0.78	0.77	0.78	0.78	0.77	0.76	0.77
D. Wetlands	1.45	1.65	1.79	2.10	2.31	2.31	2.19	2.12	2.14	2.14	2.26	2.15	2.15	2.27	2.09
E. Settlements	0.87	1.06	1.29	1.61	1.65	1.51	1.49	1.31	1.18	1.15	1.13	0.98	0.91	0.87	0.78
G. Harvested Wood Products	-2.95	-4.90	-6.61	-1.97	-2.20	-2.37	-3.03	-2.91	-3.82	-4.50	-4.58	-3.38	-1.29	-3.72	-3.25
5. Waste	**5.2**	**5.1**	**4.3**	**3.1**	**2.8**	**2.5**	**2.4**	**2.3**	**2.2**	**2.1**	**2.0**	**2.0**	**1.9**	**1.8**	**1.7**
A. Solid Waste Disposal	4.8	4.8	3.9	2.7	2.4	2.1	2.0	1.9	1.8	1.7	1.6	1.6	1.6	1.5	1.4
B. Biological Treatment of Solid Waste	0.05	0.07	0.10	0.13	0.15	0.13	0.13	0.12	0.10	0.11	0.11	0.13	0.12	0.11	0.11
D. Wastewater Treatment and Discharge	0.32	0.30	0.27	0.26	0.26	0.26	0.26	0.26	0.25	0.25	0.25	0.25	0.24	0.24	0.23
6. Other	**NA**	**NA**	**NA**	**NA**	**NA**	**NA**	**NA**	**NA**	**NA**	**NA**	**NA**	**NA**	**NA**	**NA**	**NA**
Indirect CO_2-emissions	**0.16**	**0.13**	**0.11**	**0.09**	**0.07**	**0.06**	**0.06**	**0.06**	**0.06**	**0.06**	**0.06**	**0.05**	**0.07**	**0.06**	**0.05**
National total emissions with LULUCF[1]	**48.2**	**49.9**	**49.0**	**44.9**	**53.1**	**46.1**	**40.9**	**41.8**	**48.3**	**48.0**	**58.3**	**49.4**	**42.3**	**51.1**	**50.1**
NATIONAL TOTAL EMISSIONS[1]	**71.3**	**71.9**	**70.2**	**69.7**	**75.5**	**62.6**	**58.5**	**55.0**	**57.8**	**55.0**	**55.9**	**52.6**	**47.7**	**47.6**	**45.7**

[1] including indirect CO_2-emissions from NMVOC and CH_4 from fugitive emissions, industrial processes and product use

2.2.1 Energy

The energy sector is the most significant source of greenhouse gas emissions in Finland. This reflects the high energy intensity of the Finnish industry, extensive consumption during the long heating period, as well as energy consumption for transport in a large and sparsely inhabited country. The important drivers in the trend of the energy sector's greenhouse emissions have been the changes in the level of annually imported electricity and fossil fuel-based condensing power in annual energy production as well as the growth in the consumption of renewable energy (Figure 2.2-2 and Figure 2.2-3). The availability of hydropower in the Nordic electricity market has influenced significantly to the electricity supply structure and hence the emissions from fuel combustion during the time series. If the annual precipitation in the Nordic countries is lower than usual, hydropower will become scarce and Finland's net imports of electricity will decrease. During such years, Finland has generated additional electricity using coal- and peat-fired power plants resulting higher CO_2 emissions from corresponding years. During the recent years the share of electricity generation with conventional condensing power has declined as the wind power has grown (Figure 2.2-6). The ban on the use of hard coal for energy production, which will enter into force in 2029, has beforehand affected the decrease of coal consumption. In addition, the allowance price in EU ETS has risen which speeds up the replacement of fossil fuels with renewable energy.

Total energy consumption in Finland amounted to 1.29 million terajoules (TJ) in 2022. Total consumption fell by 5% from the previous year. The use of renewable energy sources decreased by 6% but their share of total consumption remained at 42%. The use of fossil fuels and peat also decreased by 6% in total. Total electricity consumption in Finland in 2022 amounted to 81.7 TWh, of which 85% was covered by domestic production and 15% by net imports of electricity. The production of district heat decreased by 6% in 2022 from the previous year due to warmer weather than in the previous year (Figure 2.2-2). Emissions from the energy use of fuels decreased 4% being 32.8 Mt CO_2 eq.

Several significant changes took place on the energy market in 2022. At the beginning of the year, a strike occurred in Finnish forest industry, which reduced the use of wood fuels and disrupted the growth trend of renewable energy.

In reaction to Russia's large-scale attack on Ukraine, the European Union imposed various restrictions on trade with Russia. The share of energy imported from Russia in total energy consumption was 18% in 2022, while it had been 32 % in the previous year. The import of electricity and pipeline gas from Russia to Finland ceased completely in May. Imports of liquefied natural gas (LNG) from Russia increased by 31% in 2022.

The market prices of gas and electricity rose exceptionally high in Europe in the fall of 2022, which was also reflected in the price of energy in Finland. The high price in Europe was caused by a decrease in natural gas imports from Russia and the need to store natural gas, as well as a dry summer and maintenance shutdowns of French nuclear power.

Domestic production of electricity remained on level with the previous year, but the structure of production changed. Wind power grew by 41% and nuclear power by 7%. Fuel-based production fell by 13%.

Final energy consumption decreased by 5% because of savings measures, high prices, mild weather and weakened economic outlook.

In 2022, the energy sector's emissions were about 38% below the 1990 level and over half of the emission level in 2003. At the end of 1990s total energy consumption increased but emissions changed very little. The reasons for that were increased use of wood fuels, nuclear energy and net imports of electricity which lowers the condensing power production and thus emissions. Net imports of electricity declined in the beginning of the 2000s and energy sector emissions were at the highest in 2003. In 1990, the share of renewable energy in total energy consumption was just 18%, after which it has grown steadily. In addition, the net import of electricity has been at high level from 2012 on until 2021 (Figure 2.2-2 and Figure 2.2-3). The increased use of renewable energy compared to the situation in 1990 has replaced fossil fuels increasingly and is the main reason for the decreased emissions despite the growth in energy consumption.

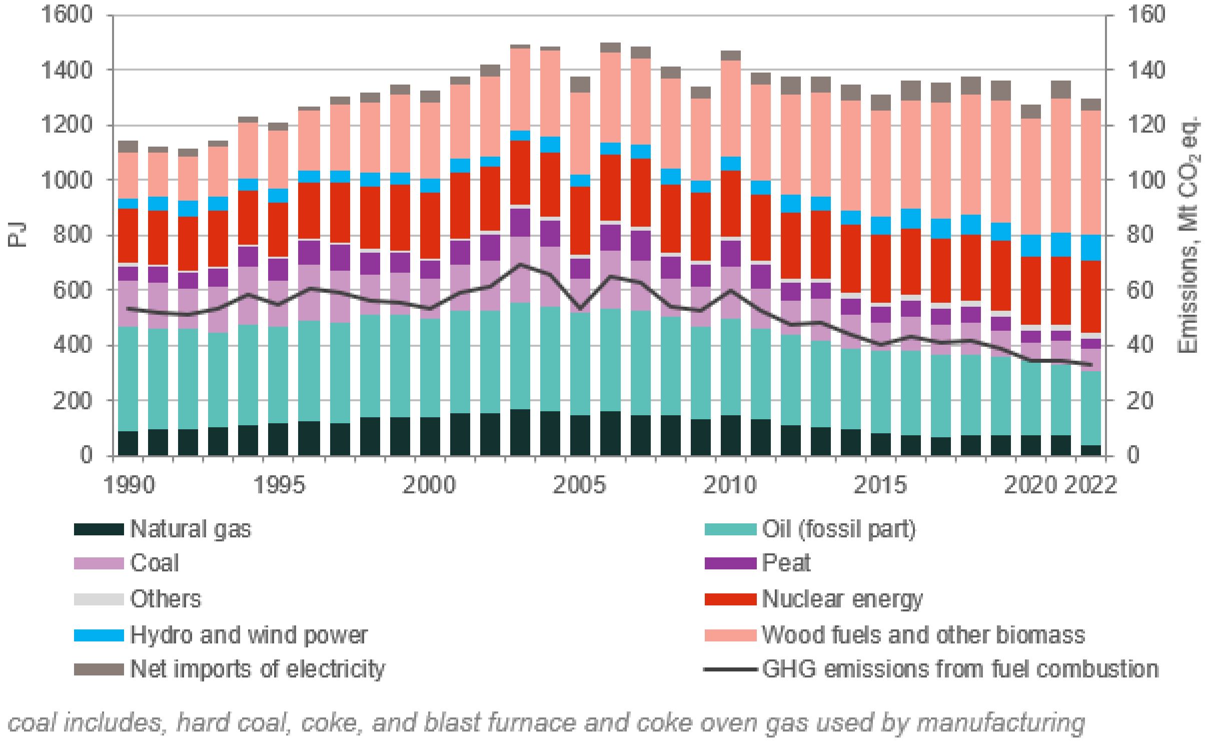


Figure 2.2-2 Development of total energy consumption by energy source (PJ) and the energy sector's greenhouse gas emissions (Mt CO_2 eq.) in Finland (GHG Inventory and Energy Statistics)

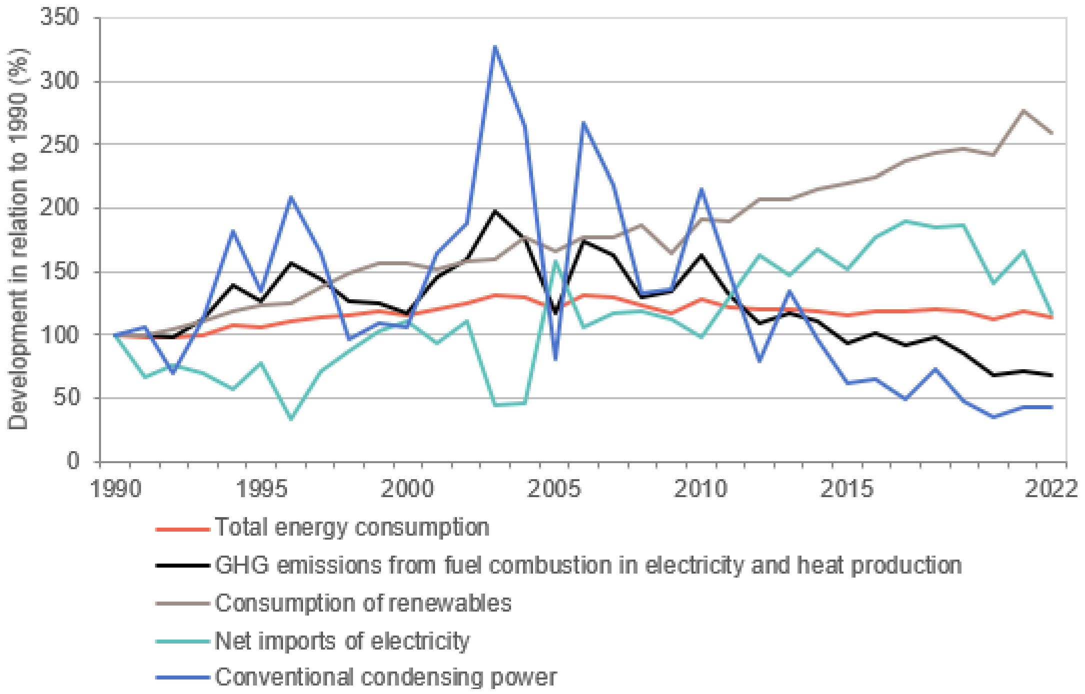


Figure 2.2-3 Development of energy consumption, net imports of electricity, conventional condensing power and the greenhouse gas emissions from electricity and heat production (Mt CO_2 eq.) in Finland in relation to 1990 (GHG Inventory and Energy Statistics)

The consumption of wood fuels decreased by 9% from the 2021. Major share of wood fuels are derived from the by-products of the forest industry, including black liquor derived from the pulp-making process and bark, sawdust and other industrial wood residues. Also logging residues or other low value biomass from silvicultural and harvesting operations are used for energy generation. Wood fuels covered 28% of total energy consumption and they were the most used energy source in Finland. (Figure 2.2-4)

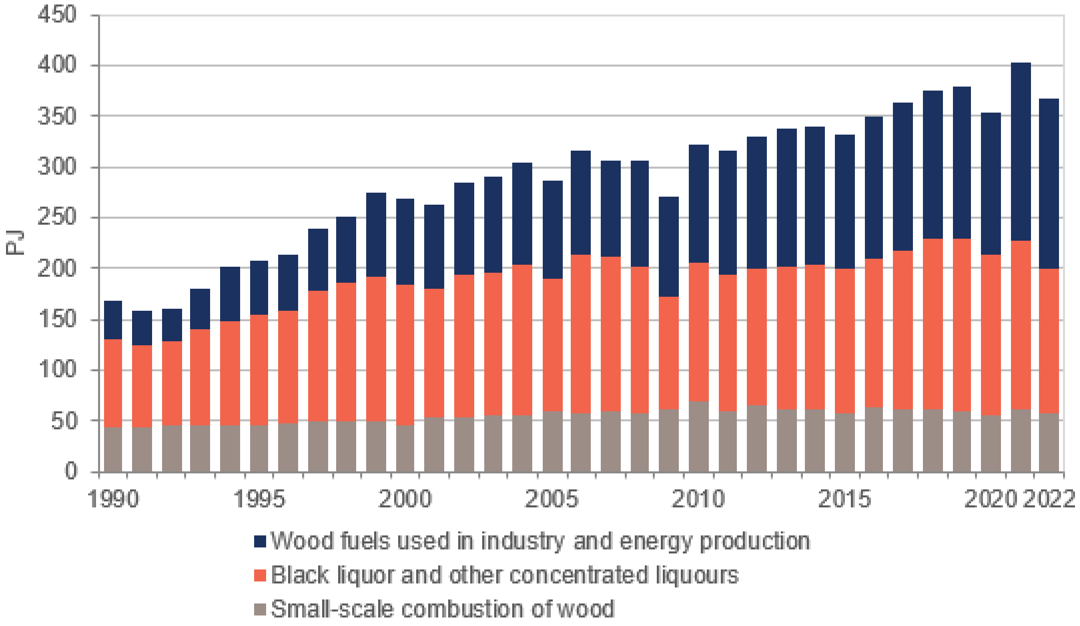


Figure 2.2-4 Development of energy consumption of wood fuels in Finland (Energy Statistics)

Energy industries

Energy industries (mainly electricity and district heat production) caused approximately 39% (12.9 Mt CO_2 eq.) of the total emissions in the energy sector in 2022. Emissions from the energy industries were 4% lower in 2022 than in 2021 and 32% lower than in 1990.

In 2022, the **production of electricity** in Finland amounted to 69.1 TWh, which was the same level than in the year before. Imports of electricity from Russia ceased in May 2022, and net imports of electricity fell by 30% from the previous year. Concerns about the sufficiency and high price of electricity rose in Finland. This resulted in more economical use of electricity than usual as electricity consumption decreased by 6%, which compensates for the drop in imports. Domestic production of emission-free electricity grew significantly in 2022: production of wind power increased by 41% and production of nuclear power by 7% when Olkiluoto 3 nuclear power plant started production. Fossil-free electricity production, that is, renewable energy sources and nuclear energy covered 89% of electricity production in 2022. Electricity produced with fossil fuels and peat decreased 23% from the year before; electricity produced with natural gas decreased 76% due to ceased import of pipeline gas from Russia. (Figure 2.2-6). (Production of electricity and heat, Statistics Finland).

The **production of district heat** totalled 38.3 TWh in 2022, being 6% lower than in the previous year. The reason for the decrease in the production of district heat was the warmer weather than in previous year. The use of fossil fuels and peat in the production of district heat decreased by 8.5% since 2021. The use of natural gas decreased by 69% and peat by 10%. The use of coal increased 22% and use of oil by 77% from the previous year. The share of renewable fuels in the production of district heat decreased 3% from the year before. 38% of district heat was produced with fossil fuels and peat and 49% with renewable fuels. Most of district heat was produced with wood fuels (43%). The second largest energy source in district heat production was hard coal (16%). The third most important source of energy for district heat production was the other energy sources group (flue gas scrubbers and heat pumps, 13%).

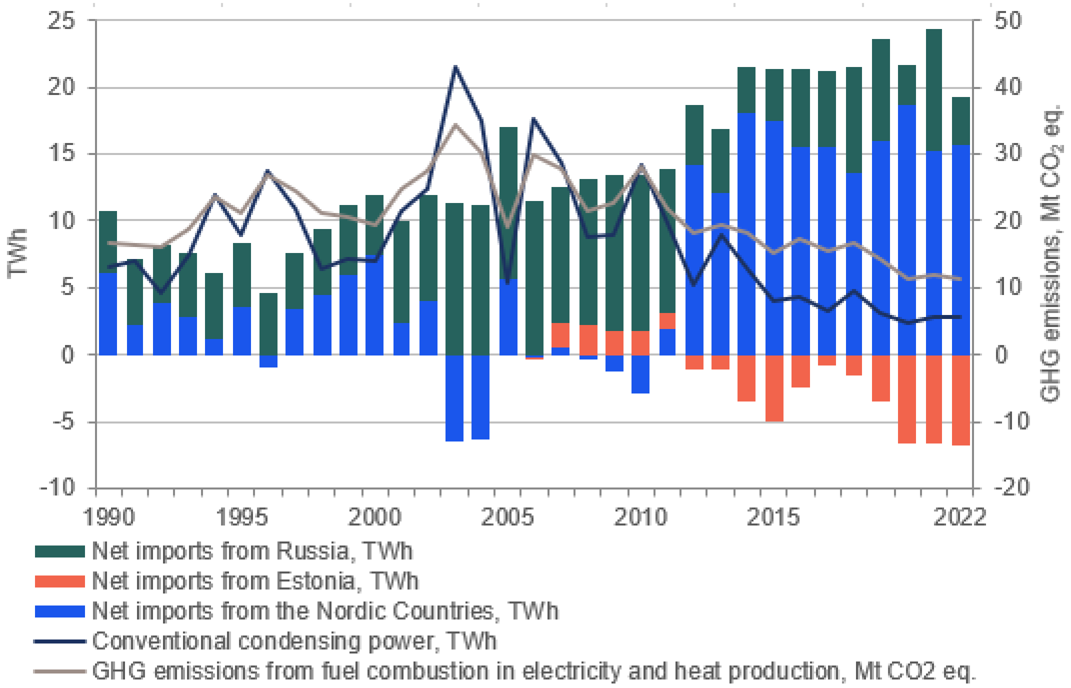


Figure 2.2-5 Greenhouse gas emissions from fuel combustion in electricity and heat production, net imports of electricity from the Nordic Countries and Estonia and Russia, and production of conventional condensing power (Energy Statistics)

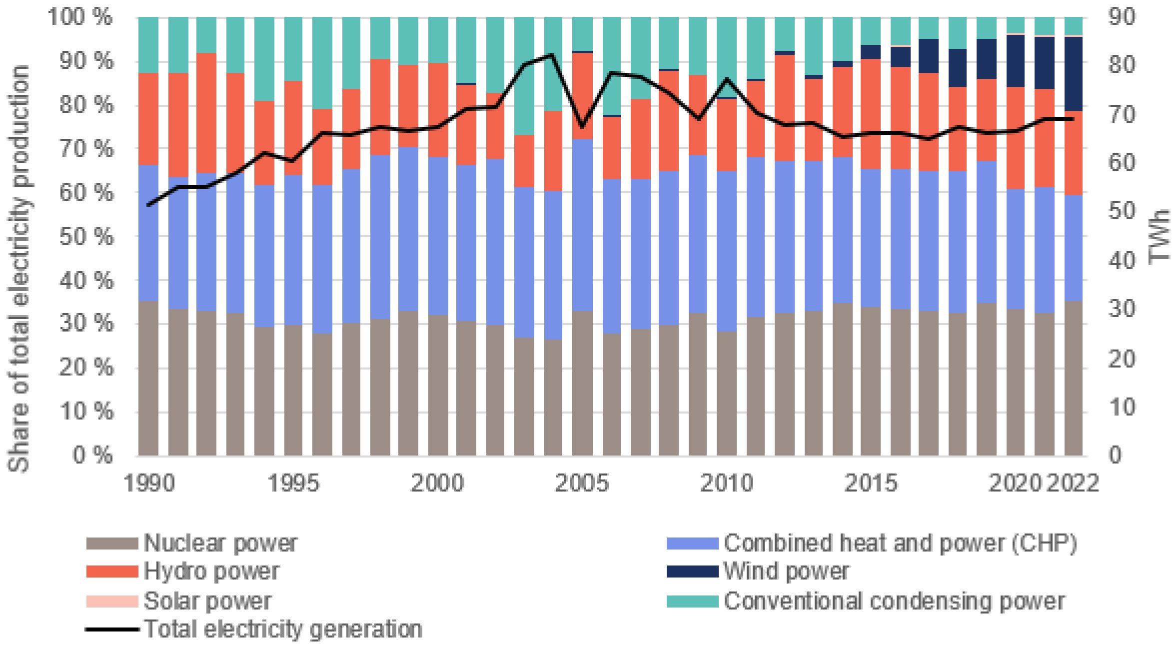


Figure 2.2-6 Total electricity generation and share of production modes (Energy Statistics)

Manufacturing industries and construction

Manufacturing industries and construction produce much energy for their own use. Their share of energy-related emissions was around 18% in 2022 (5.9 Mt CO_2 eq.). Emissions from manufacturing industries and construction have declined by 56% since 1990. The main reasons behind this trend are increased use of biofuels in the forest industry and outsourcing of power plants from industry to the energy sector. Fuel switch from fossil to biomass can be seen clearly in pulp and paper industry (1.A.2d) as well as in electricity and heat production (1.A.1a) (Figure 2.2-7).

In 2022, **energy use in manufacturing** decreased by 9%, being 128.3 TWh. The volume of electricity purchased by manufacturing decreased by 6%. The consumption of oil increased by 14% as natural gas was replaced with oil products. The share of oil was 10% of total manufacturing consumption. The use of peat dropped by 41% compared to 2021, being around 1% of all energy used in manufacturing. The consumption of wood fuels decreased by 13% and its share was 40% of all energy consumption. (Energy use in manufacturing, Statistics Finland).

The **production of industrial heat** was 47.5 TWh in 2022. Production declined by 9% from the previous year. Almost four months long strike in Finnish forest industry diminished the use of industrial heat. 51% of heat produced for the needs of manufacturing comes from black liquor. In all, 78% of the production of industrial heat was based on renewable fuels. One of the biggest users of industrial heat is the forest industry, which in its production uses its own fuels, like black liquor and other wood fuels. In the chemical, forest and metal industries, part of the use of heat is considered as direct fuel use in the statistics and is thus not visible in the production figures on industrial heat (Production of electricity and heat, Statistics Finland).

In the greenhouse gas inventory in Finland, the fuels used in the industry are allocated to CRF categories regardless of if they are used directly or for production of electricity or heat. The change of consumption of different fuel groups are presented by subcategories (1.A.1a Public electricity and hear production, 1.A.2 Manufacturing industries and construction, 1.A.2d Pulp and paper) from 1990 to 2022 in Figure 2.2-7 below.

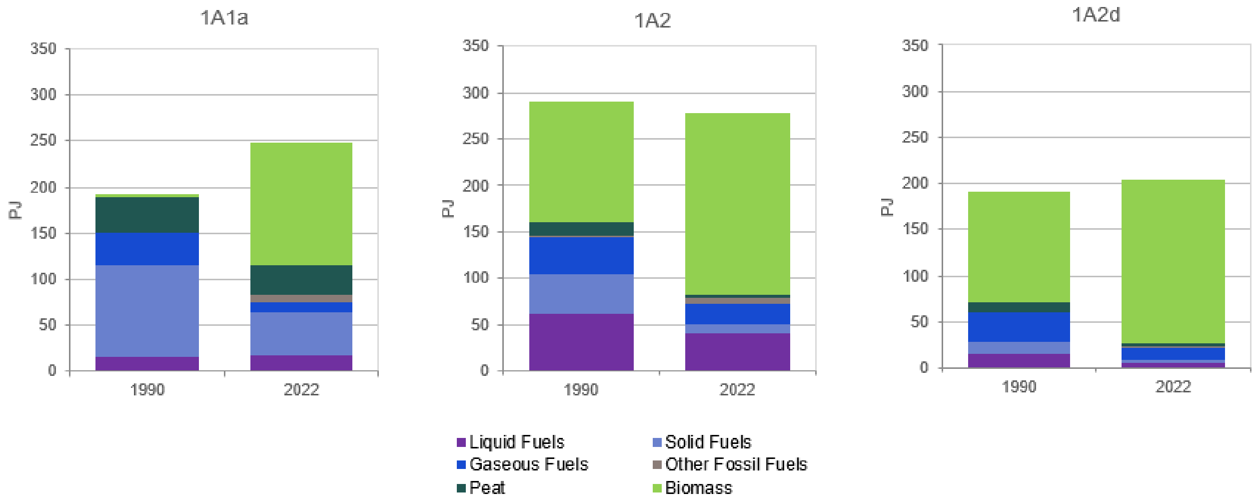


Figure 2.2-7 Fuel combustion in sectors 1.A.2, 1.A.2d and 1.A.1a

Transport

In 2022 the use of energy in transport decreased by 4% in 2022. The share of domestic transport was 16% of final energy consumption. The consumption of petrol and diesel declined by 6% and 5% respectively. These total volumes of transport fuels include the shares of liquid biofuels. (Energy supply and consumption, Statistics Finland)

The share of transportation of energy-related emissions was 30% in 2022. Emissions from transport decreased by 2% from 2021 mainly due to decreased kilometrage in road transportation. The share of biofuels in diesel and petrol declined compared to previous year. From around 2013, the bioshare in diesel oil has varied annually and caused fluctuations in the annual emissions. Finland’s biofuel legislation allows the distributors to fulfil the bio-obligation flexibly in advance.

In the beginning of the time series, the magnitude of the growth of emissions in road transport was smaller in Finland than in many other Annex I countries, mainly due to the effect that the economic recession in the early 1990s had on transport (see Section 3.2.5).

Commercial and residential sectors

Energy consumption in households fell by around 4 terawatt hours (TWh) in 2022 from the previous year. The energy crisis in the autumn with its high prices led to energy saving measures. The year was also milder than usual. The combined effect of these dropped energy consumption in households to just short of 65 TWh (Energy consumption in households, Statistics Finland).

Emissions from the residential sector have decreased by 75% and from commercial sectors by 56% compared with the 1990 levels. The decrease is mainly due to substitution of direct oil heating with district heating and electricity.

2.2.2 Industrial processes and product use

Emissions from industrial processes and product use have decreased by 5% (0.2 Mt CO_2 eq.) since 1990. At the beginning of the time series, some production plants were closed down and that caused a fast decrease in emissions. After this, the production outputs and emissions increased and reached the level of 1990 in 1996. Increase of emissions continued until 2009, when emissions decreased fast due to the economic downturn as the demand for industrial products diminished. The implementation of N_2O abatement technology happened at the same time, which is why the emissions stayed at lower level even if the production started to grow after the recession in 2010. In the 2010s emissions from industrial processes and product use have decrease slowly towards the level of 1990.

CO_2 emissions have increased by 9% from 1990 to 2022, reasons are increased production of hydrogen and increased use of limestone and dolomite. Main part of methane emissions is from ethylene production (fugitive emissions) and these emissions have decreased by 71% since 1990. Nitrous oxide emissions have fluctuated during the period 1990 to 2022 first a fast decrease due to the closing of a nitric acid production plant and after that a slow increase of emissions, the second fast decrease that started in 2009 originated from the implementation of a new N_2O abatement technology in nitric acid production and the decreased demand of fertilisers. Since 1990, nitrous oxide emissions have decreased by 1.3 Mt CO_2 eq. (89%).

The emissions of F gases increased 25-fold during 1990 to 2008. A key driver behind the trend has been the substitution of ozone depleting substances (ODS) by F gases in many applications. During 2010s F gas emissions have started to decline due to decreased leakage rates and replacement of high GWP HFC refrigerants with alternative low-GWP non-HFC refrigerants in many applications (See also Annex 7). Between 2021 and 2022, F gas emissions decreased by 8%. The decrease in emissions resulted mainly from decreased emissions from commercial refrigeration.

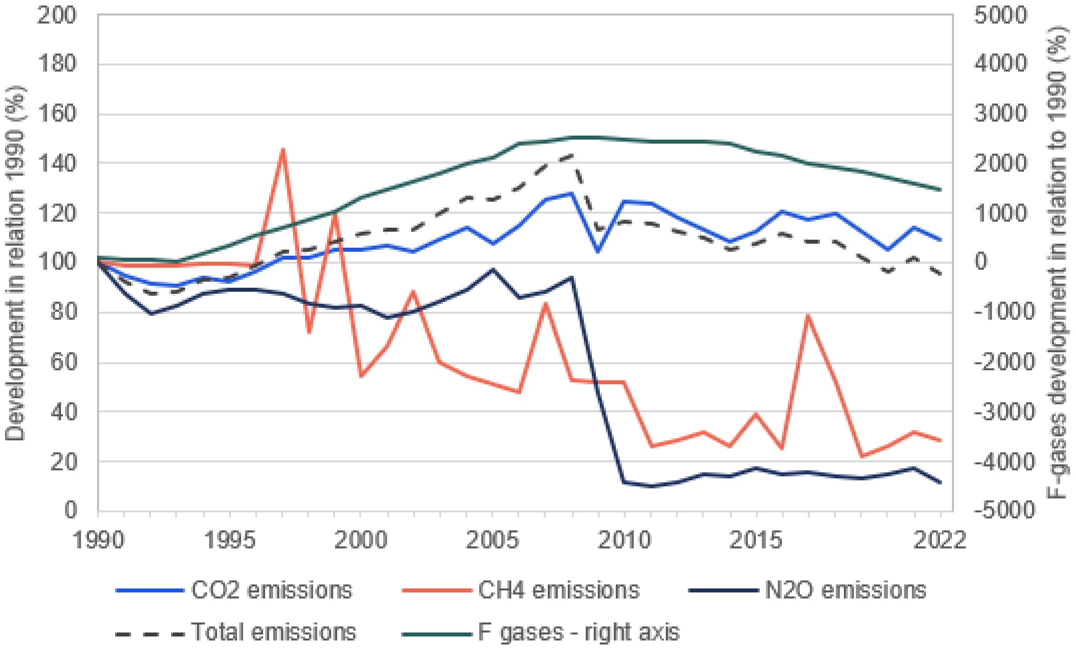


Figure 2.2-8 Relative development of greenhouse gas emissions by gases in the Industrial Processes and Product Use sector relative to the 1990 level (1990=100%)

2.2.3 Agriculture

Agricultural emissions decreased by 17% (1.2 Mt CO_2 eq.) over the period 1990 to 2022. Total agricultural emissions have been quite steady since the beginning of 21st century (yearly variation from 6.1 to 6.4 Mt CO_2 eq.) and were about 2% lower in 2022 than in 2021. The main driver behind the decreasing trend since 1990 has been the overall change in the economy of agriculture, which has resulted in a decrease in the number of animals and an average increase in farm size. Cattle produce a major part of the emissions from enteric fermentation in Finland, thus the 39% decrease in the number of cattle since 1990 has influenced both emissions from enteric fermentation and nitrous oxide emissions from manure management. Methane emissions from manure management have, on the contrary, increased somewhat, despite the decrease in the number of animals. This is mostly due to an increase in the number of cattle and swine kept in slurry-based manure management systems, which cause considerably more methane emissions compared with solid storage or pasture. Nitrous oxide emissions from manure management are smaller in slurry than in solid storage systems, which have had an impact on the decreasing trend in N_2O emissions.

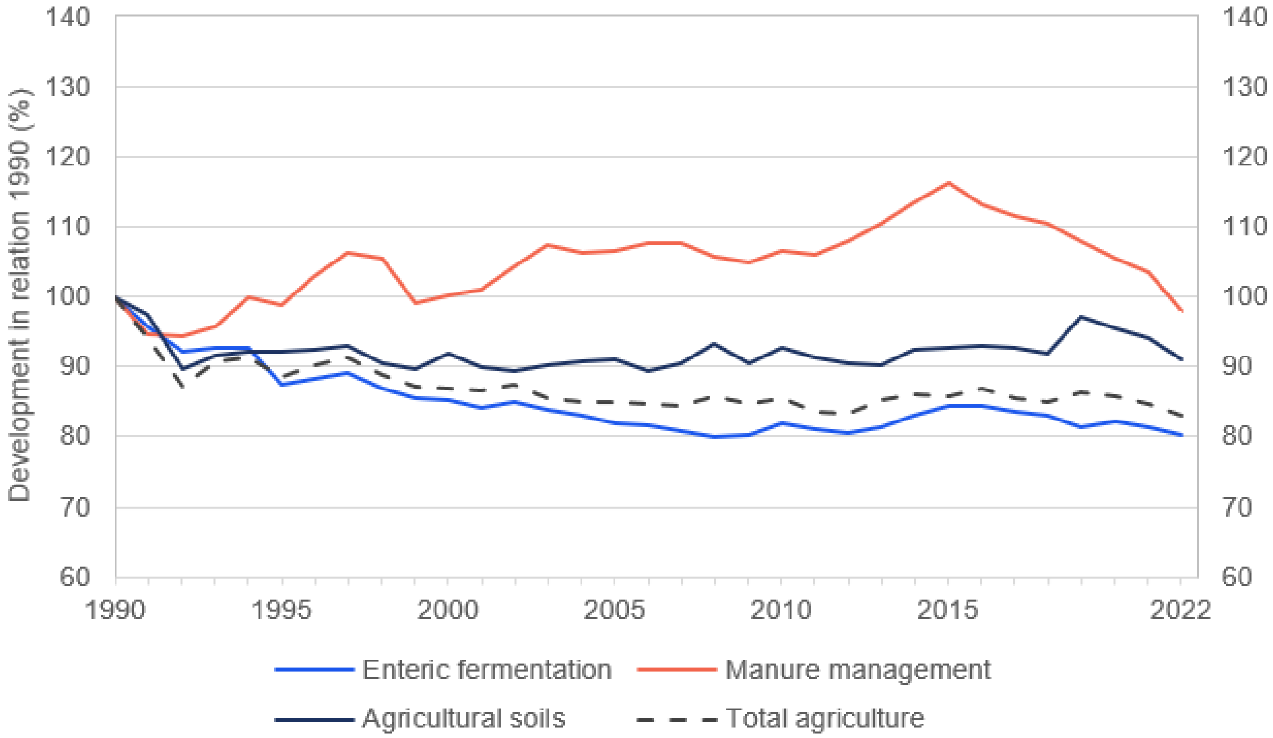


Figure 2.2-9 Relative development of greenhouse gas emissions by main sources in the Agriculture sector relative to the 1990 level (1990=100%)

The most important sources of N_2O emissions in the agricultural sector are agricultural soils. Nitrous oxide emissions from agricultural soils have decreased by 9% compared with the 1990 level. The main reasons for the decreasing trend are the reduction in animal numbers, which affects the amount of nitrogen excreted annually to soils and the reduced use of synthetic fertilisers. Also, the reduced use of lime has significantly decreased the CO_2 emissions from liming. The N_2O emissions from cultivated organic soils have increased as a result of the increased area of these soils.

2.2.4 LULUCF

The annual net removals or net emissions by the LULUCF sector have equalled approximately 4 to 51% of the annual sum of emissions from other sectors, i.e. the total emissions without LULUCF during 1990 to 2022. The determining factor is the balance of tree biomass growth and losses in the Forest Land category. The most important components of the forest sink are the increment of growing stock and the harvest removals. The annual increment of growing stock was 77.7 million m^3, based on the 8th National Forest Inventory (NFI) (measured 1986 to 1994), 107.8 million m^3 based on the NFI12 (2014 to 2018) and 103.7 million m^3 based on NFI13 (2019 to 2022). The rapid increase in increment in the 1980s and 1990s has leveled out and the increment has decreased according to the last inventory measurements. In the NFI based increments, there is less fluctuation between years contrary to the harvest rates. The economic situation and the international market of forest industry products have brought about the amount of domestic commercial roundwood removals and caused the inter-annual fluctuation in the sink. The global economic downturn had a considerable negative effect on the demand for forest-based industry products in 2009. In 2013, a slight economic upturn increased the demand of wood and forest industry products. From 2014 to 2018 the drain had an increasing trend. In 2018, the total drain reached their highest level ever, 94 million m^3, but has dropped down since, still remaining at a high level compared to historical time series. In the year 2022 the drain reached 90 million m^3. Emissions from other land-use categories have been more stable. Emissions from drained organic soils have a slight increasing trend in croplands and wetlands. The net sink of harvested wood products decreased by 13% from 2021 to 2022 mainly due to decreased production of sawn wood.

2.2.5 Waste

Emissions from the waste sector have declined quite constantly since 1990. The decrease of 67% (3.5 Mt CO_2 eq.) since 1990 has mainly been due to the implementation of the new Waste Act in Finland in 1994. In 2022, the emissions from waste were 5% lower than in 2021. At the beginning of the 1990s, around 80% of the generated municipal waste was taken to solid waste disposal sites (landfills). After the implementation of the new Waste Act, minimisation of waste generation, recycling and reuse of waste material and alternative treatment methods to landfills have been endorsed and only minimal amounts of organic waste are landfilled presently. While the emissions from solid waste disposal on land have decreased, the emissions from composting have increased. The increase of waste incineration has decreased the emissions from landfills from 2008 onwards. Implementation of landfill gas recovery has also reduced the emissions from landfills significantly. The waste tax and adoption of the National Waste Plan have also had an impact on the decreasing trend in emissions of the waste sector.

3 ENERGY (CRF 1)

3.1 Overview of the sector

3.1.1 Description

The following problems caused by the CRF Reporter have been identified:

- *Notation key C prevents the aggregation in parent cells resulting in incorrect emission figures. Finland does not consider manual input of emissions to these "pink cells" with the incorrect sums as a solution because it is time consuming and may result calculation or transfer errors easily. Therefore, notation key IE is used instead of C for confidential data in subcategory 1.A.5b and 1.A.3e.*
- *In 1.AD Feedstocks, reductants and other non-energy use of fuels notation key NA could not be entered in line 'Reported under' and therefore cells are left empty for fuels where no emissions occur.*
- *Part of the notation key explanations and official comments which are saved in the CRF Reporter are not visible in the CRF Tables. Explanations are included in the documentation boxes of CRF tables.*

The energy sector is the main source of greenhouse gas emissions in Finland. In 2022, the sector contributed 72% to total national emissions, totalling 32.9 million tonnes of carbon dioxide equivalent (Mt CO_2 eq., Figure 3.1-1). Most of the emissions originate from fuel combustion which reflects the high energy intensity of the Finnish industry, the extensive consumption of fuels during the long heating period, as well as the energy consumed for transport in this relatively large and sparsely inhabited country.

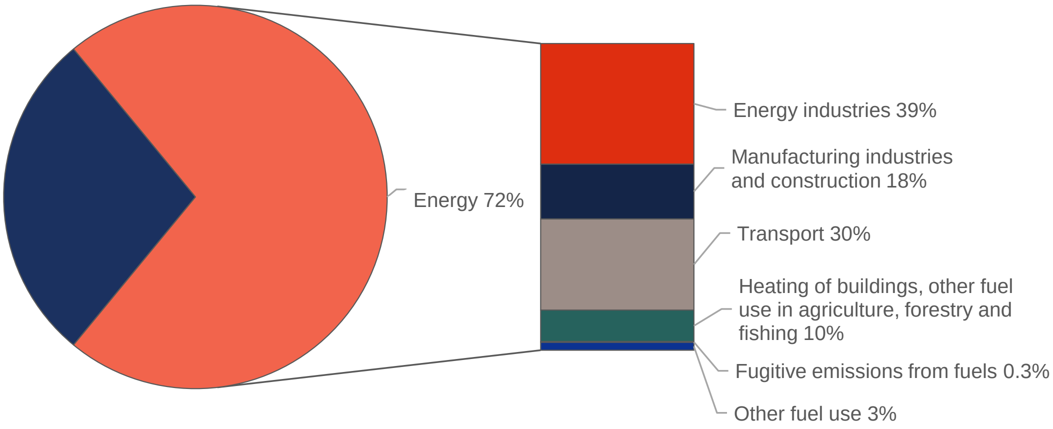


Figure 3.1-1 Emissions from the energy sector compared with total emissions in 2022. Due to independent rounding, the sums do not add up

Emissions from the energy sector are divided into three main categories: emissions from fossil fuel combustion (CRF 1.A), fugitive emissions from fuels (CRF 1.B) and CO_2 transport and storage (CRF 1.C). In the Finnish inventory, emissions from fuel combustion include direct greenhouse gases (CO_2, CH_4, N_2O) and emissions of NO_x, CO, NMVOCs and SO_2 which need to be reported in the greenhouse gas inventory. The emissions of all mentioned gases are calculated within the same system. Point sources, transport and other fuel combustion are included. Fugitive emissions from fuels in Finland consist of CH_4 and NMVOCs emissions from oil refining and storage. CO_2, CH_4 and N_2O emissions from flaring at oil refineries and the petrochemical industry are included as well, as are CH_4 emissions from natural gas transmission and distribution. Indirect CO_2 emissions from evaporative NMVOC and CH_4 emissions in the energy sector are included in the total greenhouse gas emissions but not included in energy sector emissions (See Chapter 9). A general assessment of completeness can be found in Section 1.7 and a more detailed assessment is included in Annex 5.

Consistent with the UNFCCC guidelines, emissions from the energy sector are divided into subcategories presented in Table 3.1-1. This table also includes methods and type of emission factors used in the Finnish inventory.

Table 3.1-1 Reported emissions, calculation methods and type of emission factors for the energy sector in the Finnish inventory in 2022 (CS = country-specific, CR = Corinair, D= default, PS= plant-specific, OTH= other)

CRF	Source	Emissions reported	Method	Emission factor
1.A Fuel combustion				
1.A.1	Energy Industries	CO_2 CH_4 N_2O	Tier 3 Tier 3 Tier 3	CS, D, PS CS CS
1.A.2	Manufacturing industries and construction (stationary sources)	CO_2 CH_4 N_2O	Tier 3 Tier 3 Tier 3	CS, PS CS CS
1.A.2	Manufacturing industries and construction (mobile sources)	CO_2 CH_4 N_2O	Tier 3 Tier 3 Tier 3	CS CR CR, D
1.A.3	Transport	CO_2 CH_4 N_2O	Tier 2, Tier 1* Tier 3, Tier 1 Tier 3, Tier 1	CS CR, CS, D, OTH CR, CS, D, OTH
1.A.4	Other Sectors (stationary sources)	CO_2 CH_4 N_2O	Tier 3, Tier 2, Tier 1 Tier 3, Tier 2, Tier 1 Tier 3, Tier 2, Tier 1	CS, D CS, D CS, D
1.A.4	Other Sectors (mobile sources)	CO_2 CH_4 N_2O	Tier 3, Tier 2 Tier 3, Tier 1 Tier 3, Tier 1	CS CR, OTH CR, OTH, D
1.A.5	Other	CO_2 CH_4 N_2O	Tier 2 Tier 2 Tier 2	CS CS CS
1.B Fugitive emissions from fuels				
1.B.1	Solid fuels	NA	NA	NA
1.B.2	Oil and natural gas and other emissions from energy production	CO_2 CH_4 N_2O	CS Tier 1, Tier 2, CS CS	CS CS, PS, D CS
1.C CO_2 Transport and storage				
1.C.1	Transport of CO_2	CO_2	IE**	NA

** combination Tier 1 and country-specific emission factor refers to piston-engined aircrafts, see Section 3.2.5.3.*

*** CO_2 emissions are calculated from the amount of PCC produced from captured CO_2. Therefore, no losses during the capture, transfer and production are reported separately.*

3.1.2 Quantitative overview

Energy-related emissions vary much from year to year (Table 3.1-2, Figure 3.1-2), mainly following the economic trend, the structure of the energy supply and climatic conditions. Compared with 1990, the emissions in the energy sector in 2022 were about 38% lower. The main contributors to the descent are lower emissions in the manufacturing industries and construction with a 56% reduction (7.5 Mt CO_2 eq.), energy industry with 32% reduction (6.0 Mt CO_2 eq.) and household, services etc. with a 56% reduction (4.4 Mt CO_2 eq.) in emissions relative to 1990. It should be noted that part of the emission reduction in manufacturing industries and construction is related to reallocation of some autoproducer power plants to the energy industry due to outsourcing of these power plants. In 2022, emissions from transport were 19% (2.3 Mt CO_2 eq.) lower compared to 1990. During the time series, the emissions from these source categories have been fluctuating. In 2022, emissions in the energy sector decreased 4% since the year before. The trends are discussed in more detail in Chapter 2 and the category-specific sections in this Chapter.

Table 3.1-2 Emissions from the energy sector by subcategory and gas (Mt CO_2 eq.)

	1990	1995	2000	2005	2010	2013	2014	2015	2016	2017	2018	2019	2020	2021	2022
Total energy	**53.4**	**55.3**	**53.7**	**53.7**	**60.2**	**48.1**	**44.2**	**40.7**	**43.4**	**41.0**	**42.0**	**39.0**	**34.4**	**34.2**	**32.9**
Fuel combustion	53.3	55.1	53.6	53.6	60.1	48.0	44.1	40.5	43.3	40.8	41.9	38.9	34.3	34.1	32.8
CO_2	52.5	54.2	52.7	52.7	59.1	47.1	43.3	39.8	42.4	40.0	41.0	38.0	33.5	33.3	32.0
CH_4	0.34	0.33	0.30	0.32	0.35	0.31	0.31	0.29	0.31	0.31	0.31	0.30	0.26	0.29	0.27
N_2O	0.48	0.52	0.53	0.53	0.58	0.52	0.50	0.48	0.51	0.50	0.53	0.52	0.46	0.50	0.48
Fugitive emissions from fuels	0.12	0.18	0.13	0.15	0.15	0.12	0.12	0.15	0.14	0.18	0.12	0.10	0.10	0.09	0.09
CO_2	0.11	0.07	0.06	0.07	0.10	0.08	0.08	0.11	0.10	0.15	0.09	0.07	0.08	0.07	0.06
CH_4	0.01	0.10	0.07	0.08	0.05	0.04	0.04	0.04	0.04	0.03	0.03	0.03	0.02	0.02	0.03
N_2O	0.0011	0.0007	0.0006	0.0007	0.0009	0.0011	0.0008	0.0011	0.0010	0.0014	0.0009	0.0006	0.0007	0.0007	0.0007

Table 3.1-3 Emissions from fuel combustion and fugitive emissions from fuels in Finland (Mt CO_2 eq.)

	1990	1995	2000	2005	2010	2013	2014	2015	2016	2017	2018	2019	2020	2021	2022
Total energy	**53.4**	**55.3**	**53.7**	**53.7**	**60.2**	**48.1**	**44.2**	**40.7**	**43.4**	**41.0**	**42.0**	**39.0**	**34.4**	**34.2**	**32.9**
Fuel combustion	**53.3**	**55.1**	**53.6**	**53.6**	**60.1**	**48.0**	**44.1**	**40.5**	**43.3**	**40.8**	**41.9**	**38.9**	**34.3**	**34.1**	**32.8**
Energy industries	19.0	24.0	22.1	22.1	30.9	22.1	20.9	17.8	19.1	17.5	18.6	16.2	13.1	13.4	12.9
Manufacturing industries and construcion	13.4	12.2	11.9	11.3	10.0	8.4	7.1	6.7	6.8	6.6	6.8	6.6	6.3	6.4	5.9
Transport	12.1	11.3	12.1	12.9	12.7	12.0	10.8	10.8	12.1	11.5	11.7	11.2	10.4	10.0	9.8
Other sectors	7.8	6.3	6.0	5.7	5.2	4.5	4.3	4.2	4.4	4.3	4.0	4.0	3.8	3.6	3.4
Other	1.1	1.3	1.4	1.5	1.2	1.0	1.0	1.0	0.9	0.9	0.7	0.8	0.7	0.7	0.8
Fugitive emissions from fuels	**0.12**	**0.18**	**0.13**	**0.15**	**0.15**	**0.12**	**0.12**	**0.15**	**0.14**	**0.18**	**0.12**	**0.10**	**0.10**	**0.09**	**0.09**
Oil refining	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01
Natural gas	0.005	0.10	0.06	0.07	0.04	0.03	0.03	0.03	0.03	0.02	0.02	0.02	0.02	0.02	0.02
Flaring	0.11	0.08	0.06	0.07	0.10	0.08	0.08	0.11	0.11	0.15	0.09	0.07	0.08	0.07	0.07
Town gas	0.002	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO

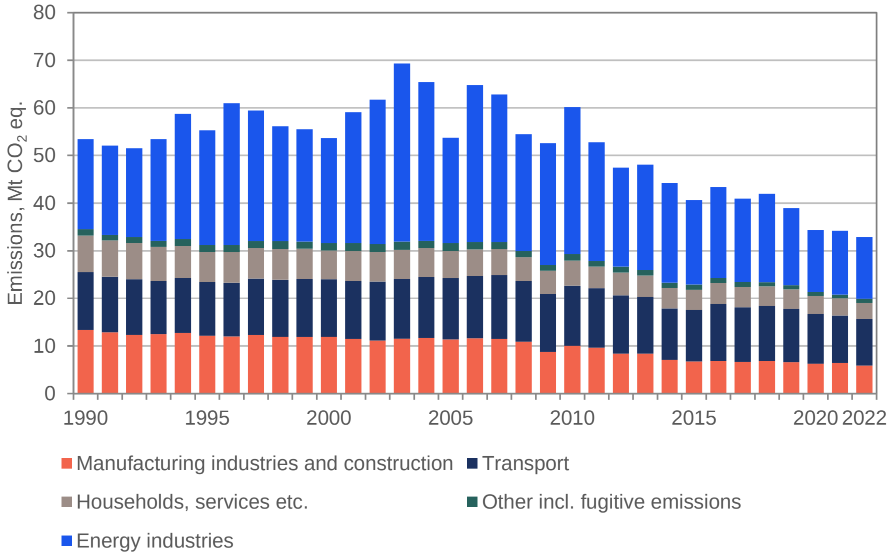


Figure 3.1-2 Emissions from the energy sector by subcategory (Mt CO_2 eq.)

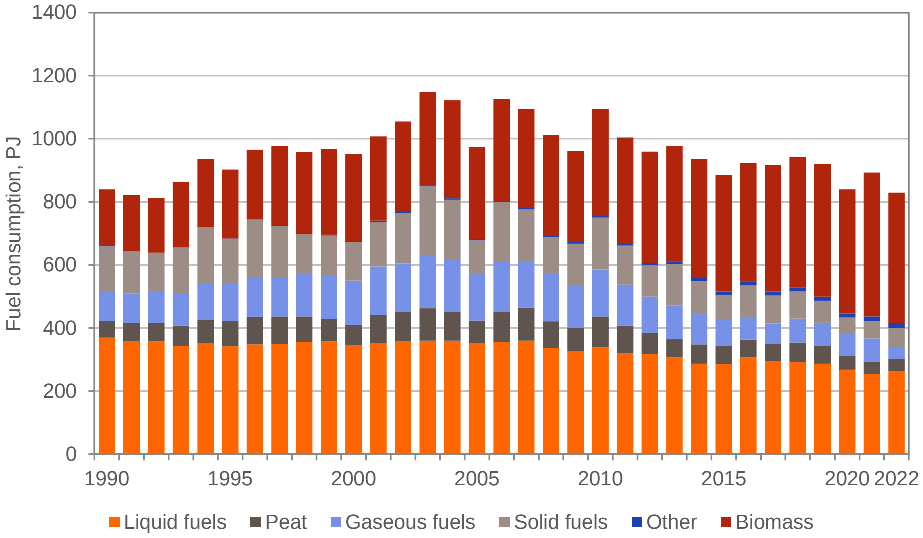


Figure 3.1-3 Consumption by fuel types (PJ)

3.1.2.1 Emissions from fuel combustion (CRF 1.A)

Total emissions from fuel combustion amounted 32.8 Mt CO_2 eq. in 2022 and were 4% less than the previous year. Emissions from fuel combustion are now 53% lower than the 2003 record level and 39% below the 1990 level.

CO_2 emissions from fossil fuel combustion (32.0 Mt) accounted for 97% of the energy sector's total emissions and for 70% of total greenhouse gas emissions in 2022.

The share of N_2O emissions of the energy sector's total emissions in 2022 was 1.5%. N_2O emissions come mainly from fluidised bed combustion and transport. The share of CH_4 emissions is 0.8% respectively. CH_4 emissions are mainly due to the incomplete combustion of wood fuels (small-scale combustion).

Fuel combustion by fuel (PJ) and related CO_2, CH_4 and N_2O emissions for total time series are given in Appendix_3b at the end of the Chapter 3.

3.1.2.2 Fugitive emissions from fuels (CRF 1.B)

Fugitive emissions from fuels comprise only about 0.3% of total greenhouse gas emissions in Finland. Emissions totalled 0.09 Mt in 2022 and 0.12 Mt in 1990. These emissions have decreased by 27% from the 1990 level, increased 2% from the previous year and have fluctuated somewhat during the time-series. (Table 3.1-3 and Figure 3.1-4). The growth in the emission level in 2017 was partly due to the opening of two LNG terminals (late 2016 and 2017) and partly to unexpected disturbances in the start-up of a petrochemical plant after a maintenance shutdown. Some disturbances in oil refineries and the petrochemical industry in the beginning of the time-series caused higher than normal flaring emissions. After the beginning of 2000 flaring emissions started an increasing trend up to 2017. In 2021 and 2022 emissions decreased especially in the petrochemical industry, after the 2017 peak.

Emissions from natural gas transmission vary depending on operation, maintenance and extension works; part of the emissions from gas transmission are caused by the normal running of older compressor stations in the transmission network, another source of emissions is the exhaustion of pipelines during maintenance breaks and extension work. Natural gas distribution in the Helsinki area network started gradually in 1991. The previously distributed town gas included only 1% CH_4, and these almost negligible emissions are included in the inventory. Emissions from natural gas distribution were at their highest in 1994 and have declined 89% since. The amount of emissions from distribution depends on the amount of exhaustion of natural gas from distribution pipelines. Exhaustions are done during the maintenance and extension works. These emissions have decreased due to better maintenance and renewal of pipelines.

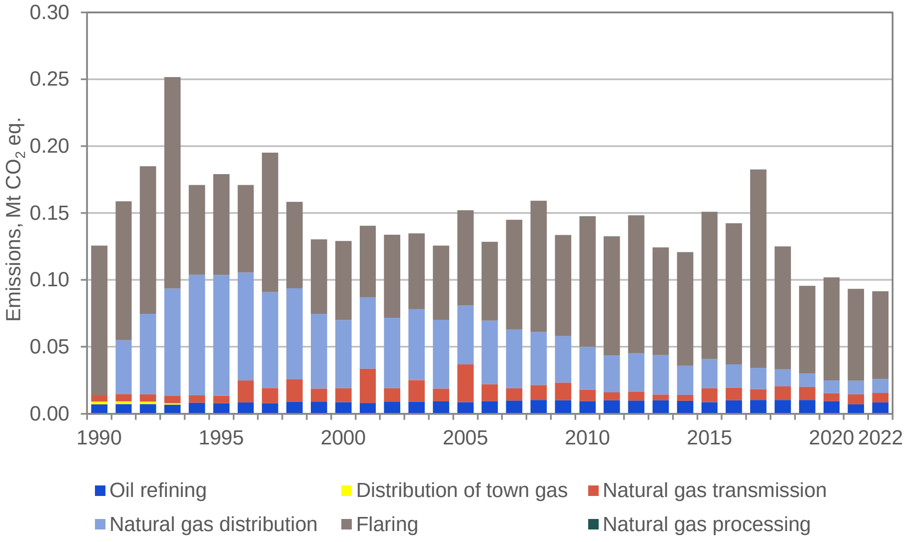


Figure 3.1-4 Fugitive emissions from fuels by subcategory (Mt CO_2 eq.)

3.1.3 Key categories

The key categories in Energy are summarised in (Table 3.1-4).

Table 3.1-4 Key categories in the Energy sector in 1990 and 2022 (Approach 1 and Approach 2)

IPCC category	Gas	Identification criteria	Method
1.A.1. Energy Industries–- Liquid Fuels	CO_2	L, T	Tier 3
1.A.1. Energy Industries–- Solid Fuels	CO_2	L, T	Tier 3
1.A.1. Energy Industries–- Gaseous Fuels	CO_2	L, T	Tier 3
1.A.1. Energy Industries – Other Fossil	CO_2	L, T	Tier 3
1.A.1. Energy Industries – Peat	CO_2	L, T	Tier 3
1.A.1. Energy Industries – Biomass	N_2O	L, T	Tier 3
1.A.2. Manufacturing Industries and Construction – Liquid Fuels	CO_2	L, T	Tier 3
1.A.2. Manufacturing Industries and Construction – Solid Fuels	CO_2	L, T	Tier 3
1.A.2. Manufacturing Industries and Construction – Gaseous Fuels	CO_2	L, T	Tier 3
1.A.2. Manufacturing Industries and Construction–- Other Fossil	CO_2	L, T	Tier 3
1.A.2. Manufacturing Industries and Construction–- Peat	CO_2	L, T	Tier 3
1.A.3a. Domestic Aviation–- Liquid	CO_2	L, T	Tier 2, Tier 1*
1.A.3b. Road Transportation–- Diesel oil	CO_2	L, T	Tier 2
1.A.3b. Road Transportation–- Diesel oil	N_2O	L, T	Tier 3
1.A.3b. Road Transportation–- Motor gasoline	CO_2	L, T	Tier 2
1.A.3b. Road Transportation–- Motor gasoline	CH_4	T	Tier 3
1.A.3b. Road Transportation–- Motor gasoline	N_2O	T	Tier 3
1.A.3c. Railways	CO_2	T	Tier 2
1.A.3d. Domestic Navigation–- Liquid Fuels	CO_2	L	Tier 2
1.A.4. Other Sectors–- Liquid Fuels	CO_2	L, T	Tier 3, Tier 2, Tier 1**
1.A.4. Other Sectors–- Peat	CO_2	T	Tier 2
1.A.4. Other Sectors–- Biomass	CH_4	L, T	Tier 3, Tier 2, Tier 1***
1.A.4. Other Sectors–- Biomass	N_2O	L, T	Tier 3, Tier 2, Tier 1***
1.A.5. Other non-specified – Liquid Fuels	CO_2	L, T	Tier 2
1.A.5. Other non-specified – Gaseous Fuels	CO_2	T	Tier 2
1.B.2. Oil and Natural gas and other	CH_4	T	CS

** Tier 1 for Aviation gasoline (piston-engined aircrafts, see Section 3.2.5.3.) which covers 1% of CO_2 emissions from 1.A.3a Liquid fuels in 2022.*
*** Tier 1 for 1A4ci which covers 10% of CO_2 emissions from 1.A.4 – Liquid fuels in 2022.*
**** Tier 1 for 1.A.4ciii which covers 0.003% and 0.08% of CH_4 and N_2O emissions respectively from 1.A.4 – Biomass in 2022.*

3.1.4 Description of the ILMARI calculation system

Calculation of emissions from fuel combustion are principally made with the ILMARI system developed in Statistics Finland. Emissions from mobile sources are mainly calculated with separate models, but aggregate results are included in the ILMARI system. The current version of the ILMARI calculation system was developed in 2002 and has been continuously improved since then. In addition, the calculation results of separate subsystems, which calculate fugitive emissions and emissions from industrial processes and product use (excl. F gases), are imported to the ILMARI system before compiling the CRF tables.

The ILMARI system has been specifically designed for the calculation of energy-based emissions. ILMARI uses mostly a bottom-up methodology consistent with the IPCC Tier 3 approach. ILMARI is closely connected to the energy statistics production and has links to economic statistics. The use of bottom-up data for emission calculation (fuel and emission data from environmental permits through the YLVA (formerly VAHTI) data, see Section 1.3 and Annex 6) makes it possible to take into account changes in the technology of combustion processes.

ILMARI combines three main types of activity source data of fuel combustion activities:

1. Detailed bottom-up data for point sources (around 2 500 boilers, covering > 2/3 of the total annual fuel combustion)
2. Aggregate transport and off-road vehicle data (covering ~1/6 of the total annual fuel combustion)
3. Aggregate sectoral/subsectoral data for other sources (covering ~1/6 of the total annual fuel combustion)

The ILMARI calculation system has been used for national emission estimations of CO_2, SO_2, NO_2, CO, CH_4, N_2O, NMVOC and PM (particulate matter) emissions of fuel combustion from 1990, except for 1991. The CRF tables for 1991 are produced by top-down estimates based on data for 1990 and 1992. All emissions from fuel combustion are calculated using as detailed fuel consumption data as possible.

For point sources, ILMARI includes in addition to identification data (plant owner, name, location etc.) also technical data on the combustion processes, such as type of power plant, capacity, combustion technique, emission reduction technology, etc. In Finland, it is typical to use power plants fired by a combination of fuels in which the fuel mix varies according to the changes in the availability of fuels as well as their prices and taxes and to the price of CO_2 in the European Union Emissions Trading System. This causes annually changes in the fuel mix, emission estimates and implied emission factors for different types of plants. All these changes cannot be reported individually in the NID due to the number of boilers and fuels used (see also in Section 3.2.4.2 factors affecting implied emission factors).

The input data for ILMARI come from various databases, models and other information sources. The data sources of the ILMARI calculation system are presented in Figure 3.1-5 and the production process of ILMARI and CRF 1 data tables is described in Table 3.1-6.

In the production process, the data of point sources are firstly taken to ILMARI for checking and corrections (see also 3.2.4.4). Thereafter, the data from the transport models and heating energy model are imported and the statistical corrections of fuel consumption and non-specified consumption of fuels and are taken into account. The total fuel consumption figures are compared with the total figures taken from the Energy statistics. If this verification check reveals significant differences, the reasons will be studied and possible corrections made to either the Energy statistics data or the GHG inventory data, depending on the case. Generally, differences causing more than 50 kt of CO_2 will be checked immediately, smaller differences will be left to next submission, but this depends also on time available before submission date. Energy statistics and GHG inventory are prepared in the same unit in Statistics Finland, which enables fluent co-operation. In the draft EU submission on 15 January energy statistics data used for the inventory are preliminary and more updated data are available for the final EU submission on 15 March. Therefore, updates between draft and final submissions are often performed in the Finnish inventory. The more detailed QA/QC procedures of the subsectors of the Energy sector are described in the corresponding chapters.

The calculation systems of mobile sources (LIPASTO) are described in detail in Section 3.2.5 Transport. Most of the emission calculation of domestic transport and non-road machinery are done in the LIPASTO model of VTT Technical Research Centre of Finland Ltd. Statistics Finland calculates emissions of civil aviation based on information received from Eurocontrol. Statistics Finland aggregates the transport data received from VTT to be used in ILMARI, following appropriate CRF categories, see
Table 3.1-5. So far vehicle type data of road transportation in the current ILMARI system is aggregated due to the procedure for handling comparisons to Energy Statistics. Therefore, emissions and activity data from categories 1.A.3bii, 1.A.3biii and 1.A.3biv are included in category 1.A.3bi.

Table 3.1-5 The differences between LIPASTO reporting and greenhouse gas inventory

LIPASTO submodel	GHG inventory
LIISA (road transport) - data reported by vehicle types	1.A.3bi- iv Road transport - Data taken from LIISA reported by fuel categories (vehicle types aggregated) - Emissions from categories 1.A.3bii, 1.A.3biii and 1.A.3biv are included in category 1.A.3bi. - Both fossil and biogenic fuels
RAILI (railways) - includes exhaust gas emissions and energy consumption caused by railway transport	1.A.3c Railways - fuels and emissions from fuels taken from RAILI
MEERI (navigation) - includes split to domestic navigation and foreign shipping traffic - breakdown by type of fleet/activity - includes fishing, reported separately	1.A.3d Navigation - Domestic navigation taken from MEERI - Bunkers are calculated separately (different definition) - Breakdown by fuel type - Fishing reported in 1.A.4ciii

LIPASTO submodel	GHG inventory
TYKO (non-road working machinery) - breakdown by machine type and fuel type (over 50 combinations)	Breakdown by following Off-road vehicles and other machinery categories (and fuel types) aggregated from TYKO: - 1.A.2gvii Manufacturing industry and construction - 1.A.4aii Commercial/institutional - 1.A.4bii Residential - 1.A.4cii Agriculture/forestry/ fisheries

Table 3.1-6 Production process of ILMARI and CRF 1.A data tables

Production of CRF data tables for Energy sector	
1. YLVA data input to ILMARI	Point source data input from database
Checks, corrections	Missing data (plants, fuels, emissions) Erroneous data Order of magnitude errors Quantity units Fuel codes
New data for plants	Technical data Classifications New emission factors
Comparison	Totals by plants Previous years' data Other plant level data Companies' environmental reports
2. EU ETS data input to ILMARI	Point source data input for comparison and supplementation of YLVA data
3. LIPASTO and aviation data input to ILMARI	Manual input of transport and off-road vehicle and other machinery data
4. Energy Statistics data input to ILMARI	Manual input of heating fuels data and other fuel consumption data
5. Comparison to Energy Statistics and EU ETS data	Totals and plant level data by fuel
6. Fugitive emissions input to ILMARI	Manual input from subsystem in which fugitive emissions are calculated
7. Industrial processes and product use (excl. F gases) data input to ILMARI	Manual input from subsystem in which emissions from industrial processes and product use (excl. F gases) are calculated
8. Final annual data sheet (output to ILMARI, stored in SAS time series database)	2 000 plants + 50 sectoral sources identification data, classifications, technical data, fuels, emission factors etc.
9. CRF query from SAS database (output to excel sheets)	SAS database functions
10. CRF time series in excel sheets	Manual cut and paste or linking to CRF Reporter excel import sheets
11. QA/QC checks	SAS and manual checks to detect data transfer or other errors
Comparisons between ILMARI and CRF data	
Comparison of the results to previous submission	
Visual IEF checks	

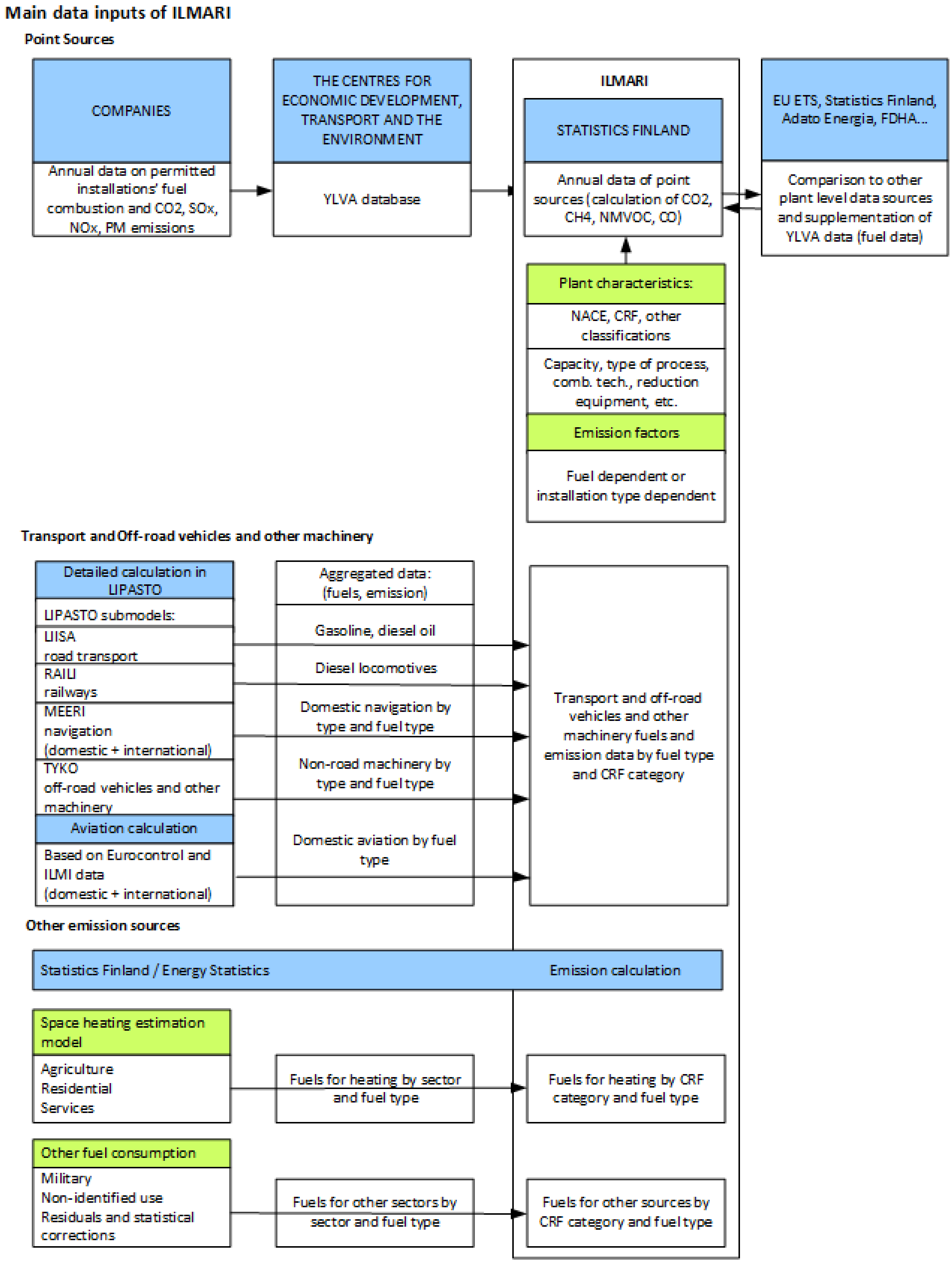


Figure 3.1-5 Data sources of the ILMARI calculation system.

3.2 Fuel combustion (CRF 1.A)

3.2.1 Comparison of the sectoral approach with the reference approach

The reference approach (RA) is carried out using import, export, production and stock change data from the energy balance (EB) sheet published in the Energy Statistics. However, the RA table requires liquid fuels reported at a more disaggregated level than in the EB sheet. These disaggregated data are taken from the background data files of the EB and for 1990 to 1994 from the published foreign trade statistics (National Board of Customs, 1990 to 1994). Another difference is that in the EB sheet, stock changes and statistical differences are combined for certain fuels, whereas in the RA table, only the stock changes are reported. Stock change data are not available as complete time series for each fuel separately. Therefore, certain stock change figures have been estimated using other available data.

Comparison of annual RA and SA data brings out uncertainties, which are not present in the SA, for example, errors in import/export and stock change data, different aggregation practises and, especially, treatment of statistical differences. Therefore, we have more confidence in the SA data than in the RA data.

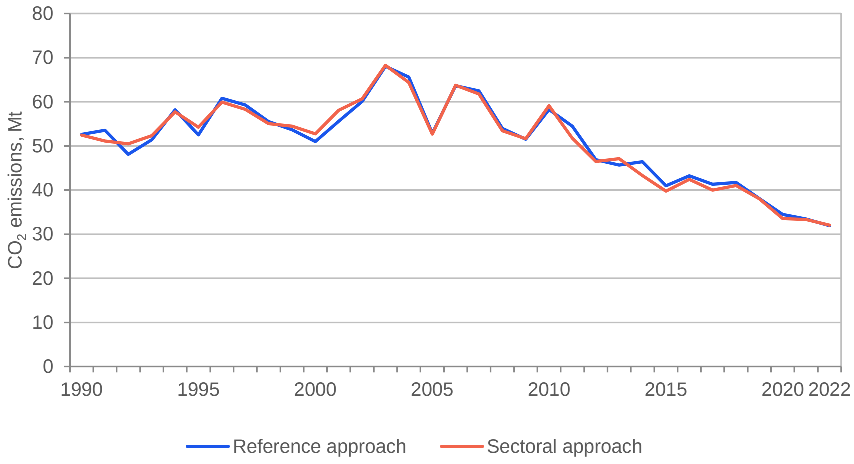


Figure 3.2-1 Carbon dioxide emissions of the Reference and Sectoral Approach in Finland

The difference between the CO_2 emissions in RA and SA was -0.3% for 2022 and 0.3% for 1990 (Figure 3.2-1). In 2022 difference in liquid fuels is 0.2%, in peat -0.1% and in other fossil fuels there is no difference.

The difference in gaseous fuels (2.5% in 2022) is related to captured and stored CO_2 which is reported as recovered CO_2 in gaseous fuels in subcategory 1.A.2.d (Manufacturing industries and construction – pulp, paper and print). The calculated amount of this stored CO_2 is approximately 0.05–0.2 Mt CO_2 per year. If the gaseous fuels were reported by excluding the stored CO_2 in the sectoral approach, the difference to reference approach would be 0.2% in 2022.

For the discrepancy in solid fuels (-3% in 2022) there are some uncertainties related to stock change and feedstock data because the information received from companies is not completely suitable for the reference approach calculation and reporting. Meanwhile, the information for the sectoral approach is highly reliable because the point source data (fuel combusted in facilities) are checked annually from at least three independent data sources for each facility. Therefore, the fuel combustion data for the sectoral approach are the best available data and that the emissions are not underestimated.

The reasons behind the highest differences during the time series between the RA and SA are explained in below.

No obvious reasons for differences in 1991 (4.7%) and 1992 (-4.7%) have been found, although some possible explanations were identified in the background data of a study by Torniainen (2006). The final conclusions on the reasons for the differences cannot be made without further data, which are no longer available for 1991 and 1992. Therefore, explaining the differences between RA and SA fully would be resource consuming and require demanding investigations. In addition, these differences are not exceptionally high when compared with data reported by other countries, and within 5% range which the 2006 IPCC Guidelines gives the thresholds for explaining differences. Due to the resource demands of the task, as well as the low significance of the issue, there are no plans to further investigate the reasons for the differences in the RA and SA for 1991 and 1992.

The difference between RA and SA in 2011 is 5.2% for the CO_2 emissions. The difference between RA and SA in 2011 is caused by likely errors in stock change data for hard coal. We have checked the plant-level consumption figures from several independent sources and found no discrepancies here. The problems with the stock change data are probably related to the changes in the ownership of some hard coal stockpiles and reporting of stock levels.

In 2014, the difference between RA and SA was 7.2% for the CO_2 emissions. This difference is partly due to corrections in stock level data of certain oil products in 2012 to 2013; this correction affects in 2013 and 2014 data (opposite signs in RA-SA difference in Liquid fuels and also Total fuels).

There are statistical differences in oil balances, which can be seen in the RA-SA comparison. These differences, among other, were addressed in the study by Torniainen (see above). As an example, we could mention statistical differences of crude oil, which vary from –1,317 to +783 kt during 1990 to 1997. These figures alone correspond to several percentage differences in the RA-SA comparison.

In recent years, new challenges for the RA-SA comparison have emerged, when more biocomponents have been included in transport fuels. It is not always clear, whether these biocomponents and biogenic feedstocks are included in import and export data. This subject has become important, because production and also import and export of transport biofuels are growing in Finland.

Collaboration with energy statistics group, the greenhouse gas inventory unit, other authorities (the Customs and Tax Administration) and most important fuel producers and importers is continuous. Aim of this collaboration is to understand the reasons behind large annual statistical differences and different figures in oil balance, import/export statistics and Reference Approach. One result of this co-operation is the revision of fuel properties (density, NCV and CO_2 emission factor) for the latest years (especially fossil diesel) for the 2019 and 2020 submissions.

In addition, the energy statistics group and greenhouse gas inventory unit have combined plant-specific data from different reporting and data collection systems concerning refineries and petrochemical industry in single sheets for internal use. This has made the data more transparent, comparable and usable and has increased the understanding on how different types of feedstocks and fuels are reported in import and export statistics, refinery plant data, fuel surveys. As a result, energy statistics group can provide more accurate and correctly allocated data for IEA/Eurostat Joint Questionnaires.

In general, cumulative difference between RA and SA over 1990 to 2022 is -0.4% of total cumulative CO_2 emissions, which seems acceptable.

The energy balance for the 2022 inventory is be included in Annex 3. Differences between RA and IEA data are explained in Annex 7/ Comparisons with other international reportings.

Recalculations

Compared to 2023 submission no recalculations for 1990 nor 2005 were done. Recalculations in the sectoral approach also reflects to the RA-SA difference. The total difference between RA-SA changed from -4.7% to 0.4% in 2021 from the previous submission due to recalculations described below.

The largest recalculation concerning reference approach was revised methodology for correcting (taking into account) the effect of transport biofuels in RA emission data. As described above, is it not always clear, whether these biocomponents and biogenic feedstocks are included in import and export data. Due to this problem, in the latest inventory submissions, the RA-SA difference for liquid fuels for most recent years had become larger. For the March 2024 submission, the previously used biocomponent correction was removed, as the methodology used started to give unreasonable results in latest years. This recalculation affected mostly years 2008-2022. For 2005 this recalculation had no effect, as biofuel use in transport was zero. Overall, this recalculation affected RA liquid fuels emissions from 0.2 Mt in 2008 to 2.3 Mt CO_2 in 2021 (in 2002-2007 the figures are very low).

Another recalculation was done to correct wrong export data of natural gas in 2012 to 2022. Also, for 2021 the reference approach of peat, bitumen and residual fuel have been recalculated due to updated energy statistics data.

3.2.2 International bunker fuels

International bunkers cover international aviation and navigation according to the IPCC Guidelines.

Emissions from international bunkers were 1.6 Mt CO_2 eq. in aviation and 1.1 Mt CO_2 eq in navigation in 2022. The amount of emissions in international aviation has increased gradually from 1993 until the 2008 recession, after which the trend stabilised until 2016. After that emissions increased due to continuing growth in Far East and North America travel (Figure 3.2-2). In 2020 and 2021 emission from international aviation dropped due to COVID-19 pandemic. In 2022 emissions increased 98% compared to previous year but are still nearly 37% below the level in 2019.

The trend of emissions in international navigation has fluctuated during most of the period. The most important reason for these fluctuations has been the variation in bunker fuel prices. Especially the ferries between Finland and Sweden can refuel in one or the other country depending on fuel prices. The Finnish currency was devalued in the early 1990s, which affected fuel prices strongly. This effect has disappeared due to Finland's EU membership and the common currency. Since the beginning of the 2000s refuelling in Finland diminished to a very low level until 2015. Since then, marine bunker sales have increased again. In 2022 marine bunker emissions increased 21% compared to 2021. The use of LNG in international navigation started in 2016.

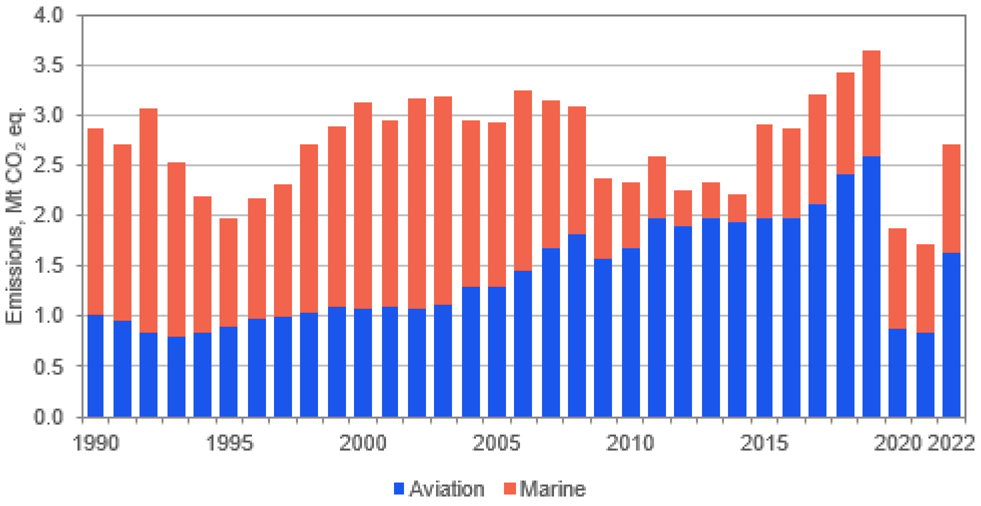


Figure 3.2-2 Emissions from international bunker, Mt CO_2 eq.

The emissions are calculated using the ILMARI calculation model of Statistics Finland (see Section 3.1.4 for more details). Fuel consumption data by transport mode are obtained from the energy statistics and they include fuel sales to ships and aircrafts traveling abroad. The country-specific CO_2 emission factors are the same as for domestic aviation and navigation. The average non-CO_2 emission factors have been partly selected from the IPCC Guidelines and partly derived from the results of ILMI calculation system (see Section 3.2.5.3) and Eurocontrol data.

The case of Åland could be seen as an exception to the IPCC definitions. In the present inventory, all trips to Sweden via Åland are treated as international, because the number of passengers (or cargo) leaving or entering the ships in Åland is very low. A small share of Åland transport has been allocated to domestic navigation (see Section 3.2.5.6). The fuel volumes (gasoil and residual fuel oil) of the Åland correction are subtracted from the original bunker fuel data and added to total domestic fuel consumption.

No uncertainty estimation for international bunkers has been carried out.

Bunker fuel quantities are originally taken from the Energy statistics. The data have been checked against the data reported to the IEA Oil Questionnaire. There were small differences (< 0.5%) in physical quantities, caused probably by differing roundings during the time series. The NCVs used by the IEA may differ from those used in the inventory. Also, the Åland correction mentioned above causes some difference, because it has not been included in the IEA bunker fuel data. Until 2008, the difference has been less than 2%, but after that it has become higher. From 2012 to 2014 percentual difference between CRF and IEA data caused by Åland correction has been around 13 to 15%, because the total marine bunker sales have been very low due to market situation. As bunker sales have grown back closer to previous level, from 2015 on the difference has decreased to the level of 4% to 5%.

The bunker fuel figures reported in Sectoral background data for energy tables; Table 1.D 'International aviation and international navigation (international bunkers) and multilateral operations' and Table 1.A (b) 'CO_2 from fuel combustion activities–- Reference approach' are as consistent as possible. Note: the weighted average NCV for residual fuel oil used in the RA is slightly different from the value used for bunker fuels in the SA, which causes a small deviation.

Recalculations

No category-specific recalculations have been done.

Sector-specific planned improvements

There are no sector-specific planned improvements.

3.2.3 Feedstocks and non-energy use of fuels

The emissions from the non-specified burning of feedstocks are calculated by a separate module in ILMARI. The ILMARI system includes point source (bottom-up) data on feedstock combustion in the petrochemical industry and these emissions are reported in corresponding subcategories of 1.A.2. These specified energy uses of feedstock are subtracted from the corresponding total amounts of feedstock. For the rest of the feedstock, 100% of carbon is estimated to be stored in products (mainly plastics).

Residual fuel oil, PCI-coal and coke are used as feedstocks in the metal industry and corresponding amounts are subtracted from the reference approach. Some of this carbon is estimated to be released as CO_2 during the process and emissions are reported in category 2.C.1 (see Section 4.4.2), while the rest of the carbon is mainly included in blast furnace gases and will be used for energy production (reported under category 1.A, see more details in Section 4.4.2.2). Natural gas, heavy fuel oil, LPG, naphtha and other oil products are used as feedstock in the chemical industry. Carbon included in these feedstocks is subtracted from the reference approach. Most of carbon is stored in the products, but certain process emissions are reported in sector 2.B.10 (see Section 4.3.5).

From other feedstocks, only carbon from paraffin waxes is estimated to be oxidised and these emissions are reported in sector 2.D.2 (Section 4.5.3).

The ILMARI system includes point source (bottom-up) data also on waste oil (used lubricants) combustion in different branches of industry, and these emissions are reported in corresponding subcategories of 1.A.2.

For the rest of lubricants, we use a top-down calculation methodology, presuming that 33% of carbon is stored in products (recycled lubricants) and 67% of carbon is released as CO_2 either in burning of lubricants in motors (two-stroke oil and part of motor oil in four-stroke engines) or illegal combustion of waste oil in small boilers. These non-specified emissions from burning of lubricants (excluding above mentioned emissions reported in 1.A.2) are included in category 2.D.1 (Section 4.5.2).

Table 3.2-1 Reporting of carbon stored and emissions related to use of feedstock and lubricants (figures show approximate ranges for the years from 2010 on.

	Use in kt	kt CO_2	Reported in inventory
Feedstock for metal industry	1 100-1 400	1 700-2 400	2.C.1; in RA subtracted from residual fuel oil and coke oven coke
Feedstock for hydrogen production	280-430 (1 000 m^3)	550-870	2.B.10; in RA subtracted from natural gas
Feedstocks for petrochemical industry	1 100-1 200		
Combusted on site	150-210	420-550	1.A.2c
Flaring	10-40	40-90	1.B.2c
Stored in products (plastics, chemicals)	700-900	1900-600	RA carbon stored; subtracted from LPG, naphtha and other oil 'apparent consumption emissions'
Lubricants			
Combustion of recycled waste oil	10-30	30-100	1.A.1 and 1.A.2
Non-specified consumption	40-60		
- of which, estimated combustion (2/3)	25-40	80-120	2.D.1
- stored carbon (in recycled lubricants)	10-20	30-50	RA carbon stored; subtracted from lubricants 'apparent consumption emissions'
Paraffin waxes			
burning of candles	5-8, included in other oil	18-20	2.D.2; in RA subtracted from other oil

According to 2006 IPCC Guidelines emissions from 2-stroke oil should be reported in the Energy Sector. We do not have data on sales of 2-stroke oil separately, thus we have not separated these emissions from the use of 4-stroke oil and other lubricants. However, we have made a rough estimate for 2013, showing that CO_2 emissions from 2-stroke oil might be around (less than) 7 kt. To be able to reallocate these emissions to Energy Sector, we would have to split the figure to four subsectors (road transport, residential non-road machinery, commercial non-road machinery and leisure boats). As we do not have full time series of activity data to allocate these emissions to Energy subsectors, we are not able to do the split and have included them in 2.D.1, correspondingly to the top-down calculation methodology described above. This practise of aggregation and allocation does not result in an over- or underestimation of the emissions.

3.2.4 Energy industries and Manufacturing industries and Construction (CRF 1.A.1, CRF 1.A.2)

3.2.4.1 Category description

Energy industries (CRF 1.A.1) and Manufacturing industries and construction (CRF 1.A.2) include emissions from fuel combustion in point sources in energy production and industrial sectors (power plants, boilers P_{fuel}>5MW and industrial plants with boilers and/or other combustion). In addition to these point sources the emissions from off-road vehicles and other machinery in Manufacturing industry and construction are reported under this category. The emissions from Energy industries by relevant subcategory and gas are presented in Table 3.2-2 and emissions from Manufacturing industries and construction in Table 3.2-3.

In Finland, three pulp and paper mills, one paper mill and two hydrogen plants are capturing and directing part of their fuel combustion-based CO_2 emissions to PCC (Precipitated Calcium Carbonate). The calculated amount of this stored CO_2 (around 0.05 to 0.2 Mt annually) is reported as recovered in gaseous fuels in subcategory 1.A.2d (See Section 3.4).

In 2022, the greenhouse gas emissions from Energy industries amounted to 12.9 Mt CO_2-eq. and Manufacturing industries and construction amounted to 5.9 Mt CO_2 eq. The share of energy industries was 39% of the energy sector’s total emissions. The corresponding share was 18% for manufacturing industries and construction. These two subsectors together accounted for 41% of the total greenhouse gas emissions of Finland.

Table 3.2-2 The emissions from Energy industries by relevant subcategory and gas (Mt CO_2 eq.)

	1990	1995	2000	2005	2010	2013	2014	2015	2016	2017	2018	2019	2020	2021	2022
Energy industries	**19.0**	**24.0**	**22.1**	**22.1**	**30.9**	**22.1**	**20.9**	**17.8**	**19.1**	**17.5**	**18.6**	**16.2**	**13.1**	**13.4**	**12.9**
CO_2	**18.8**	**23.8**	**21.9**	**21.9**	**30.6**	**21.8**	**20.7**	**17.5**	**18.9**	**17.2**	**18.4**	**15.9**	**12.8**	**13.1**	**12.6**
Public electricity and heat production	16.5	21.1	19.1	18.9	27.7	19.1	17.8	14.9	16.9	15.3	16.4	14.0	11.0	11.6	10.9
Petroleum refining	2.04	2.5	2.5	2.6	2.7	2.5	2.5	2.2	1.7	1.6	1.6	1.7	1.6	1.2	1.4
Manufacture of solid fuels and other energy industries	0.35	0.32	0.35	0.39	0.24	0.25	0.30	0.33	0.34	0.33	0.30	0.29	0.27	0.33	0.32
CH_4															
Total	**0.011**	**0.017**	**0.021**	**0.028**	**0.033**	**0.029**	**0.029**	**0.027**	**0.030**	**0.032**	**0.035**	**0.034**	**0.033**	**0.038**	**0.036**
N_2O															
Total	**0.10**	**0.16**	**0.18**	**0.22**	**0.31**	**0.26**	**0.24**	**0.22**	**0.24**	**0.22**	**0.25**	**0.24**	**0.21**	**0.23**	**0.23**

Table 3.2-3 The emissions from Manufacturing industries and construction by relevant subcategory and gas (Mt CO_2 eq.)

	1990	1995	2000	2005	2010	2013	2014	2015	2016	2017	2018	2019	2020	2021	2022
Manufacturing industries and construction	**13.4**	**12.2**	**11.9**	**11.3**	**10.0**	**8.4**	**7.1**	**6.7**	**6.8**	**6.6**	**6.8**	**6.6**	**6.3**	**6.4**	**5.9**
CO_2	**13.2**	**12.0**	**11.7**	**11.2**	**9.9**	**8.2**	**6.9**	**6.6**	**6.6**	**6.5**	**6.6**	**6.4**	**6.1**	**6.2**	**5.7**
Iron and steel	2.50	2.66	3.69	3.67	3.00	2.15	0.98	0.83	0.91	0.88	0.90	0.83	0.81	0.89	0.80
Non-ferrous metals	0.34	0.11	0.15	0.10	0.12	0.11	0.10	0.10	0.11	0.10	0.12	0.11	0.10	0.08	0.09
Chemicals	1.19	1.30	1.09	1.25	0.78	0.75	0.74	0.75	0.78	0.67	0.74	0.73	0.70	0.73	0.70
Pulp, paper and print	5.33	4.77	3.86	3.39	3.44	2.79	2.70	2.68	2.64	2.48	2.55	2.46	2.19	2.21	1.87
Food processing, beverages and tobacco	0.83	0.70	0.33	0.21	0.24	0.23	0.23	0.15	0.17	0.15	0.13	0.15	0.13	0.10	0.10
Non-metallic minerals	1.37	0.80	0.89	0.95	0.72	0.63	0.59	0.59	0.64	0.67	0.60	0.58	0.57	0.58	0.57
Other	1.64	1.65	1.74	1.62	1.60	1.58	1.57	1.49	1.40	1.53	1.60	1.57	1.64	1.66	1.59
CH_4															
Total	**0.018**	**0.020**	**0.021**	**0.019**	**0.021**	**0.024**	**0.025**	**0.024**	**0.024**	**0.025**	**0.025**	**0.024**	**0.023**	**0.025**	**0.022**
N_2O															
Total	**0.15**	**0.14**	**0.16**	**0.15**	**0.12**	**0.12**	**0.12**	**0.12**	**0.13**	**0.13**	**0.14**	**0.14**	**0.12**	**0.14**	**0.12**

Fuel combustion CO_2, CH_4 and N_2O emissions by fuels are given in Appendix_3b at the end of the Chapter 3.

3.2.4.2 Methodological issues

Methods

Emissions from fuel combustion in point sources are calculated with the ILMARI calculation system (See Section 3.1.4). Emissions within CRF 1.A.1 and 1.A.2 (except off-road vehicles and other machinery) are based on actual bottom-up data. In the ILMARI system, emissions are calculated using the annual fuel consumption data. Fuel combustion data are available by installation and by fuel type. For each point source, SO_2, PM, NO_x and CO_2 emissions are reported by plant. In the ILMARI system, SO_2, PM and NO_x emissions are split into each fuel. CO_2, N_2O, CH_4 and NMVOC are calculated based on fuel combustion data. The calculated CO_2 emissions from each fuel in a certain plant are summarised and compared with total CO_2 emissions reported by the same plant.

The basic calculation formulas used in the calculations are the following:

Carbon dioxide:

$E = F * EF(fuel) * OF(fuel),$

Other greenhouse gases:

$E = F * EF(technology)$

F = fuel consumption (by combustion unit and by fuel type)
$EF(fuel)$ = fuel-specific emission factor
$OF(Fuel)$= fuel-specific oxidation factor
$EF(technology)$ = technology-specific emission factor

Technology-specific emission factors depend on the type, capacity, main fuel and combustion technology of the installation (power plant/boiler/process), as well as on emission reduction equipment (for PM, SO_2 and NO_x).

Calculation of the CO_2 emissions is based on a country-specific method (consistent with Tier 3[17], 2006 IPCC Guidelines) using detailed activity (fuel consumption) data and fuel-specific emission factors. For off-road vehicles and other machinery reported under CRF 1.A.2gvii see Section 3.2.5.7.

The SO_2 and NO_x emissions are based on the emission data reported by the plants and recorded in the YLVA (formerly VAHTI) system. The emissions of each plant are split into fuel-based emissions (CRF 1) by each fuel and non-fuel-based, i.e. process emissions (CRF 2).

The allocation of fuel combustion and process CO_2 emissions in the Iron and steel sector is described in Section 4.4.

The emissions of CH_4, N_2O and CO are based on a country-specific method (consistent with Tier 3, 2006 IPCC Guidelines), using detailed activity data and technology-based emission factors for each boiler or process type (emission factors are available for approximately 250 categories of boilers and processes).

In Finland, it is typical to use multi-fuel fired power plants in which the fuel mix varies according to the changes in the availability of fuels as well as fuel prices and taxes and to the price of CO_2 in the European Union Emissions Trading System. This causes annually changes in the fuel mix, emission estimates and implied emission factors for different types of plants. All these changes cannot be reported individually in the NID due to the number of boilers and fuels used and also due to confidentiality issues (see also subtitle Factors affecting implied emission factors in this Section).

Emission factors and other parameters

Mainly country-specific or plant-specific emission factors are used in the calculations, although IPCC default emission factors are used for some fuels of minor importance. CO_2 emission factors, oxidation factors and default net caloric values for different fuels are presented in Table 3.2-4.

Table 3.2-4 CO_2 emission factors, oxidation factors and net caloric values (NCV) by fuel

Fuels	Year	NCV	Unit	Emission factor g CO_2/MJ	Oxidation factor	Source of emission factor
Liquid fuels						
Town gas	all	16.9	GJ/1 000 m³	59.4	1	Neste 1993
Refinery gas (+ other gases)		49.4 (30-55)	GJ/t	49.1-61.4	1	Plant-specific
LPG (liquefied petroleum gas)	1990-2012	46.2	GJ/t	65	1	Neste/ET2004
LPG (liquefied petroleum gas)	from 2013	46.3	GJ/t	64.9	1	SF 2014

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[17] Bottom-up installation level activity and technology data; technology dependent non-CO_2 emission factors.

Fuels	Year	NCV	Unit	Emission factor g CO_2/MJ	Oxidation factor	Source of emission factor
Naphtha		44.3	GJ/t	72.7	1	EE
Motor gasoline (fossil part)	1990-2012	43	GJ/t	72.9	1	VTT/LIISA Model/Neste
Motor gasoline (fossil part)	from 2013	43.4	GJ/t	71.5	1	SF 2018
Aviation gasoline		43.7	GJ/t	71.3	1	EE/Neste
Jet fuel		43.3	GJ/t	73.2	1	EE /Fortum 2002
Other kerosenes (vaporising oil, lamp kerosene)		43.1	GJ/t	71.5	1	EE/2006 IPCC GL
Diesel oil (fossil part)	1990-2012	42.8	GJ/t	73.6	1	VTT/LIISA Model/Neste
Diesel oil (fossil part)	from 2013	42.8-43.2	GJ/t	72.9-73.4	1	SF 2018
Gasoil (light fuel oil, heating fuel oil) (fossil part)	1990-2012	42.7	GJ/t	74.1	1	Neste/EE
Gasoil (light fuel oil, heating fuel oil) (fossil part)	from 2013	43.2	GJ/t	73.1	1	SF 2018
Gasoil (for non-road use) (fossil part)	1990-2004			74.1		
Gasoil (for non-road use) (fossil part)	2005-2012	42.8	GJ/t	73.6	1	EE (same as diesel oil)
Gasoil (for non-road use) (fossil part)	from 2013	43.2	GJ/t	73.1	1	SF 2018
Residual fuel oil (RFO, heavy fuel oil), low sulphur	1990-2012	41.1	GJ/t	78.8	1	Neste/EE
Residual fuel oil (RFO, heavy fuel oil), low sulphur	from 2013	40.4	GJ/t	79.2	1	SF 2014
Residual fuel oil (RFO, heavy fuel oil), normal	1990-2012	40.5	GJ/t	78.8	1	Neste/EE
Residual fuel oil (RFO, heavy fuel oil), normal	from 2013	40.2	GJ/t	78.4	1	SF 2014
Residual fuel oil (RFO, heavy fuel oil), sulphur < 0.1%	from 2015	42.1	GJ/t	76.1	1	SF 2014
Residual fuel oil (RFO, heavy fuel oil), sulphur < 0.5%	from 2016	41.5	GJ/t	77.0	1	SF 2014
Other residual fuel oil (heavy bottom oil)		40.2	GJ/t	79.2	1	Neste/EE
Petroleum coke		33.5 (20-36)	GJ/t	97 (89-102)	1	Plant-specific
Recycled waste oil		41	GJ/t	78.8	1	EE
Other petroleum products		35 (30-47)	GJ/t	78.8 (65-78.8)	1	EE
Solid fuels						
Anthracite		33.5	GJ/t	98.3	0.99	2006 IPCC GL
Hard coal (bituminous)	1990-2004	25.2 (21-32)	GJ/t	94.6	0.99	StatFi 2005
Hard coal (bituminous)	2005-2007	24.9-25.3 (23-31)	GJ/t	93.7-94.0	0.99	EE
Hard coal (bituminous)	from 2008	24.6-25.2 (23-30)	GJ/t	92.7-94.1	0.99	ETS from 2008 onwards
Coal briquettes		30	GJ/t	94.6	0.99	EE
Coal tar		36.5	GJ/t	90.6	0.99	Plant-specific
Coke		29.3 (25-35)	GJ/t	107	0.99	2006 IPCC GL
Coke oven gas		16.7	GJ/1 000 m^3	41.5	0.99	Plant-specific
Blast furnace gas (BFG)		3.6	GJ/1 000 m^3	263-265	0.99	Plant-specific
Carbon monoxide		10.9-11.5	GJ/1 000 m^3	155	0.99	
Gaseous fuels						
Natural gas	1990-2012	36	GJ/1 000 m^3	55.04	1	Gasum
Natural gas	from 2013	36.3-36.76	GJ/1 000 m^3	55.19-55.37	1	Gasgrid
LNG	2013-2018	49.3	GJ/t	55.8	1	EE2015
LNG	from 2019	49.6-49.7	GJ/t	55.3	1	EE2020
Biomass fuels						
Motor gasoline (biogenic part)		27.2-29.9	GJ/t	64.0-70.2	1	Neste, various sources

Fuels	Year	NCV	Unit	Emission factor g CO_2/MJ	Oxidation factor	Source of emission factor
Diesel oil (biogenic part)		38.5-43.9	GJ/t	71.4-81.0	1	Neste, various sources
Gasoil (light fuel oil, heating fuel oil) (biogenic part)		43.5-44.0	GJ/t	70.9-71.8	1	Neste/EE
Gasoil (for non-road use) (biogenic part)		44.1	GJ/t	70.9-71.8	1	Neste/EE
Biogenic parts of MSW/REF etc.		5-33	GJ/t	110-140	1	EE2023
Biogenic parts of rubber waste		33	GJ/t	91	1	EE2015
Wood fuels (solid, includes e.g. firewood, bark, chips, sawdust and other industrial wood residues, recycled wood, pellets and briquettes)		7.8–16	GJ/t	112	0.99	2006 IPCC GL
Black and sulphite liquors		7.3–15	GJ/t	95.3	0.99	2006 IPCC GL
Other by-products from wood processing industry						
pine oil and tar		37	GJ/t	77	0.99	EE
methanol and turpentine		19.5-45	GJ/t	70	0.99	EE
fibrous sludge		2.5	GJ/t	112	0.99	2006 IPCC GL
wastepaper		11-13	GJ/t	112	0.99	2006 IPCC GL
stink gas		20	GJ/1 000 m^3	59	0.99	EE
other by-products		15	GJ/t	112	0.99	2006 IPCC GL
Plant and animal residues		5-37	GJ/t	72-110	0.99	EE
Biogas (landfill gas, biogas from wastewater treatment, industrial biogas and other biogas)		15–20.5	GJ/1 000 m^3	54.6	1	2006 IPCC GL
Biogas (gasified biomass)		5	GJ/1 000 m^3	108	1	EE
Hydrogen		10.8	GJ/1 000 m^3	0		
Other fuels, peat						
Peat (milled)	1990-2011	10.1	GJ/t	105.9	0.99	VTT 2003
Peat (milled)	from 2012	9.5-10.2	GJ/t	106.3-107.9	0.99	ETS
Peat (sod peat)	1990-2011	12.3	GJ/t	102	0.99	VTT 2003
Peat (sod peat)	from 2012	11.7-12.4	GJ/t	103-104	0.99	ETS
Peat (pellets and briquettes)		18.0	GJ/t	97	0.99	VTT 2003
Other fuels, wastes etc. (fossil parts)						
Mixed fuels* (REF, RDF, PDF)		3-30	GJ/t	80-110	0.99	StatFi 2004, ETS, EE2015
Mixed fuels* (MSW)		9-12	GJ/t	80	0.99	StatFi 2004, EE2015
Gasified solid waste*		13.3 (7-30)	GJ/1 000 m^3	59	0.99	EE
Demolition wood*		8-15	GJ/t	114	0.99	StatFi 2004, EE2015
Impregnated wood*		12	GJ/t	114	0.99	StatFi 2004. EE2015
De-inking sludge*		4	GJ/t	60	0.99	EE
Other residues and by-products		30	GJ/t	78.8	0.99	EE
Plastics waste		33 (25-40)	GJ/t	74.1	0.99	EE
Rubber waste		33	GJ/t	91	0.99	EE2015
Hazardous waste		15 (10-15)	GJ/t	117	0.99	Ekokem 2004
Other non-specified waste (industrial waste, etc.)		15–30	GJ/t	75	0.99	EE

* Mixed fuels: contains fossil and non-fossil carbon
REF = recovered fuel
RDF = refuse-derived fuel
PDF = package derived fuel
MSW = municipal solid waste

Sources:
EE, EE2015; EE2023: expert estimation Kari Grönfors, Statistics Finland
ETS: aggregated data or plant level data taken from EU Emissions Trading System
Neste 1993: Composition and properties of natural gas and liquefied petroleum gas (in Finnish, Neste 1993)

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Neste: product data sheets, personal communications
Neste/ET2004: EF from Energy Statistics which is based on information from Neste (Energy Statistics, 2004)
VTT/LIISA Model: Calculation system of road traffic emissions
StatFi 2004: Mixed fuels in Finland's greenhouse gas inventory and on compilation of the energy statistics (Jokinen, M 2004)
StatFi 2005: Not published research of Oinonen, T. 2005Ekokem 2004: Environmental report 2004
Gasum, Gasgrid: annual personal communication (Nuppunen)
VTT2045: Properties of fuels used in Finland, VTT 2000 (Alakangas, 2000)
Fortum 2002: Composition of kerosenes (Fortum, 2004)
VTT 2003: Vesterinen 2003
SF 2014/2018: Results from projects by Statistics Finland in which CO_2 emission factors and NCVs of liquid fuels were checked and updated based on information and measurement data received from oil refineries and importers.

Oxidation factors for liquid and gaseous fuels follow the 2006 IPCC Guidelines' default value (1). For solid fuels, the national default value 0.99 is used. The background for this decision is that there are a small number of coal fired power plants that measure the oxidation factor and report the values in ETS data. Based on these very few results, we regard 0.99 as a good approximation for solid fuels. The same decision was also applied to peat, waste-derived fuels and wood fuels.

The default NCVs are practically constant over time. There are some exceptions concerning plant-specific fuels like refinery gases and certain waste-derived fuels. For these fuels the range of the NCV values over time are given in the table above.

The operators should report both fuel quantities as well as energy contents of the fuels used to the YLVA system. Thus, in bottom-up data, there are some variations in the NCVs. The annual average values of reported data are compared to the default NCVs. In addition, plant level NCVs are compared to default NCVs, as described later in this Section.

Appendix_3b presents the shares of each fuel in the fuel combustion subsector.

The inventory and energy statistics team collaborate with the main operators/companies in the field to ensure that data on the fuel's properties are up-to-date. The collaboration is based on established contacts and discussions, among others during annual/periodic meetings.

Emission factors for liquid fuels prior 2013 are based on information received from Neste between 2004 and 2008. Properties of liquid fuels were checked and updated in a project during 2014. In the project, measurements and market data of liquid fuels in the Finnish oil market were gathered, and based on these data, average CO_2 emission factors and NCVs suitable for Finnish conditions were calculated for LPG, diesel oil, gas oil and low sulphur residual fuel oil. These CO_2 emission factors are used, starting from 2013.

In 2018 we received more information from the oil companies on the properties of gasoil, gasoline and diesel oil, and the emission factors were updated again, back to 2013. The use of fossil paraffinic diesel has increased fast since 2013, which has had a remarkable impact on the average properties of fossil diesel oil. The range of the NCV values and emission factors for diesel oil are given in the table above. From 2018 on, information on changes of the fuel properties is collected every few years from the most important oil suppliers.

In the Finnish inventory, solid fuels include hard coal, coke and other fuels (BFG, coke oven gas) derived from coal. These coal-based fuels are originally imported. Until 2004, the national CO_2 EF for hard coal was used based on a research study (Oinonen, 2005). In this study, the applicability of the default IPCC CO_2 emission factor of coal (94.6 g CO_2/MJ) in Finnish conditions was studied. The emission factor was found to be suitable for the Finnish inventory in years 1990 to 2003 even though there is annual variation between 93.2 to 94.9 g CO_2/MJ due to different properties of imported coal. Starting from 2008, the installations in EU ETS are obliged to monitor the CO_2 EF. The country-specific CO_2 EF for hard coal has been determined annually based on the ETS data, starting from 2008. The verified values taken from the EU ETS in 2008 to 2021 are considered to be accurate. For years 2005 to 2007, annual country-specific CO_2 emission factors were estimated using the annual average NVC taken from EU ETS data.

Peat is one of the main fuels in Finland and it is a domestic energy source. In stationary combustion, it is the fourth largest fuel (after wood, hard coal and natural gas), representing typically 3% to 7% of total primary energy supply (TPES) and 5% to 10% of combustible fuels. Due to local weather conditions in peat production and storage areas in 2012 and again in 2013, the quality of peat was lower than usually. This can be seen from measured plant level data: NCV and CO_2 emission factors have exceeded the normal range of accepted values

(+-1% variation has been seen as normal). Therefore, the annual CO_2 emission factors for milled peat and sod peat have been taken into account starting from 2012.

The CO_2 emission factor of natural gas (55.04 g/MJ, until 2012) is clearly lower than the IPCC default value (56.1 g/MJ). Until 2019, all natural gas used in Finland was imported from Russia and consisted almost totally (>98%) of methane. The sole importer of natural gas (Gasum Oy) has monitored monthly CO_2 EF from January 2005. Monthly emission factors from January to August 2005 varied between 54.99 and 55.09 g/MJ. Usually, the emission factor is lower in the wintertime and higher in the summertime. Based on this information, Statistics Finland decided to use 55.04 g/MJ as the annual average emission factor, although the second decimal represents likely a “too accurate” value (personal communications with Arto Riikonen and Tuomo Saarni from Gasum Oy, 2005). During the centralised review of 2011 submission, more information on the CO_2 EF was requested. Gasum Oy provided monthly data for 2005 to 2010 (Nuppunen, A 2011). The range of EF was 54.98 to 55.22 g/MJ and the range of NCV was 35.838 to 36.408 MJ/m^{3}n. Annual average EF varied from 55.02 to 55.07 g/MJ. Based on these results, the country-specific NCV and EF seem to be well applicable. However, later data received from Gasum (Nuppunen, 2015 and 2016) showed that the NCV and EF have started to change slightly. Starting from 2013 data, annual values have been used.

In 2020 the situation changed, as new import pipeline (Baltic Connector) was opened. From 2020 national grid operator Gasgrid is responsible for the natural gas data, including NCV and CO_2 EF. Now these figures are calculated as weighed average values from import pipelines. The import of pipeline gas from Russia to Finland ceased in May 2022. For 2021, the CO_2 EF was 55.34 g/MJ, whereas the average NCV was 36.51 MJ/m^{3}n and for 2022, the CO_2 EF was 55.37 g/MJ, whereas the average NCV was 36.76 MJ/m^{3}n.

In 2016 and 2017 two LNG terminals were opened. Preliminary estimates of properties (NCV and CO_2 EF) based on literature was used. Starting from 2019 we have received measured data from terminals.

Each reported batch of mixed fuels (mainly different types of wastes and waste-derived fuels) has been split to fossil and biogenic part, using either a default share for each type of mixed fuel or plant-specific values based on the ETS data. In certain cases, the operators participating in EU ETS are obliged to measure plant-specific CO_2 emission factors for each fuel from 2008 onwards. Using these data, the share of fossil/non-fossil energy has been adjusted; this concerns a relatively small number of plants. In CRF tables biogenic part is reported in biomass and fossil part in other fuels in categories under 1.A.1a and 1.A.2.

Table 3.2-5 Default biogenic shares of mixed fuels, calculated from the energy content

Mixed fuel	Percentage, %
SRF (REF, PDF, RDF)	60
MSW	50
Rubber waste	25
Demolition wood	90
Impregnated wood	90
Other (non-specified)	10

As described above, plant-specific values (from EU ETS) used for certain operators show annual variation.

Plant-specific NCVs and emission factors have been used for refinery gases. From 2005, EFs are based on ETS data. For 1990 to 2004 (prior to ETS), EF and NCV values have been estimated using ETS data (average values for 2005 to 2013). There are changes in refinery processes, which partly explain the declining trend in the CO_2 IEF of refinery gas. The output palette of the refineries has been developed to get lighter products (gasoline, LPG, diesel oil) instead of heavy fuel oil, which also led to much higher use of natural gas in one plant. These clearly affect the properties of refinery gases because releases of methane and hydrogen are also collected in the fuel gas system. This change has been taken into account in the estimation of CO_2 EF of one plant. Therefore, CO_2 EF is slightly higher in 1990 to 2004 than in later years.

The CH_4, N_2O, CO and NMVOC emission factors used in the Finnish inventory were originally based on the compilation of research data by Prosessikemia Oy (Boström et al. 1992; Boström 1994) and they have been revised using the results of the research study by VTT (Tsupari et al. 2005; Tsupari et al. 2006, see below).

Prosessikemia Oy provided the emission factors for the inventory calculations for 1990 for Finland’s first national communication to the UNFCCC. The emission factor database has been expanded to fit ILMARI’s more detailed classification of boilers and processes. As new boiler types have been included in the boiler database, the emission factors have been determined based on expert judgment (when no data have been available from other sources).

The research study at VTT Technical Research Centre of Finland Ltd has evaluated the non-CO_2 (CH_4 and N_2O) emission factors used in the Finnish inventory. In 2005, VTT measured the non-CO_2 emissions at several power plants in Finland. The power plants were selected based on a literature survey of the emissions and advice from the project’s management group with representatives from administration and industry. The emissions were measured at the plants during longer periods to cover start-ups, partial loads and other exceptional conditions as well. The results of the study were published in late 2005 and in 2006 and 2007 (Tsupari et al. 2005; Tsupari et al. 2006; Tsupari et al. 2007). The results of this study have been used in the calculation of time series.

CH_4 and N_2O emission factors by main category/fuel are presented in Table 3.2-6 and Table 3.2-7 .

Table 3.2-6 CH_4 emission factors of stationary sources in the ILMARI calculation system

Type of installation	Main category	Combustion technique* / Fuel capacity, MW	Emission factor, mg/MJ
Coal fired boiler	10 (>80% coal) and 81 (50% - 80% coal)	CFB/BFB/PFB / < 15	4
		CFB/BFB/PFB / > 15	1
		Other (grate, pulverised comb., not specified / < 50	4
		Other (grate, pulverised comb., not specified / > 50	1
Peat fired boiler	40 (>80% peat) and 84 (50% - 80% peat)	CFB/BFB/gasification / > 50	3
		CFB/BFB/gasification / 5–- 50	4
		CFB/BFB/gasification / < 5	10
Wood/bark fired boiler	50 (> 80% wood) and 85 (50% - 80% wood)	CFB/BFB/gasification / >50	3
		CFB/BFB/gasification / 5–- 50	4
		CFB/BFB/gasification / < 5	10
Multi-fuel fired boiler	88 (no primary fuel > 50%)	CFB/BFB/gasification / > 50	3
		CFB/BFB/gasification / 5–- 50	4
		CFB/BFB/gasification / <1	10
		Other (grate, pulverised comb., not specified / 5–- 50	10
		Other (grate, pulverised comb., not specified / 1–- 5	50
		Other (grate, pulverised comb., not specified / <1	200
		Other (grate, burner, not specified / > 50	2
Oil fired boiler	30 (> 80% oil) and 83 (50% - 80% oil)	All / > 1	1
		All / <1	5
Gas fired boiler	60 (> 80% gas) and 86 (50% - 80% gas)	All / >1	1
		All / <1	5
Soda recovery boiler	70 (> 80% black liquor)	All	1
Gas turbine	121 (gas turbine plant, oil) and 123 (gas turbine plant, other)	All / < 50	3
		All / > 50	1
Gas turbine	122 (gas turbine plant, gas) and 130 (combined cycle power plant)	All / < 5	3
		All / > 5	1
Engines	141 (diesel power plant, oil) and 143 (diesel power plant, other liquid fuel)	Diesel / < 50	4
		Diesel / > 50	2
Gas engines	142 (natural gas fired engines) and 143 (biogas fired engines)	Otto or Diesel engine	240
Processes	90 (other combustion, not specified)		1
	91 (mesa kiln)		1
	92 (hospital waste incineration)		1
	93 (asphalt station)		1
	94 (coking plant)		1
	95 (drying oven)		1
	96 (blast furnace)		1
	97 (sinter plant)		1
	98 (rolling mill)		1
	99 (melting oven)		1
	100 (brick furnace)		1
	101 (cupola oven)		1

* CFB = Circulating Fluidised Bed,
BFB = Bubbling Fluidised Bed
PFB = Pressurised Fluidised Bed

Sources:
Expert estimates by Statistics Finland based mainly on the VTT studies (Tsupari et. al., 2005, Tsupari et. al., 2006 and Tsupari et al., 2007)
http://www.vtt.fi/inf/pdf/tiedotteet/2005/T2321.pdf
http://www.vtt.fi/inf/pdf/workingpapers/2006/W43.pdf

Table 3.2-7 N_2O emission factors of stationary sources in the ILMARI calculation system

Type of installation	Main category	Combustion technique*	Emission factor, mg/MJ
Coal fired boiler	10 (>80% coal) and 81 (50% - 80% coal)	CFB	30
	10 (>80% coal) and 81 (50% - 80% coal)	BFB/PFB	20
	10 (>80% coal) and 81 (50% - 80% coal)	Grate + combined techniques, not specified	3
	10 (>80% coal) and 81 (50% - 80% coal)	Pulverised comb.	1
Peat fired boiler	40 (>80% peat) and 84 (50% - 80% peat)	CFB	7
		BFB + combined techniques	3
		Grate + combined techniques, pulverised comb., gasification, not specified	2
Wood/bark fired boiler	50 (> 80% wood) and 85 (50% - 80% wood)	CFB	7
		BFB	3
		Grate + combined techniques, gasification, not specified	1
Multi-fuel fired boiler	88 (no primary fuel > 50%)	CFB	7
		BFB + combined techniques	3
		Grate + combined techniques, pulverised comb., not specified	2
Oil fired boiler > 50 MW	30 (> 80% oil) and 83 (50% - 80% oil)	All	1
Oil fired boiler < 50 MW	30 (> 80% oil) and 83 (50% - 80% oil)	All	3
Gas fired boiler	60 (> 80% gas) and 86 (50% - 80% gas)	All	1
Soda recovery boiler	70 (> 80% black liquor)	All	1
Gas turbine	121 (gas turbine plant, oil) and 123 (gas turbine plant, other)	All	4
Gas turbine	122 (gas turbine plant, gas) and 130 (combined cycle power plant)	All	1
Engines	141 (diesel power plant, oil) and 143 (diesel power plant, other liquid fuel)	Diesel	4
Gas engines	142 (natural gas fired engines) and 143 (biogas fired engines)	Otto or Diesel engine	1
Processes	90 (other combustion, not specified)		2
	91 (mesa kiln)		1
	92 (hospital waste incineration)		1
	93 (asphalt station)		1
	94 (coking plant)		1
	95 (drying oven)		1
	96 (blast furnace)		1
	97 (sinter plant)		1
	98 (rolling mill)		1
	99 (melting oven)		1
	100 (brick furnace)		1
	101 (cupola oven)		1

* CFB = Circulating Fluidised Bed,
BFB = Bubbling Fluidised Bed
PFB = Pressurised Fluidised Bed

Sources:
Expert estimates by Statistics Finland based mainly on the VTT studies (Tsupari et. al., 2005, Tsupari et. al., 2006 and Tsupari et al., 2007)
http://www.vtt.fi/inf/pdf/tiedotteet/2005/T2321.pdf
http://www.vtt.fi/inf/pdf/workingpapers/2006/W43.pdf

Factors affecting implied emission factors

There are several factors which have an effect to the implied emission factors of different plants or fuel groups in different CRF categories:

1. In Finland, it is typical to use multi-fuel fired power plants in which the fuel mix varies according to the changes in the availability of fuels as well as fuel prices and taxes and to the price of CO_2 in the European Union Emissions Trading System. This causes annually changes in the fuel mix, emission estimates and implied emission factors for different types of plants. In addition, the use of peak and reserve boilers varies according to heating degree days and prices of fuels, etc.
2. In a bottom-up-system, there are always some sub-sectors, which consist of a very small number of plants. In a small set of plants (or actually plant- fuel combinations), there may be different technologies, which have different CH_4 and N_2O emission factors. The changes in annual operation of plants easily change the share of each fuel and each plant/technology within the sub-category, which is immediately reflected in the implied emission factors.
3. In the Finnish industries it is typical, that there are a lot of CHP plants and heat boilers at industrial sites, producing steam for the manufacturing industry. In some cases, these heat and power plants are owned by the industrial companies, and sometimes by energy companies. There may be changes in the ownership during the time series, for example a power plant belonging to industrial company may be outsourced to an energy company or vice versa. Due to these ownership changes allocation of plants with different technologies to CRF categories may change (1.A.1a versus 1.A.2x). In these cases, we may see unexpected variations for example in IEFs at aggregated level (combination of CRF source category and CRF fuel category), although time series of each plant are consistent (see example Figure 3.2-3).

All these changes cannot be reported individually in the NID due to the number of boilers and fuels used, and confidentiality. This type of bottom-up system differs from the situation, where emission factors have been defined for sector-fuel combinations using top-down-estimates. It seems clear, that implied emission factors are more unstable in a bottom-up system, but this reflects actual variations in fuel palettes in each sector/technology (unlike in top-down calculations).

The effect of outsourcing (bullet point 3) can be seen for example in the increase of the CO_2 implied emission factor of Solid fuels in 1.A.1.a (Figure 3.2-3) from 2014 on. Correspondingly the CO_2 IEF in 1.A.2a decreases. Power plants from iron and steel production were outsourced to energy industries (two new plants were built by energy companies, replacing older power plants and boilers owned by industry). These new power plants use a remarkable amount of BFG (EF 264 Gg/TJ) and carbon monoxide (CO-gas, 155 Gg/TJ). Together these two fuels affect to the CO_2 IEF of Solid fuels in these categories.

As it comes to changes in CO_2 IEF in 1.A.2f, the share of coke, hard coal and CO-gas coke varies annually in different plants. CO_2 IEF in 1.A.1a peaks in 2020 and 2021 as the share of used hard coal from the total solid fuels has declined (see also 2.2.1 and Table 3.2 8). In 2022 the share of hard coal increased again.

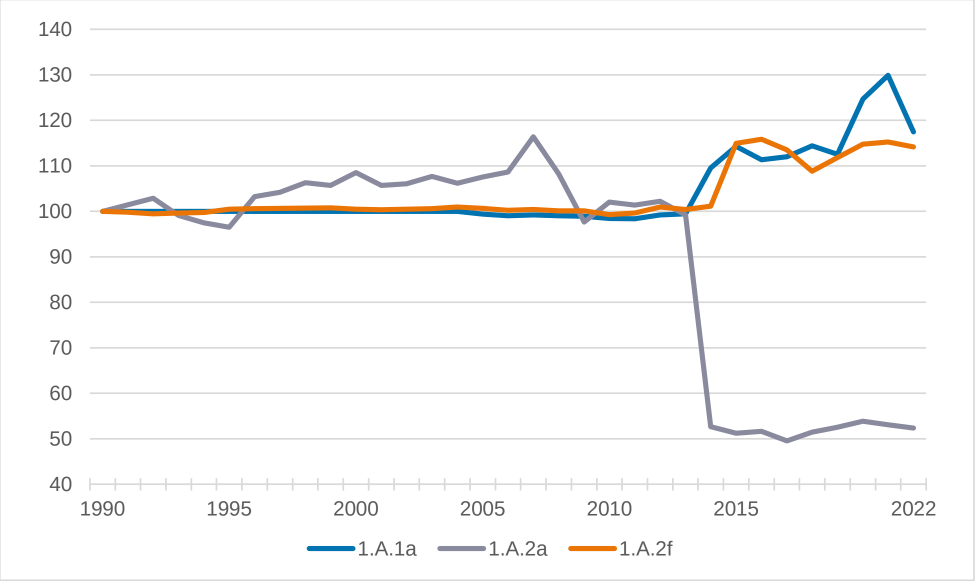

Figure 3.2-3 Indexed CO_2 implied emissions factor of solid fuels

Changes due to legislation can be seen for example in the use of heavy fuel oil which has decreased rapidly (bullet point 1) in 1.A.1a. Mostly heavy oil has been substituted by wood fuels. In reserve and peak load use there has also been a shift to lighter oil products due to legislation on SO_2 emissions. All in all, the use of oil has decreased, and the remaining use consists of lighter products, thus CO_2 emission factor becomes lower (Figure 3.2-4).

The petroleum refining industry (1.A.1b) uses their own refinery gases and the petrochemical industry (1.A.2c) their own fuel gases as energy source. These fuels are mapped under Liquid fuels. The CO_2 emission factor of these gases is much lower than other liquid fuels, for refinery gases 55-60 Mg/TJ and for fuel gases around 50 Mg/TJ varying annually. The share of these fuels is dominant in these categories, but it also has some annual variation which has an effect to CO_2 implied emission factor (bullet point 2, Figure 3.2-4). CO_2 emission factor of refinery gas is slightly higher in 1990 to 2004 than in later years due to changes in refinery processes (see also 3.2.4.2 Emission factors and other parameters).

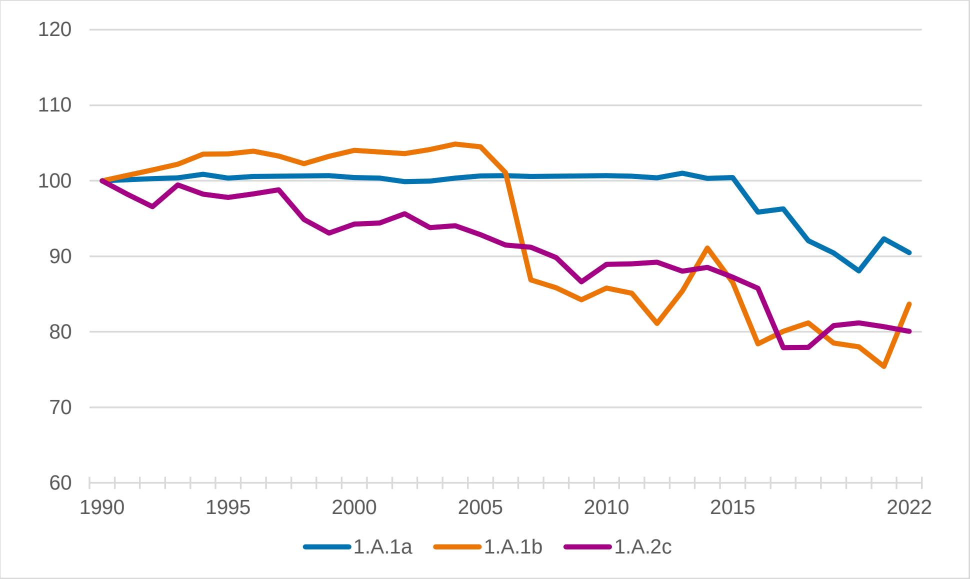

Figure 3.2-4 Indexed CO_2 implied emissions factor of liquid fuels

Activity data

Activity data for the ILMARI calculations are collected from several data sources. The detailed bottom-up data for point sources are collected mainly from the YLVA (formerly VAHTI) system (see also Section 1.3 and Annex 6). Supplementary data are obtained from other plant level data sources.

The YLVA data contain, for example:

- Basic data, like identification of plants, location, etc.
- Technical data, like boiler or process type, emission reduction technology, capacity, etc.
- Fuel consumption data, like fuels used by individual point sources (power plant units, boilers, industrial processes, etc.)
- Emission data (annual end-of-pipe emissions from these point sources.)

The YLVA system includes detailed (boiler/process level) data, which allows emissions calculation using technology-specific emission factors for non-CO_2 emissions. There are numerous emission components reported directly in the YLVA system; CO_2, SO_2, NO_x, PM emission data are used as input for the ILMARI system. These input data from the YLVA system are supplemented with plant level data taken from other sources like:

- Data from the EU Emissions Trading System (by the Energy Authority)
- Fuel consumption statistics of manufacturing industries (survey by Statistics Finland)
- Electricity and heat production statistics (survey by Adato Energia Oy and Statistics Finland)
- District heating statistics (survey by the Finnish District Heating Association)
- Fuelwood consumption data from Natural Resources Institute Finland (Luke)
- Structural business statistics (survey by Statistics Finland)
- Business Register (by Statistics Finland).

Individual plants and boilers from the YLVA data are linked to statistical data collection units (local kind-of-activity unit) to allow comparisons with fuel consumption surveys and business surveys made by Statistics Finland. This linking enables the use of standard classifications, such as the NACE code, which is a pan-European classification system of economic activities. Fuel codes used in the YLVA system are also linked to the national fuel classification (http://tilastokeskus.fi/tup/khkinv/khkaasut_polttoaineluokitus.html).

The total number of plants (sites) included in the ILMARI system is ~1,000, including ~2,500 individual combustion units or process installations annually.

Many point sources in this category are part of the EU Emissions Trading System. Monitored data for CO_2 emissions from these sources have become available from the Emissions Trading System for the inventory starting from 2005. In the Energy sector, ETS data have been mainly used in:

- Identifying (and completing) missing point sources
- Checking, updating or verifying fuel consumption data
- Verifying emission data
- Verifying NCVs and CO_2 emission factors by fuel type
- Defining plant-specific CO_2 emission factors for refinery gases, starting from 2005
- Defining plant-specific NCV and CO_2 emission factors for refinery gases for data prior to ETS
- Defining national NCV and CO_2 emission factors for hard coal, starting from 2008
- Defining plant-specific CO_2 emission factors for MSW/REF, starting from 2008
- Defining national annual NCV and CO_2 emission factors for peat, starting 2012.

Quality assurance of emissions trading data is described in Appendix_3e of Energy.

Fuel combustion totals by fuel (PJ), as well as greenhouse gas emissions and implied emission factors by fuel for 1990 to 2021 are given in Appendix_3b at the end of the Chapter 3.

The fuel consumption data by fuel categories in Energy industries and Manufacturing industries and construction are presented in Table 3.2-8 and Table 3.2-9.

Waste combustion

Energy use of waste has increased significantly in Finland over the last years. There are eleven waste incineration plants in operation in Finland at the moment, the oldest was built in 2007. Waste is also co-incinerated in Finland in boilers using typically peat and/or biomass as primary fuel. There are 20 co-incineration plants, which use significant amounts of waste in Finland. Different types of waste are used in incineration and co-incineration plants. Incineration plants typically use source separated municipal solid waste. In co-incineration plants, high quality industrial waste, solid recovered fuels and recovered wood are typically combusted (Finnish Energy, 2023).

All waste incineration/combustion plants are equipped with energy recovery, mostly combined heat and power production. Therefore, no MSW incineration has been reported in the Waste sector.

As described in Section 3.2.4.2, waste derived fuels are split to fossil and biogenic parts. The split is done as expert estimates by Statistics Finland (fuel data collection systems do not originally include this split, except indirectly in a very small number of ETS plants). Fossil shares are included in “Other Fuels” and biogenic shares in ”Biomass”.

There are some plants licenced for incineration or co-incineration of hazardous wastes. Also these plants contain energy recovery, and they are included in subcategories of the Energy sector.

Table 3.2-8 Fuel consumption in Energy industries (CRF 1.A.1) (PJ)

		1990	1995	2000	2005	2010	2013	2014	2015	2016	2017	2018	2019	2020	2021	2022
Liquid fuels	Heavy fuel oil	16.1	21.1	17.1	16.8	17.5	7.0	7.7	8.5	7.1	5.6	2.8	2.2	0.9	1.7	1.7
	Light fuel oil	0.5	1.1	0.9	0.7	0.6	0.6	0.7	0.7	1.7	2.0	2.5	2.0	1.7	4.0	8.3
	Refinery gases	16.1	16.8	15.4	16.3	18.4	18.1	17.1	16.6	20.2	20.0	19.8	21.7	19.8	14.7	20.8
	Other liquid fuels	3.9	4.3	4.5	5.1	5.1	5.3	5.3	4.5	5.0	4.6	4.7	7.1	6.4	5.3	7.0
Solid fuels	Hard coal	99.2	105.9	88.0	73.2	139.3	110.8	83.8	58.3	75.7	66.2	63.4	49.0	28.7	32.5	41.2
	Other solid fuels	2.1	3.2	3.2	3.4	3.0	4.0	9.4	10.4	10.6	10.0	10.7	9.1	9.5	11.6	9.6
Gaseous fuels																
	Natural gas and other gaseous fuels	47.9	68.8	94.4	104.5	104.6	70.1	61.9	50.8	41.8	34.8	45.9	41.2	42.6	40.6	11.4
Biomass	Woodfuels	3.1	16.2	34.6	58.5	80.7	94.1	92.7	88.8	96.0	96.6	97.5	100.2	94.4	121.6	120.2
	Biogas	NO	0.1	0.1	1.0	0.4	0.3	0.3	0.4	0.4	3.5	3.1	2.9	2.4	2.6	1.9
	Other non-fossil fuels	NO	0.4	0.3	3.6	5.9	7.4	8.3	9.9	11.4	12.0	13.4	13.0	13.5	14.1	13.4
Peat	Peat	37.8	63.5	50.6	57.0	82.2	46.1	48.5	46.0	45.2	43.2	50.5	45.8	34.9	31.0	31.5
Other fuels	Mixed fuels and waste (fossil part)	0.01	0.4	1.4	1.5	2.2	4.1	5.2	5.8	6.9	7.8	8.2	8.5	8.3	8.9	8.1

Other liquid fuels includes e.g. petroleum coke, LPG, recycled waste oil and some other oil products.

Other solid fuels includes e.g. coke, coke oven gas and blast furnace gas.

Table 3.2-9 Fuel consumption in Manufacturing industries and construction (CRF 1.A.2) (PJ)

		1990	**1995**	**2000**	**2005**	**2010**	**2013**	**2014**	**2015**	**2016**	**2017**	**2018**	**2019**	**2020**	**2021**	**2022**
Liquid fuels	Heavy fuel oil	34.2	27.7	22.6	18.3	11.1	8.3	7.8	7.6	7.8	7.1	6.0	5.9	6.1	5.7	6.2
	Light fuel oil	14.4	14.2	16.1	16.1	17.1	16.5	15.8	15.1	14.1	16.0	16.9	16.9	17.4	16.9	17.5
	LPG	4.5	4.7	8.2	10.0	9.2	8.2	8.5	8.6	8.9	8.3	7.8	3.7	3.2	3.3	3.0
	Refinery gases	5.0	5.7	6.6	7.9	9.0	8.9	8.7	9.1	9.3	7.9	9.3	9.7	9.3	9.7	9.7
	Recycled waste oil	0.5	0.5	0.9	1.3	1.2	0.6	0.8	0.5	0.5	0.6	0.4	0.4	0.7	0.5	0.6
	Other liquid fuels	2.3	1.9	1.3	1.9	1.5	2.5	2.2	2.3	2.5	2.5	3.5	3.3	2.6	2.4	2.4
Solid fuels	Hard coal	28.4	16.4	10.3	7.3	5.4	3.4	3.3	3.8	5.5	5.3	4.5	4.2	3.4	3.9	3.8
	Coke	5.9	4.9	5.4	5.6	4.5	1.2	1.2	1.1	1.1	0.9	1.1	1.0	1.0	0.9	0.8
	Other solid fuels	9.0	11.9	15.2	14.7	12.5	11.5	7.0	5.8	6.5	6.2	6.1	5.9	5.4	6.2	5.5
Gaseous fuels																
	Natural gas and other gaseous fuels	39.9	43.1	39.8	36.4	35.9	30.3	27.3	25.0	24.0	23.3	24.8	26.9	27.4	29.2	22.8
Biomass	Woodfuels	42.1	43.9	51.2	39.1	35.6	42.1	42.3	41.6	44.2	45.5	44.2	44.9	42.4	47.8	43.0
	Black/sulphite liquor	87.4	111.1	139.8	129.4	135.7	140.7	141.9	142.1	146.3	154.8	167.0	169.7	158.1	166.2	142.4
	Biogas	0.1	0.3	0.3	0.3	0.8	1.4	1.7	1.8	1.7	2.9	3.8	4.0	3.6	4.1	3.9
	Other non-fossil fuels	1.3	1.5	2.1	2.2	3.9	4.7	4.8	4.4	4.7	4.7	4.8	4.5	4.1	5.2	5.4
Peat	Peat	14.1	14.9	11.4	12.2	13.0	9.4	10.6	9.9	8.8	8.3	9.1	8.6	6.7	5.8	3.8
Other fuels	Mixed fuels and waste (fossil part)	1.0	1.1	1.9	2.4	3.0	5.1	5.2	4.6	4.7	5.0	4.7	4.9	4.8	5.6	5.8

Other liquid fuels includes e.g. petroleum coke.

Other solid fuels includes e.g. coke oven gas and blast furnace gases.

3.2.4.3 Uncertainty assessment and time series' consistency

Quantitative estimates of uncertainty are provided in Annex 2. The annex also documents assumptions made for the analysis. A description of the uncertainty analysis is included in Section 1.6.

The uncertainty analysis is carried out at a fairly detailed level, covering more than 30 fuel types mainly at the ^{4t}h CRF category level (e.g. 1.A.1a). The disaggregation level is such that uncertainties of AD and EFs (within the same year) can be considered independent (in most cases).

Uncertainties in the activity data are based on expert estimates, taking into account both observed differences and errors in the plant level fuel consumption data and statistical differences in the national fuel balances.

The aggregation of fuels follows the level shown in Table 1_App_3b (around 30 fuel types, aggregated from originally around 50 different fuel categories).

The uncertainties in activity data vary from fuel type to another and from subcategory to another. CO_2 emission factors are independent of the subcategory. In most cases, CO_2 emission factors are not studied annually, but the same EF has been used throughout the time series.

The EU ETS started from 2005, the second period from 2008 and the third period from 2013. This has provided more reliable data on both activity data and properties of fuels. These new data have been taken into account in the revised uncertainty estimation. There are three main types of changes:

- The uncertainty of the activity data has become lower
- The uncertainty of the CO_2 EF has become lower, although the EF itself has not changed (the same EF has been used over the years)
- Annual CO_2 EF has been taken from ETS data; in addition, the uncertainty has become lower.

The first two bullet points are relevant to most of the fuel types. The third bullet point refers mainly to hard coal, peat, waste-derived fuels and refinery gases.

In the 2015 submission, a new type of time series correction was launched. Country-specific default values for NCV and CO_2 EF (prior to measured ETS data) were re-estimated using the data taken from EU ETS. This approach was taken for refinery gases (1990 to 2004) and hard coal (2005 to 2007).

Discussions with the refinery plant staff (Ryyppö, 2015) showed, that there are no reliable direct sources for revision of activity data available for the early years (beginning of 1990s). The most reliable (and the only reliable) data for the whole time series are feedstock input data [ktonnes of feedstocks]. A decision was made to use that data as starting point to estimate the total production of refinery gases. Annual production data of refinery gases in 1990 to 2004 are calculated as a constant share from the feedstock use. The share was judged based on the average from more reliable recent data (2005 to 2013).

In general, the uncertainties in activity data and CO_2 EFs for fossil fuels (oil, gas and coal) are lower than for domestic fuels (peat and wood). There are two reasons for this. First, the national balance of domestic fuels is more uncertain because both production and consumption figures are partly based on surveys instead of more accurate total sales statistics. Secondly, the properties of peat and wood fuels include higher variation (density, NCV, wet content, carbon content).

This variability of CO_2 EF for peat has been studied in a measurement project done at VTT Processes (Vesterinen, 2003). In the study, the CO_2 emission factor for peat combustion was measured from five different power plants. The selected power plants were located at different sites in Finland. Therefore, the peat they used represents fairly well the variation in peat quality in geographically different locations in Finland. The uncertainty estimate was based on the variation of the measured emission factors, and was ±5%, which was chosen as the base year uncertainty. The uncertainty of EF for 2022 was chosen to be 2%. As described in Section 3.2.4.2 CO_2 EF for peat is based on monitored and verified ETS data from 2012 onwards.

Emission factors for CH_4 and especially N_2O from combustion are highly uncertain. The nitrous oxide emission factor depends strongly on combustion technology. For example, fluidised bed combustion has higher N_2O emissions than conventional combustion technologies. The emissions are also strongly dependent on fuel type, boiler design and maintenance and process conditions (e.g., temperature and residence time in furnace, air fraction, NO_x reduction technologies).

The research and measurement project at VTT on non-CO_2 (CH_4 and N_2O) emission factors from stationary sources in Finland (Tsupari et. al. 2005 and Tsupari et. al. 2006) has given new information on the emission factors and uncertainties of these emissions. Based on this study, a ±60% uncertainty was chosen for CH_4 and N_2O emission factors in all stationary combustion categories.

The Monte Carlo simulation has been used to combine the uncertainties of each calculation parameter in order to get the total uncertainty of the category (see Section 1.6).

Minor inconsistencies in the earlier inventories caused by missing data of some plants, changing classifications, etc. are corrected annually. Overall, methodologies and data sources are as consistent as possible with reasonable resource demands. The only exception is 1991; the point source data of 1991 are not included in the ILMARI system. Instead of the actual point source data, the inventory for 1991 is partly based on interpolation between 1990 and 1992 data at CRF category and fuel category level.

Due to ownership changes allocation of plants with different technologies to CRF categories may change (1.A.1a versus 1.A.2x) resulting unexpected variations for example in IEFs at aggregated level, although time series of each plant are consistent (see also subtitle *Factors affecting implied emission factors* in this Section).

3.2.4.4 Category-specific QA/QC and verification

The quality objectives and the QA/QC plan for the Finnish greenhouse gas inventory at the national inventory level are presented in Section 1.5. The QC procedures are performed according to the QA/QC plan in the Energy sector in order to attain these quality objectives. The bilateral quality meeting or quality desk review is held annually between the inventory unit and the sectoral expert.

QC procedures

Several QC procedures are used in the ILMARI system. The most resource demanding and the most important QC procedure is the checking of point sources' bottom-up fuel data, which are used for emission calculation. Automatic checking routines are included in the YLVA data input process. For example, fuel data should be reported in physical quantities (t or 1,000 m^3), as well as in energy quantities (TJ). If both quantity values are reported, the NCV is calculated and compared with the default NCV of this fuel. If the calculated value is out of range, data will be marked for checking. If either the physical quantity or energy is missing, the missing value will be calculated using the default NCV. If neither the quantity nor energy has been reported, then missing data will be taken from other available data sources. For certain non-standard fuel types both the fuel code and the fuel quantity data will be marked for checking in all cases.

Checking of installations' combustion technology and other technical properties is performed continuously and minor corrections are done annually.

The ILMARI system is a part of Statistics Finland's YEIS database system. The YEIS database has links between records from several different sets of bottom-up fuel data (see also Section 3.2.4.2/ Activity data), which are included in the same database system:

- ILMARI/YLVA, installation data
- ETS, installation data (in some cases production site data)
- Manufacturing industry fuel survey; local kind-of-activity-unit data
- Electricity and heat production survey; production site data.
- District heating statistics (survey by the Finnish District Heating Association)
- Fuelwood consumption data from Natural Resources Institute Finland (Luke)
- Other plant level data

Automatic SAS checks facilitate the comparison of different data sets at plant level. The checks include, for example, comparison with previous years' data (total and single values) and comparison with fuel data from EU ETS and surveys of Statistics Finland. The output of the automatic check is manually looked through and several corrections to point sources' fuel data are performed.

Both the original data from the YLVA system and possibly corrected data are stored in the ILMARI system, thus, corrections can be checked afterwards. The results of point source checks concerning year 2018 are presented in Table 3.2-10 as an example.

Table 3.2-10 An example of the results of the point source QC procedures concerning year 2018

	Number	Quantity	PJ
Fuel records total (final values)	4 000	47 500	620
Fuel records original (data from YLVA before corrections)	2 000	40 300	540
Non-corrected original (data from YLVA, accepted as such)	1 400	22 400	310
Imputed fuel records (missing from YLVA, taken from other sources)	1 850	7 100	80
TJ corrected	170	0	-80
Quantity corrected	70	-1 900	0
Quantity and TJ corrected	280	-2 800	-60
Fuel code corrected	180	-240	-400
Total corrected records (net Quantity and PJ corrections)	2 600	7 200	80

Note: Rounded values. Values of corrections do not add up; there are deleted records (double values) as well as imputed records (missing data). The last row shows total net corrections. Quantity includes figures in 1,000,000 m^3 or in 1,000 tonnes depending on the fuel type. These figures represent the first round of calculation. After the second round there will be some more corrections, mainly more imputed fuel records.

After the point sources' data have been checked, the data from the transport models and heating energy model are imported to ILMARI system and the total fuel consumption figures are compared with the total figures taken from the Energy statistics. If there are notable differences, the reasons will be studied and possible corrections made to either the Energy statistics data or the GHG inventory data, depending on the case.

Both the Energy statistics compilation and the GHG inventory are prepared side by side and they have links to each other. For example, total use of peat in Finland is mostly based on a bottom-up calculation. This means that energy surveys, ETS data and GHG inventory data are used to complement each other to find out the total consumption of peat.

CO_2 emissions from the ILMARI system and ETS data are checked at CRF and plant level data. If the amount of CO_2 emissions in a specific CRF category or in some plant differs, the reason will be checked from plant level data. In some cases this comparison reveals different CO_2 emission factors which are then taken into account in the inventory.

One reason for deviations have been found to be wrong allocation of ETS plants in the ILMARI system; ETS plants in the ILMARI system have been classified as non-ETS plants or vice versa. As a result, this check has improved the quality of ETS plant classification in the ILMARI system and consistency between these data.

There is also another cross checking of plant level CO_2 emissions. The ILMARI system includes calculated CO_2 emissions from each fuel batch. It also includes plant level CO_2 emissions reported by the plant operators to the YLVA system, but those data are not split between different fuels and non-fuel-based emissions (although CO_2 from biomass is separated from fossil CO_2). The reported data are compared with the calculated data and out-of-range differences are checked. However, this checking is very resource-intensive, and is done only for a subset of plants, depending on the available time.

When transferring the ILMARI data to the CRF Reporter several QC checks are performed. SAS query is used to aggregate the ILMARI data at the CRF level. Results are compared to the ILMARI data. The data are imported to CRF Reporter with Excel. Finally, xml data exported from the CRF Reporter are checked against the original data in order to detect any errors in the data transfer.

QA procedures

Statistics Finland has its own internal quality audit system (statistical auditing). The objectives of this quality audit are, for example, to evaluate and question ways of working, methods and techniques, and to identify and search for good practices (Piela, 2011). The internal quality auditing of the greenhouse gas statistics was performed in autumn 2020 and its focus was on energy and IPPU (excl. F gases) calculation processes. Improvement needs identified during the audit included for example suggestions to reduce manual work during data checks (see also Section 1.5).

The documentation of energy sector calculations in the NID were audited in 2017 by an independent person who is not involved in the Finnish inventory but has some knowledge of Finland‘s energy sector and in-depth knowledge of the greenhouse gas inventory system and calculation methodologies. The objective of this audit was to improve the transparency of the NID. In the audit report it was concluded that in general the quality of the Finnish NID is high but some improvements could be made to improve the transparency. For example, some significant changes in the time series should be explained and more comparisons could be presented at aggregate level (Nielsen, 2017). Results of the audit were taken into account when the 2018 and 2019 submissions were prepared.

During 2014, the comparison of different statistics of total amounts of sales of oil products, including bioshares, in the Finnish market was started together with Energy Statistics, Finnish oil companies and the Finnish Petroleum and Biofuels Association. The work continued until 2018. Starting from the end of 2018, the situation changed, as the operation of Petroleum and Biofuels Association ended. Statistics Finland has been responsible for oil statistics data collection since autumn 2018. This requires even more increasing direct co-operation with Finnish oil companies.

In 2014, the inventory unit together with the energy statistics team visited one Finnish steel production plant. During the visit, the material flows and emission measurements of the plant were studied and compared to the inventory information. As a result, a new fuel code was included in the Finnish fuel classification and as regards to classification, the Finnish response to the IEA questionnaire was slightly changed. Also, the assumptions behind the inventory calculations were checked and found suitable.

Nordic cooperation has occasionally been used as a quality assurance tool:

- A comparison and review of the emission factors in the energy sector in Swedish and Finnish inventories was carried out in 2006.
- In the 2011 meeting between the Finnish and Swedish inventory teams, the use of EU ETS data in inventories was discussed.
- From 2015 on Nordic greenhouse gas inventory experts’ meetings, which included participants from Finland, Sweden, Norway and Denmark, have been held almost annually. In these meetings, several issues concerning the energy sector have been discussed and approaches and EFs have been compared. The topics discussed have included for example confidentiality issues, the use of ETS data, the use of emission and oxidation factors, small scale combustion, transport and SA-RA comparisons. It is decided to continue cooperation in order to get input to the QA and verification of inventory data and to create a network for sharing information.

A voluntary bilateral cross-country review on the testing of adjustment procedures was conducted between Finland and Germany in 2004. The review covered emission categories 1.A.1 and 1.A.2 in the Energy sector.

Verification

The sectoral approach of the Energy sector is annually compared to the Reference approach and differences are explained (see Section 3.2.1). Reference approach is compared to data reported to IEA (Annex 7/ Comparisons with other international reportings.).

Each year, the latest inventory calculations (activity data and CO_2 emissions) are verified by crosschecking the results against the national energy balance. This reference calculation is based on the energy balance and shows activity data (PJ) and CO_2 emissions. The idea of this crosschecking is to compare the results of the bottom-up calculation (reported as the Sectoral approach in the CRF data) with the top-down calculation (from the energy balance sheet). Figures based on the energy balance are aggregated to the best matching CRF and fuel categories.

The Finnish Environment Institute (Syke) calculates the final data for the UNECE Air Pollutant inventories and NEC directive. The calculation system is separate from the GHG calculation system but uses mostly the same basic data sources for calculating emissions from fuel combustion. This independent calculation system is used as a verification tool for the GHG inventory, and moreover, as a source of additional corrections in point source data. Comparisons between the data in these two calculations systems are performed continuously during the inventory preparation. The annual calculation in Syke is performed a bit later than the GHG inventory and, thus, the source data set usually includes more updated data than used in the preliminary EU GHG inventory. The thorough comparison between the Air pollutant and GHG inventory in accordance with the EU Commission Implementing Regulation (EU) 2020/1208 is performed after 15 February and the differences are either corrected or accounted for by the 15 March submissions.

Calculation of emissions from fuel combustion are principally made with the ILMARI system. New calculation system was under development, but implementation has delayed. During this development results received from the ILMARI system and new calculation system were compared. Deviations are explained and corrections were made when needed. Both systems calculated similar results for the most recent years and comparisons work was a good verification tool. This comparison has not been done for the 2021 and 2022 data.

ETS data

CO_2 emission data taken from the EU ETS (Emissions Trading System, see Section 1.3) are annually compared with the calculated emission data in the ILMARI system. Both systems include point source (bottom-up) data. In the ILMARI system, the boilers and plants included in the ETS are marked. Thus, summaries of total ETS and non-ETS plants can be made easily. Quality assurance of emissions trading data is described in Appendix 3e. The calculation method of the amount of transferred emissions in the GHG data is explained in Section 3.4.1.

Total CO_2 eq. emissions taken from the ETS data were 19.0 Mt in 2022 as also the corresponding emission data taken from the GHG inventory. The difference between the ETS and GHG emission data was -26 kt CO_2 eq in 2022 and has varied from 217 kt CO_2 eq. to -48 kt CO_2 eq. in 2005 to 2022 (Figure 3.2-5).

There are more differences in the allocation of emissions to CRF categories. The most important difference is in the Iron and steel sector, which is almost totally allocated to Industrial Processes and Product Use in the ETS data. All iron and steel plants calculate and report their emissions according to the mass balance approach in the ETS. In the GHG inventory, emissions are split between Energy and Industrial Processes and Product Use. Another difference is the emissions of combustion of catalytic cracking coke in oil refineries, which is included in the Energy sector in the inventory and in Industrial Processes and Product Use in the ETS.

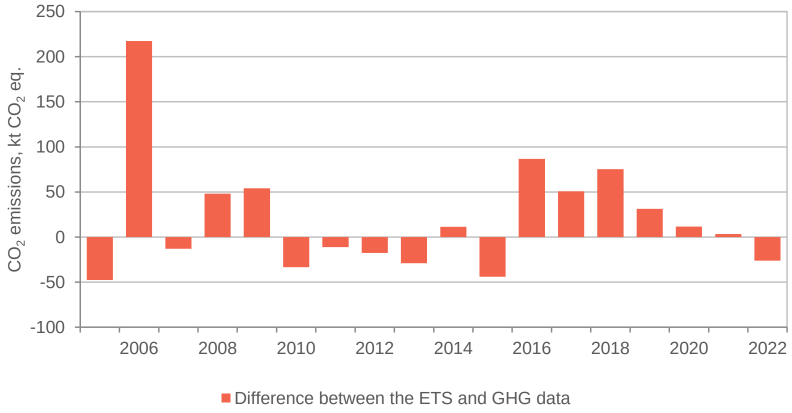

Figure 3.2-5 Difference between the ETS data in the inventory and ETS data reported to emissions trading system

Relatively high difference in 2006 requires some explanation. During the first period of ETS (2005 to 2007) plants were allowed to use default CO_2 emission factors for solid fuels (instead of monitored data). As described earlier (see Section 3.2.4.3), CO_2 EF for hard coal was re-estimated afterwards for inventory calculations 2005 to 2007. The difference between the original default value (94.6) used in ETS and corrected value used in the inventory (93.7) is highest in 2006, causing most of the difference seen in Figure 3.2-5.

NCVs, CO_2 emission factors and fuel consumption data taken from the ETS plants are aggregated at the most detailed fuel code level and compared with the corresponding data in the ILMARI system. If there are significant differences, corrections will be done in the ILMARI data (either plant-specific NCVs of emission factors or both). Concerning the most common and the most important fuels, the differences in aggregated NCVs and EFs are generally less than +-1%. For different types of wood fuels, the differences in NCVs are somewhat larger (generally +-2% to 10%). This is mainly due to difficulties of plant operators in disaggregating different types of wood residues to the existing fuel code system, but also due to variations in the moisture content of wood fuels. The difference in total amount of woodfuels (incl. black liquor) in TJs was 0.5% in 2022.

3.2.4.5 Category-specific recalculations

For 1990, 2005 and 2021 following recalculations were performed:

- Total fuel use of biomass and peat has been changed in the energy statistics resulting changes in 1.A.1a Biomass and Peat as the non-specified fuel use is allocated here (+ 19 kt CO_2 eq. in 2021).
- Emission factors of biogenic CO_2 from MSW and other waste-derived fuels were updated for the whole timeseries due to new information received. Biogenic CO_2 emissions in 1.A.1a and 1.A.2 increased 8 kt in 1990, 41 kt in 2005 and 446 kt in 2021.

Other recalculations in this sector were minor updates and corrections in the point sources' data (activity, combustion technology or allocation) to remove inconsistencies in plant level time series. These corrections were in some cases reflected also in category 1.A.5, which includes residuals of certain fuels. In most cases, the reasons for these recalculations are updates in the latest years' source data or minor, previously undetected, errors in the older data.

3.2.4.6 Category-specific planned improvements

There are no category-specific planned improvements.

3.2.5 Transport (CRF 1.A.3) and off-road vehicles and other machinery

3.2.5.1 Category description

In 2022, the greenhouse gas emissions from transportation amounted to 9.8 Mt CO_2 equivalent. Compared to 2021, emissions decreased 2% in 2022 mainly due to decrease in road transport kilometrage and fuel consumption. The share of the transport sector of the total greenhouse gas emissions was approximately 17% (12.1 Mt CO_2) in 1990 and 21% (9.8 Mt CO_2) in 2022. CO_2 emissions from transport decreased considerably in the early 1990s. The reason for the decrease was the economic depression that was much deeper in Finland than in other European countries. The bottom was reached in 1993 and after that, the increase has been fairly constant reaching the 1990 emission level in 2000. The increase has happened mainly in road transport due to the increased kilometrage. In 2008, the emissions deviated from the upward trend. The worldwide economic downturn that began that year decreased the kilometrage of all transport modes. At the same time the increased use of biofuels has lowered the CO_2 emissions from road transportation. In 2010s, the bioshare in diesel oil has varied annually and caused fluctuations in the annual emissions (see Table 3.2-15).

Transport (CRF 1.A.3) include all emissions from domestic transport sectors: civil aviation, road transport, railways and domestic navigation. Emissions from pipeline transportation (natural gas transmission pipelines) are addressed under Transport in Section 3.2.5.7 but reported in CRF 1.A.5a due to confidentiality issues. Emissions from off-road vehicles and other machinery are reported in the Manufacturing industries and construction (CRF 1.A.2) and Other sectors (CRF 1.A.4). However, the calculation methodologies are described in Section 3.2.5.8 as off-road vehicles and other machinery model TYKO is part of the LIPASTO model developed by VTT Technical Research Centre of Finland (see Section 3.2.5.2). More detailed information on the emissions sources and how the emissions are allocated is given in Table 3.2-11.

The trend in the emissions of these categories is given in Figure 3.2-7 and in Table 3.2-12. In Figure 3.2-6, the emissions of the transport category are given by gas. The fuel consumption in the transport sector in 1990 to 2022 can be seen in Table 3.2-13. Road transportation is the most important emission source in transport, covering 94% of the category's emissions in 2022. The emission trends for each sub-category are discussed in the corresponding sections.

Table 3.2-11 Reporting categories in the transport and off-road vehicles and other machinery categories

Reporting category	Description	Remarks
CRF 1.A.3		
a. Civil Aviation	Jet and turboprop powered aircraft (turbine engined fleet) and piston engined aircraft, domestic flights only	Emissions from helicopters are not calculated separately. These emissions are included in calculation of category 1.A.5.
bi-iv. Road Transport	Transport on roads by vehicles with combustion engines: cars, vans, buses, coaches, lorries, articulated vehicles, motorcycles and mopeds and diesel microcars (light quadricycles).	Farm and forest tractors driving on roads are included in CRF 1.A.4ciii Agriculture/Forestry. Fuel consumption and emissions from military vehicles are included in category 1.A.5. Emissions from 1.A.3bi-iv are reported aggregated in 1.A.3bi (see Section 3.1.4).
c. Railways	Railway transport operated by diesel locomotives	
d. Navigation	Sea-going ships (between domestic ports), icebreakers, working boats, cruisers, ferryboats and leisure boats	Fishing boat emissions are included in the CRF 1.A.4ciii.
e. Pipeline Transportation	Emissions from pipeline transportation (natural gas transmission pipelines) are received from the YLVA system (see 3.1.4 and Annex 6).	Calculation methodologies of Pipeline transportation are described in Section 3.2.5.7 but reported in 1.A.5a due to confidentiality issues.
Off-Road vehicles and other machinery	Non-road machinery and other vehicles from the TYKO model cover several types of machines, for example road maintenance tractors, forklifts, all-terrain vehicles and snowmobiles.	Calculation methodologies of Off-Road vehicles and other machinery are described in Section 3.2.5.8 but reported in following CRF categories: 1.A.2gvii Manufacturing industry and construction 1.A.4aii Commercial/institutional 1.A.4bii Residential 1.A.4cii Agriculture and forestry

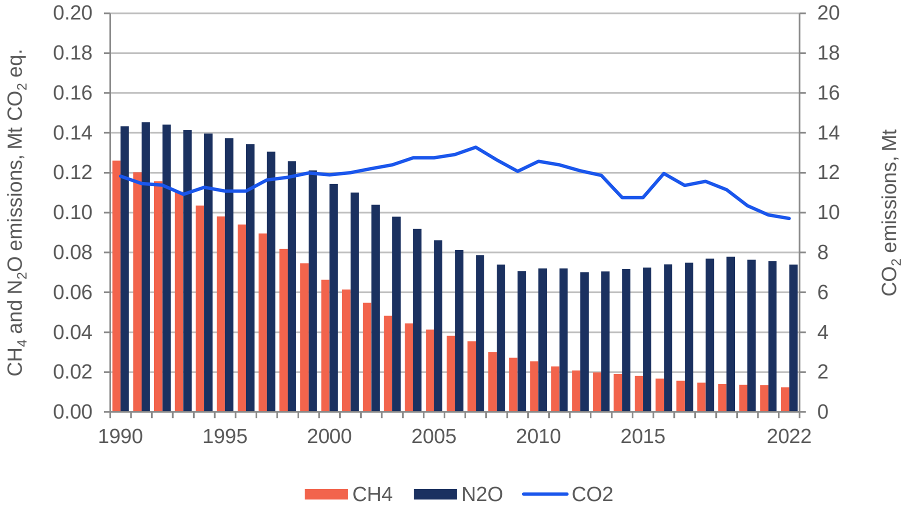

Figure 3.2-6 Emissions from transport sector by gas (Mt CO_2 eq.)

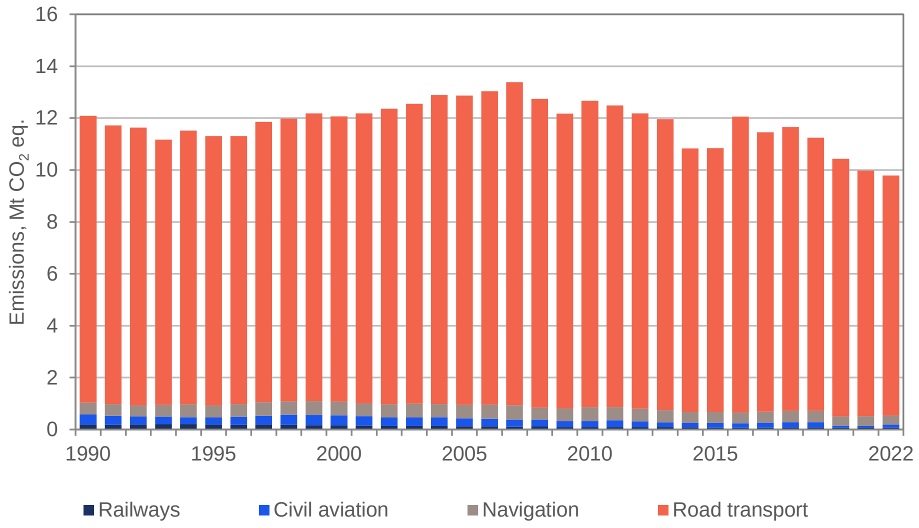

Figure 3.2-7 Emissions from transport by subcategory (Mt CO_2 eq.)

3.2.5.2 Methodological issues

In the Finnish calculation system, separate models have been developed for the different categories of transport, allowing detailed use of traffic data and data on transport equipment fleet. The emissions and energy consumption of all traffic modes except aviation are calculated with the LIPASTO models developed by VTT Technical Research Centre of Finland Ltd.

The LIPASTO system is comprised of four sectoral submodels:

- Road transport emissions model LIISA
- Domestic navigation emissions model MEERI and
- Railways emissions model RAILI
- Off-road vehicles and other machinery model TYKO.

VTT is responsible for running the calculation models LIISA, MEERI, RAILI and TYKO. Finavia has estimated the emissions from aviation for 1990 to 2008 (ILMI model). From 2009 on, Statistics Finland, with expert support from Finavia, has estimated the aviation emissions based on Eurocontrol data (see Section 3.2.5.3).

Statistics Finland aggregates the results of these models to sub-categories of the CRF sector 1.A Fuel combustion (see Section 3.2) and to national energy balances as well. MEERI includes both domestic and international transport, but only domestic transport data are taken to ILMARI as part of the greenhouse gas inventory calculations. The definition used for international transport in MEERI is different from the IPCC definition, thus, Statistics Finland (see Section 3.2.2) separately calculates bunker emissions.

In order to ensure consistency between LIPASTO transport submodels, greenhouse gas inventory and Energy Statistics, Statistics Finland supply VTT the information on the total diesel oil, gasoline and natural gas consumption, the share of biofuels and on the properties of fuels (bio additives change the density and NCV of fuels). Only small differences (average between 2014 to 2022 -0.02% and between 1990 to 2013 -0.6%)in total diesel oil and gasoline consumption data taken as a sum from the LIPASTO transport submodels compared with total fuel sales data taken from the Energy Statistics have been identified. These differences are caused by disaggregation, conversions between quantity units and roundings in different stages of the process, and the share of biofuels (bio additives change the density and NCV of fuels). Also, in some cases total fuel consumption figures are updated during the inventory process. These differences are taken into account in the ILMARI system in road transport, which is the largest subcategory of diesel oil and gasoline consumption, to ensure full consistency between the Energy Statistics and the GHG inventory. The corresponding CO_2 emissions are updated as well; both updates in activity data and bioshares of fuels affect the final CO_2 emissions. All other emission components in the Transport sector are based on the LIPASTO models and split to fossil and biogenic parts according to energy (TJ) shares.

Table 3.2-12 Emissions from the Transport sector by subcategory (Mt CO_2 eq.)

	1990	1995	2000	2005	2010	2013	2014	2015	2016	2017	2018	2019	2020	2021	2022
Total transport	**12.1**	**11.3**	**12.1**	**12.9**	**12.7**	**12.0**	**10.8**	**10.8**	**12.1**	**11.5**	**11.7**	**11.2**	**10.4**	**10.0**	**9.8**
CO_2															
3. Transport	**11.8**	**11.1**	**11.9**	**12.7**	**12.6**	**11.9**	**10.7**	**10.8**	**12.0**	**11.4**	**11.6**	**11.2**	**10.3**	**9.9**	**9.7**
a. Civil aviation	0.39	0.26	0.38	0.30	0.23	0.18	0.18	0.18	0.18	0.19	0.21	0.21	0.09	0.08	0.14
b. Road transportation	10.8	10.2	10.8	11.8	11.7	11.1	10.1	10.1	11.3	10.7	10.9	10.4	9.8	9.4	9.2
c. Railways	0.19	0.19	0.16	0.13	0.10	0.09	0.08	0.07	0.06	0.07	0.07	0.07	0.06	0.07	0.06
d. Navigation	0.44	0.46	0.53	0.50	0.53	0.47	0.41	0.42	0.41	0.42	0.42	0.43	0.35	0.35	0.34
e. Other transportation *	C	C	C	C	C	C	C	C	C	C	C	C	C	C	C
CH_4															
3. Transport	**0.126**	**0.098**	**0.066**	**0.041**	**0.025**	**0.020**	**0.019**	**0.018**	**0.017**	**0.016**	**0.015**	**0.014**	**0.014**	**0.013**	**0.013**
N_2O															
3. Transport	**0.143**	**0.137**	**0.114**	**0.086**	**0.072**	**0.071**	**0.072**	**0.072**	**0.074**	**0.075**	**0.077**	**0.078**	**0.076**	**0.076**	**0.074**
a. Civil aviation	0.003	0.002	0.003	0.002	0.002	0.001	0.001	0.001	0.001	0.001	0.002	0.002	0.001	0.001	0.001
b. Road transportation	0.137	0.132	0.108	0.080	0.066	0.066	0.067	0.068	0.070	0.070	0.072	0.073	0.073	0.073	0.071
c. Railways	0.0013	0.0012	0.0009	0.0006	0.0004	0.0004	0.0004	0.0003	0.0003	0.0003	0.0003	0.0003	0.0003	0.0003	0.0003
d. Navigation	0.0025	0.0026	0.0031	0.0030	0.0035	0.0030	0.0026	0.0027	0.0025	0.0027	0.0027	0.0027	0.0022	0.0023	0.0022
e. Other transportation *	C	C	C	C	C	C	C	C	C	C	C	C	C	C	C

* Reported in CRF 1.A.5a due to confidentiality

Table 3.2-13 Fuel consumption by fuel type in transport (PJ)

	1990	1995	2000	2005	2010	2013	2014	2015	2016	2017	2018	2019	2020	2021	2022
Civil aviation															
Aviation gasoline	0.11	0.08	0.08	0.04	0.04	0.03	0.03	0.03	0.02	0.02	0.03	0.03	0.03	0.03	0.02
Jet kerosene	5.15	3.51	5.11	4.09	3.07	2.44	2.45	2.42	2.46	2.61	2.89	2.83	1.17	1.05	1.83
Road transportation															
Gasoline	80.7	76.7	71.2	74.9	62.6	58.0	55.8	55.5	55.3	53.2	52.4	51.2	47.2	47.5	44.2
Diesel oil	66.9	62.1	76.5	86.2	97.1	95.6	83.3	83.8	100.7	93.9	96.8	92.4	88.0	81.4	81.8
Natural gas	NO	NO	0.05	0.11	0.20	0.11	0.10	0.07	0.10	0.11	0.13	0.24	0.35	0.40	0.03
Liquid biofuels	NO	NO	NO	NO	5.41	9.46	20.6	20.6	7.3	16.2	15.2	17.7	16.4	27.7	22.4
Gaseous biofuels	NO	NO	NO	0.0001	0.002	0.04	0.06	0.08	0.08	0.11	0.19	0.28	0.40	0.50	1.16
Railways															
Gasoil	2.58	2.61	2.17	1.73	1.30	1.26	1.15	0.93	0.87	0.91	0.98	0.95	0.87	0.97	0.80
Liquid biofuels	NO	NO	NO	NO	0.020	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO
Navigation															
Residual oil	1.56	1.79	2.23	1.74	1.74	1.23	0.64	0.45	0.41	0.43	0.44	0.47	0.24	0.17	0.17
Gasoil	2.52	2.44	2.82	3.09	3.19	3.26	3.20	3.51	3.34	3.54	3.60	3.57	2.50	2.48	2.69
Gasoline	1.80	1.88	1.94	1.92	1.63	1.39	1.35	1.42	1.37	1.35	1.36	1.36	1.57	1.72	1.40
Diesel oil	NO	NO	NO	NO	0.52	0.51	0.35	0.35	0.39	0.35	0.35	0.34	0.38	0.35	0.30
LNG	NO	NO	NO	NO	NO	NO	NO	NO	0.064	0.10	0.08	0.16	0.18	0.19	0.13
Liquid biofuels	NO	NO	NO	NO	0.14	0.10	0.14	0.14	0.09	0.13	0.13	0.15	0.18	0.35	0.33
Other transportation *															
Natural gas	C	C	C	C	C	C	C	C	C	C	C	C	C	C	C

* Reported in 1.A.5a due to confidentiality

There have been some changes in legislation and fuel tax decisions concerning the use of diesel oil and gasoil over time. A new fuel product, non-road gasoil, was introduced during 2005. Non-road gasoil is technically the same fuel as diesel oil but has lower taxes and includes a Euromarker to allow monitoring of illegal use. During 2011 to 2013 the situation changed again. Almost all gasoil is presently sold under the title “sulphur free gasoil”, which is in practise the same product as non-road-gasoil. In this report, we use the terminology “non-road-gasoil” to describe the use of gasoil in diesel engines in off-road vehicles and other machinery and domestic navigation (wherever it is allowed to use lower taxed gasoil instead of higher taxed diesel oil). All other uses of gasoil (heating, industrial use etc.) are allocated under heating gasoil.

In leisure boats, the use of diesel oil (instead of gasoil) was made obligatory from the beginning of 2008. Table 3.2-14 shows the changes in the allocation of diesel oil, non-road gasoil and heating gasoil used in different subsectors of the inventory.

Table 3.2-14 The allocation of diesel oil, heating gasoil and non-road gasoil (PJ); numbers include bioshares

PJ (including bio-shares)		1990	1995	2000	2005	2010	2011	2012	2013	2014	2015	2016	2017	2018	2019	2020	2021	2022
Road transportation	Diesel oil	66.9	62.1	76.5	86.2	99.6	102.5	101.4	102.4	101.1	101.7	105.3	106.7	108.5	106.5	100.5	104.5	99.4
Leisure boats		0.4	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.4	0.4	0.4	0.4	0.4	0.4	0.4	0.4	0.4
Domestic navigation	Non-road gasoil	4.4	4.1	4.2	4.2	4.8	4.8	4.5	4.9	4.7	4.9	4.6	4.8	4.8	5.0	3.8	3.9	4.2
Railway transport		2.6	2.6	2.2	1.7	1.3	1.4	1.3	1.3	1.1	0.9	0.9	0.9	1.0	1.0	0.9	1.0	0.8
Off-road vehicles and other machinery		29.4	28.3	30.4	30.7	31.5	30.0	31.8	31.2	30.6	31.1	30.2	32.4	32.0	33.4	33.8	32.0	32.1
Energy production, heating, industry	Light fuel oil (=heating gasoil)	69.0	63.4	59.5	53.6	44.1	36.9	39.2	34.8	34.1	31.4	33.2	31.7	30.2	28.6	26.9	29.8	33.0
Total gasoil + diesel oil		172.7	161.0	173.2	176.9	181.9	176.1	178.9	175.0	172.1	170.5	174.5	176.9	176.9	174.9	166.4	171.6	169.9

Bioshares of transport fuels

Increasing amounts of biogenic additives or biofuels are mixed in road transport fuels and some other liquid fuels (Table 3.2-15). Activity data of blended biofuels for 2002 to 2007 are based on a separate survey made by Statistics Finland (Energy statistics team). The data includes the amount of blended biogasoline (ethanol), starting from 2002, as well as blended biodiesel, starting from 2007. Due to the expiration of the periodic deduction of fuel tax, there was no consumption of bioethanol in 2005 (Ministry of Economic Affairs and Employment, 2006), but in 2006 bioethanol re-entered the market. The data of other biogenic compounds, like ETBE (ETBE = ethyl tert-butyl ether, a bioethanol-based gasoline component), are not available for 2002 to 2007, but their shares are estimated to be almost negligible.

The activity data of blended and pure biofuels from 2008 to 2015 was collected by Finnish Customs, data from 2016 to 2020 by Tax Administration and data from 2021 on by Energy authority. These data include the following biofuels and bio-components [18]:

- Bioethanol, BTL-gasoline, bioshares of ETBE, TAEE and tHxEE
- Biodiesel and synthetic renewable diesel (mostly BTL-diesel, bioshare of FAME)
- Biogasoil mixed in the non-road gasoil (mostly BTL-diesel, bioshare of FAME)

FAME is produced from glyceride and methanol. The end product contains fossil carbon if the methanol is produced from a fossil fuel (e.g. natural gas). Fossil content of FAME has been taken into account. Fossil share has been included in fossil diesel, correspondingly fossil shares of ethers have been included in fossil gasoline.

Time series on biogas (CBG) use in transport starting from 2002 are available in the Energy statistics. Use of LBG started in 2017.

The consumption of biofuels was originally included in the total sales data of gasoline, diesel oil and gasoil which was prior 2018 received from Petroleum and Biofuels Association both for the LIPASTO system and for the ILMARI system. Since the operation of Petroleum and Biofuels Association ended in 2018, Statistics Finland has been responsible for this oil statistics data collection. Shares of biofuels are calculated in the

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[18] TAEE = tertiary amyl ethyl ester, THxEE = tert-hexyl ethyl ether, BTL = biomass to liquid, FAME = fatty acid methyl ester

ILMARI system by Statistics Finland based on data received from Finnish Customs, Tax administration and/or Energy authority.

Calculations in LIPASTO transport submodels are performed using total fuel consumption data, including biofuels. In the LIPASTO system, the CO_2 emission data include only fossil emissions; thus CO_2 emission factors are defined to include the fossil share of total fuel mix.

After the LIPASTO data are imported to the ILMARI system (see Section 3.1.4), the fuel consumption data are split to fossil and biogenic parts using calculated bioshares. Biogenic emissions are from 2008 onwards allocated to the transport and machinery subcategories according to the consumption of these fuel types. CO_2 emissions are calculated separately in the ILMARI system for fossil parts and biogenic parts of transport fuels. All other emission components in the Transport sector are based on the LIPASTO models and split to fossil and biogenic parts according to energy (TJ) shares.

From 2013 until 2020 the bioshare of gasoil was at a very low level (0.1 to 0.2%). Because the share was so low, we decided to allocate this bioshare into road transport (diesel oil) instead of non-road use. By this way we could avoid the disappearance of very small figures in disaggregated data due to roundings. Distribution obligation of biofuel oil started in 2021. The bioshare of gasoil was 3.3% in 2021 and 3.9% in 2022 both in transport and heating.

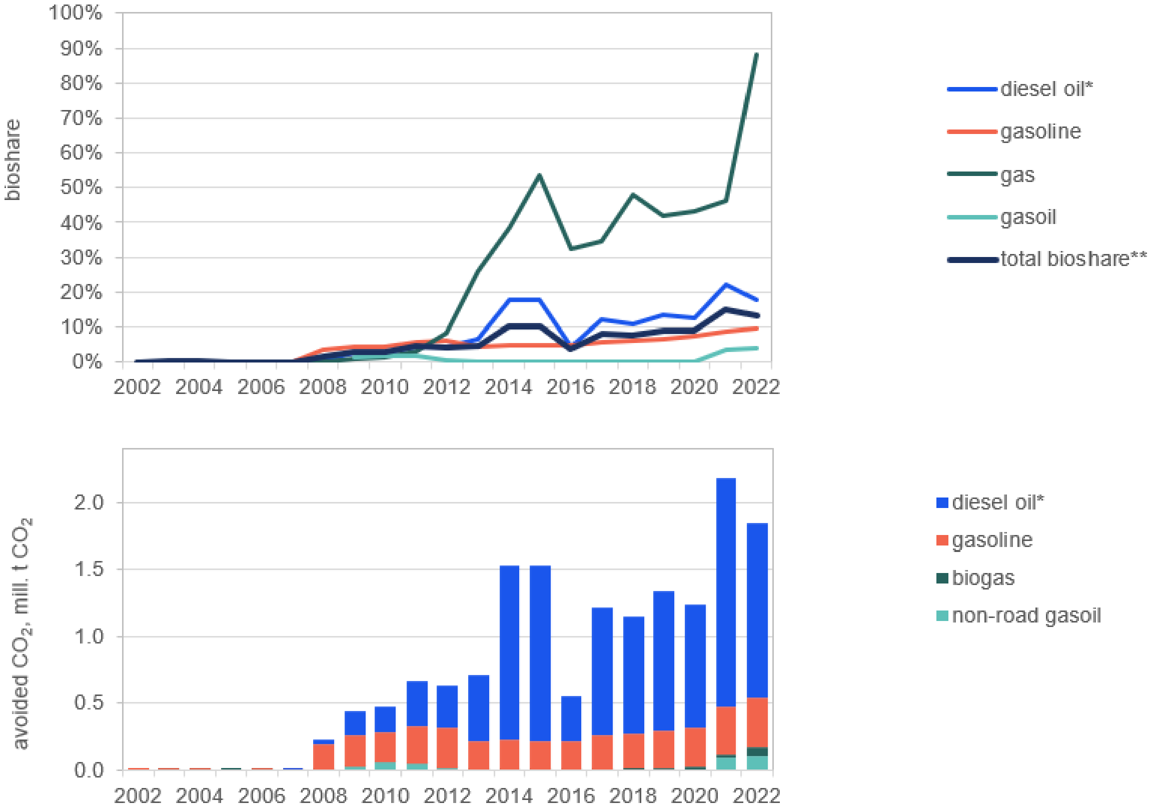
In 2022 bioshares of gasoline and diesel oil were 9.8% and 17.8% respectively (calculated from TJ). The share of biogas (incl. LBG) in transport and non-road machinery gas consumption was 88% in 2022. (Table 3.2-15 and Figure 3.2-8)

The CO_2 emission factors for biogenic components of gasoline and diesel oil are based on the stoichiometric C-contents of 52% for bioethanol (C_2H_5OH) and 85% for biodiesel ($C_{18}H_{38}$); these give respectively 1.913 t CO_2/t of bioethanol and 3.12 t CO_2/ t of biodiesel. Emission factor for bioethanol (per mass unit) has been used for all types of bioadditives in gasoline, and correspondingly EF for biodiesel have been used for different types of biodiesel (HVO and FAME). Emission factors per TJ in Table 3.2-4 have been calculated using NCVs and shares of different biocomponents in gasoline and diesel oil (see also Section 3.2.5.4). For biogas used in transport, the same CO_2 EF (56.1 t/TJ) has been used as for other uses of biogas.

Table 3.2-15 Amount of biocomponents in liquid fuels, amount of biogas and avoided fossil CO_2, 2002 to 2022 (TJ)

	Gasoline	Diesel oil	Non-road gasoil	Heating gasoil	Biogas	Avoided fossil CO_2, kt
2002	33	NO	NO	NO	0.01	2
2003	176	NO	NO	NO	0.07	13
2004	186	NO	NO	NO	0.07	14
2005	NO	NO	NO	NO	0.07	0.004
2006	34	NO	NO	NO	0.11	3
2007	71	5	NO	NO	0.22	6
2008	2 704	473	NO	NO	0.29	232
2009	3 209	2 456	393	544	1	484
2010	3 040	2 605	878	713	2	531
2011	3 881	4 564	670	641	6	716
2012	4 034	4 317	258	231	15	649
2013	2 943	6 789	IE	NO	39	707
2014	3 082	17 859	IE	NO	61	1 526
2015	2 899	18 027	IE	NO	82	1 528
2016	3 008	4 541	IE	NO	77	551
2017	3 586	12 929	IE	NO	109	1 210
2018	3 738	11 775	IE	NO	195	1 142
2019	3 918	14 178	IE	NO	285	1 335
2020	4 144	12 612	IE	NO	400	1 243
2021	4 998	23 212	1 244	925	505	2 245
2022	5 222	17 714	1 461	1 300	1 159	1 938

IE = included in diesel oil



** Minor bioshares of non road gasoil have been included in diesel oil from 2013 to 2020.*
*** Total bioshare of diesel, gasoline, gas and gasoil in transport (1.A.3) and non-road machinery*

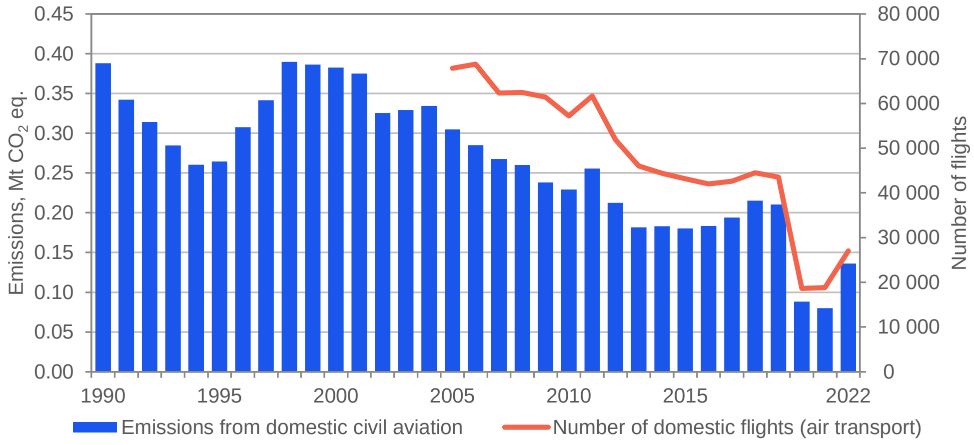
Figure 3.2-8 Bioshares in transport and non-road machinery fuels and avoided fossil CO_2 emission

3.2.5.3 Civil aviation

Emissions from civil aviation include all domestic civil aviation: jet and turboprop powered aircraft (turbine-engined fleet in air transport) and piston engined aircraft (mostly general aviation). Helicopters are not included in the calculations of civil aviation as a separate category due to the small number of flights and lack of emission factors. However, the fuel consumption of helicopters is included as part of sector 1.A.5 (part of jet fuel consumption).

The share of the emission from civil aviation of total emissions in the transport category was 1.4% and the amount of the emissions was 0.14 Mt CO_2 eq. in 2022. These emissions increased 71% compared to 2021. In 1990, the emissions were 0.39 Mt CO_2 eq. See Figure 3.2-9 and Table 3.2-16.

The variations in fuel consumption and emissions are caused by the variations in the number of flights, flight hours and aircraft fleet. The economic recession in the early 1990s decreased the number of flights. In the late 1990s, the demand on domestic air transport and the number of commercial flights increased. During the 2000s, the overall emission trend has been decreasing, partly due to renewed fleet and partly due to the recession that started in 2008. In 2013 to 2016, the emissions were almost at the same level, 50% below the 1990 emissions. From 2017 to 2019 some increase can be seen, as the number of flights has started to increase. The years 2020 and 2021 and exceptional as the number of flights dropped due to COVID-19 pandemic. In 2022 emissions are still below the emission level in 2019.



Number of flights not available for 1990-2004.

Figure 3.2-9 Emissions from domestic civil aviation (Mt CO_2 eq.)

Table 3.2-16 Emissions, fuel consumption and number of flights or flight hours by fuel type in the Civil Aviation (1.A.3a) sector

	1990	1995	2000	2005	2010	2013	2014	2015	2016	2017	2018	2019	2020	2021	2022
Civil aviation, emissions, Mt CO_2 eq.	0.39	0.26	0.38	0.30	0.23	0.18	0.18	0.18	0.18	0.19	0.22	0.21	0.09	0.08	0.14
Aviation gasoline															
Fuel consumption, PJ	0.11	0.08	0.08	0.04	0.04	0.03	0.03	0.03	0.02	0.02	0.03	0.03	0.03	0.03	0.02
Flight hours (general aviation)	-	-	-	52 662	51 104	30 279	39 097	33 964	26 448	25 923	35 005	31 117	32 692	36 435	26 585
Jet kerosene															
Fuel consumption, PJ	5.15	3.51	5.11	4.09	3.07	2.44	2.45	2.42	2.46	2.61	2.89	2.83	1.17	1.05	1.83
Number of flights (air transport)	-	-	-	67 857	57 203	45 996	44 349	43 185	42 014	42 618	44 488	43 503	18 633	18 800	27 053

number of flights and flight hours not available for 1990-2004.

Methods

From 2005 on jet fuel and emission data for domestic aviation (jet and turboprop engines) have been taken from Eurocontrol calculation system (see description Eurocontrol, 2018). The methods for calculating CO_2 emissions from turbine-engined fleet are comparable with the IPCC Tier 2 level.

Emissions from domestic aviation from 1990 until 2004 and partly until 2008 have been calculated by the ILMI calculation model maintained by Finavia. The results from ILMI (fuel consumption of jet fuel and aviation gasoline and emissions of air pollutant emissions) have been used for the years 1990 to 2004 (see description of ILMI model below). From 2010 on Finavia has not performed the calculations and ILMI model has not been updated since then (see also Section 1.2.1.2). Therefore we decided to use Eurocontrol data for jet and turboprop engines starting from 2005, as described above.

Calculation of piston-engined aircraft (using aviation gasoline) continued using ILMI results for 2005 to 2008, corrected with changes in flight hours for later years. Eurocontrol data could not be used here, because the system covers only a small portion of piston-engined flights. The methods for calculating CO_2, CH_4 and N_2O emissions from piston-engined aircrafts are estimated to be comparable with the IPCC Tier 1 level method for whole time series. In this method (Vol 2, Eq.3.6.1) emissions are calculated by multiplying fuel consumption data with emission factors (separate CH_4 and N_2O emission factors have been used for LTO and cruise).

The description of the ILMI model

Energy consumption of civil aviation within the Finnish Flight Information Region (FIR) have been calculated using the ILMI calculation model from 1990 to 2004 and for aviation gasoline also from 2005 to 2008 (Figure 3.2-10**,** Savola M. & Viinikainen M., 1995, in Finnish only). The model also includes calculation of air pollutants but the model has not been updated since 2009. Therefore, greenhouse gas emissions are calculated separately from the model in order to comply the requirements of the 2006 IPCC Guidelines and to ensure time series consistency. The model is meant for emission studies on jet and turboprop powered aircraft (turbine-engined fleet in air transport). Furthermore, it includes a simplified routine for estimating emissions from piston-engined aircraft (mostly general aviation). The ILMI model has been prepared and maintained until 2009 by Finavia and the data have been fed to the ILMARI system (see Section 3.1.4).

In the ILMI model, each flight operation is divided into the following flight segments: taxi in, take-off, climb-out, cruise, descent, approach, taxi out. Only the flight segments and flight time within the Finnish FIR are included. It means that the full length of domestic flights is covered, but international flights and overflights are not (only the parts within the Finnish FIR). Domestic and international flights and overflights are shown separately in the summary results. The emissions from domestic flights are reported under CRF 1.A.3a. The emissions from international flights, such as they are included in the ILMI model, do not follow the definition of bunker fuels in 2006 IPCC Guidelines (the coverage of flight segments is different). Therefore, the emissions from International bunkers are calculated separately (see Section 3.2.2).

In the ILMI model fuel burn is calculated separately for each aircraft type assuming fixed and representative aircraft type and engine type pairs, more detailed information of engine type of all turbine engined fleet are not available or applicable for the model. The model contains approximately 140 aircraft and jet engine pairs and 90 aircraft and turboprop engine pairs.

The calculation is based on traffic statistics and aircraft performance data of each flight segment from the ICAO (International Civil Aviation Organisation) database (Engine Emission Databank).

The fuel consumption per flight segment (fs) is calculated by the formula:

*FUEL BURN per fs = FF per fs * FLIGHT TIME per fs * NUMBER OF ENGINES*

The methodology for assessing fuel burn from general aviation (piston engine aircraft) is different from the one used for air transport. It is based on the statistics of total flight hours annually published by the Finnish Civil Aviation Authority. The fuel burn is generalised for two typical reference aircraft types only. Therefore, the results are not as reliable as for air transport.

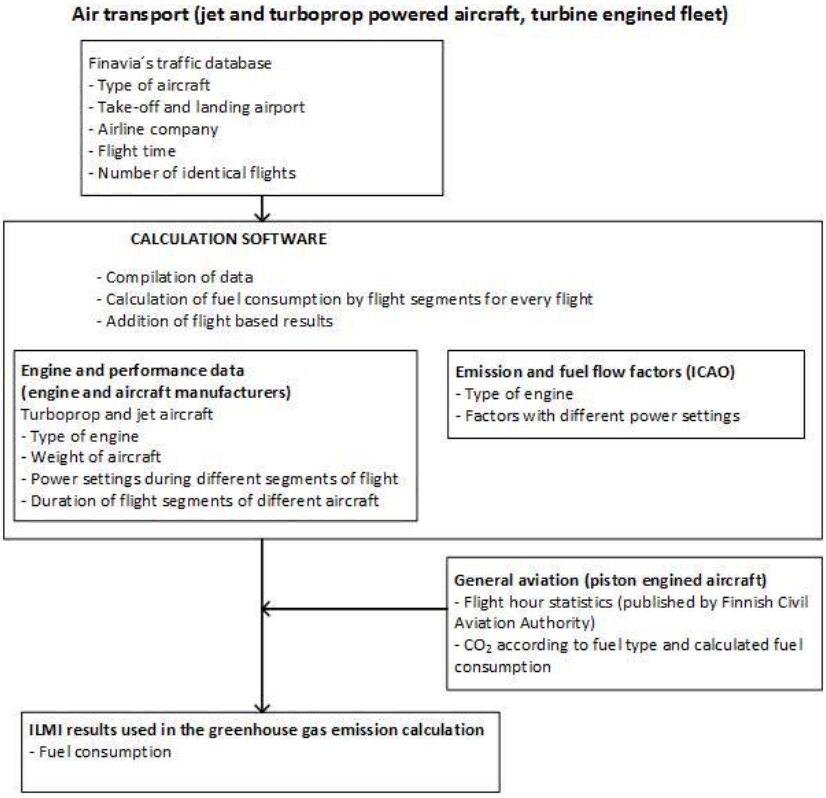


Figure 3.2-10 Calculation of jet fuel consumption data in the ILMI calculation model (inventory years 1990 to 2004)

Activity data

Jet fuel consumption data in civil aviation is taken from the ILMI model for 1990 to 2004. From 2005 on data is received from Eurocontrol separately for LTO and cruise. Aviation gasoline consumption data are taken from the ILMI model from 1990 to 2008 and calculated based on flight hours from 2008 on.

As regards to Eurocontrol fuel consumption data, for the LTO cycle average fuel consumption data are assumed for each combination of aircraft type and type of engine. For the cruise phase the masses of fuel burnt are calculated by flight segment basis. In this Eurocontrol method best estimate of the 4D trajectory for every EU-28 flight during the year exists. Then, the mass of fuel burnt during the LTO and cruise phases of every EU-28 flight are calculated by processing the trajectories with advanced emission model (AEM) (Eurocontrol, 2018).

In the ILMI model the traffic data for calculating the air transport were taken from Finavia's database for the calculation year for years 1990 to 2004. The database was adopted to serve as a source of flight data for statistics and also for charging the airlines for airport and air navigation services. Some of the information came electronically from the airlines; some was fed into the system manually at the airports. Calculation of fuel consumption data in the ILMI model is described in section 'Method'.

Emission factors and other parameters

Emission factor for N_2O (2 kg/TJ) is from the 2006 IPCC Guidelines (Volume 2, Table 3.6.5) for both jet fuel and aviation gasoline and for LTO and cruise. The emission factors for CH_4 are also taken from the mentioned table. For jet fuel cruise mode CH_4 emissions are assumed to be negligible. For LTO cycle emission factor 5 kg/TJ is used. The same factors are used for aviation gasoline.

CO_2 emission factors are country-specific (see Table 3.2-4: jet fuel 73.2 g/MJ and aviation gasoline 71.3 g/MJ).

Uncertainty assessment and time series' consistency

Quantitative estimates of uncertainty are provided in Annex 2. The annex also documents assumptions made for the analysis.

A summary of the uncertainty analysis methodology used in the inventory is given in Section 1.6. The Monte Carlo simulation has been used to combine the uncertainties of each calculation parameter in order to get the total uncertainty of the category.

Consistency of fuel consumption data between the two models (ILMI and Eurocontrol) has been studied. Before switching to using Eurostat jet fuel data, both data sets for 2005 to 2008 were compared. The results were fairly close, with a 3 to 10% difference. The result was expected because the latest changes in the fleet had not been fully updated to the ILMI system. After this comparison, it was decided that Eurostat jet fuel data could be used starting from 2005.

Category-specific QA/QC and verification

Jet fuel and aviation gasoline consumption data are summed up in the ILMARI system with other user's estimated consumption and the calculated totals are compared with total sales of these fuels. Also comparisons have been made to EU ETS aviation sector data. The differences were expected, taking into account slightly different coverage of flights and different set of operators (only data on domestic operators' flights were available from EU ETS).

Category-specific recalculations

No recalculations were done in this category.

Category-specific planned improvements

There are no category-specific planned improvements.

3.2.5.4 Road transportation

Road transportation (CRF 1.A.3b) covers all transportation on roads in Finland except farm and forest tractors and ATVs (all-terrain vehicles) driving occasionally on the roads (their emissions are included in emissions of off-road vehicles) or military vehicles. Types of vehicles with combustion engines are cars, vans, buses and coaches, lorries and articulated vehicles, motorcycles and mopeds. Vehicle type data of road transportation in the ILMARI system is aggregated due to the procedure for handling of differences in data between LIISA model and Energy Statistics. Therefore emissions and activity data from categories 1.A.3bii, 1.A.3biii and 1.A.3biv are included in category 1.A.3bi (see also Sections 3.1.4 and 3.2.5.2). More disaggregated information provided in the NID are taken from the LIISA model.

Road transportation is the most important emission source under the Transport category. The emissions of road transportation were 9.2 Mt (CO_2 eq.) in 2022; that was 94% of the transport emissions and 20% of the total emissions. Compared to 2021, emissions decreased 2%, mainly due to decrease in kilometrage and fuel consumption. Emissions were 11.1 Mt (CO_2 eq.) in 1990. Emissions in 2022 were 17% lower than in 1990 (Figure 3.2-11).

The road transport emissions decreased strongly in early 1990s due to an economic depression causing a decrease in the road transport kilometrage. The emissions stabilised in 1994 but in 1997 a new decade long period of growth started due to yearly increasing kilometrage. The 1990 level of emissions was reached by 1999.

From 2008 onwards, the emissions have decreased due to many simultaneous different factors, both societal and legislative.

- Economic depression in 2008 and the COVID-19 pandemic in 2020 and 2021 and strong fluctuations in fuel prices in 2022 have decreased kilometrage and thus emissions as well
- The fuel consumption of cars has started a continuous steady decrease trend due to the CO_2 limits set to the car manufacturers by the EU.
- A tax reform on cars in Finland changing the taxation to be mainly based on CO_2 emissions. This caused a dramatic transition from gasoline to diesel cars which decreased CO_2 emissions in 2009.
- In 2010s, biofuels have lowered the CO_2 emissions. The bioshare in diesel oil has varied annually (Figure 3.2-8) and caused fluctuations in the annual emissions. This is due to Finland’s biofuel legislation which allows the distributors to fulfil the bio-obligation flexibly in advance (e.g. in years 2014 and 2015). While gasoline has a technical limit for the maximum ethanol blend diesel has no technical limit for HVO blending, which is used to fulfil the bioshare obligations. The bioshare of diesel oil calculated from TJ has been at the highest in 2021 (22.1%). In 2022 the bioshare was 17.8%.

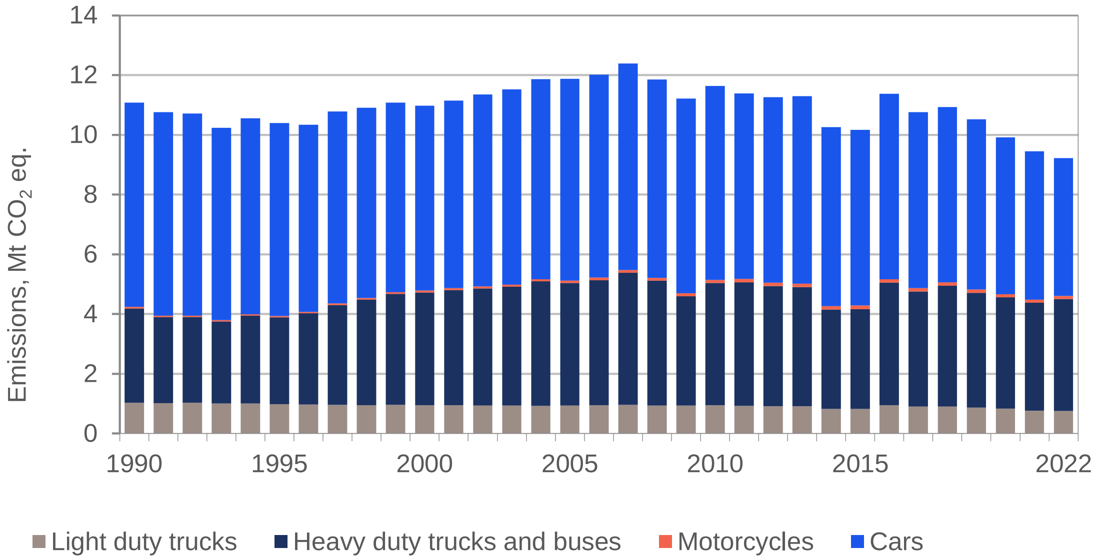
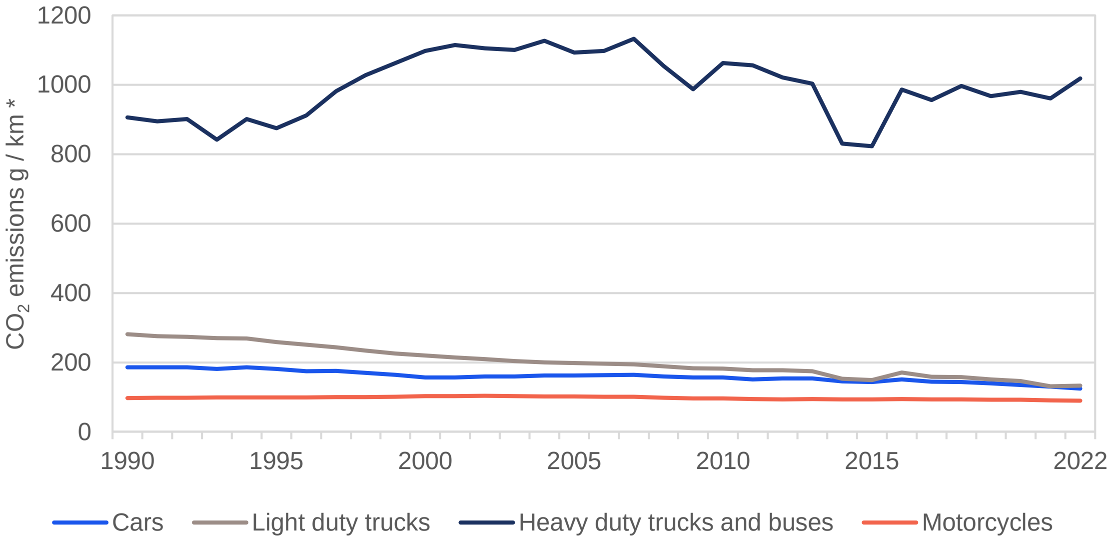


Figure 3.2-11 Emissions from road transportation by types of vehicle (Mt CO_2 eq.) (LIISA Model)



note: excluding kilometrage of battery electric vehicles (BEV) and kilometres driven using electricity in plug-in hybrid electric vehichles (PHEV).

Figure 3.2-12 CO_2 emissions per kilometre (LIISA Model)

The economic recession of the early 1990s in Finland may perhaps explain why road traffic emissions did not increase as rapidly in Finland as in other Annex I countries, consumption actually fell from 1990 onwards (Figure 3.2-13). Diesel consumption started to increase again from 1995, but gasoline consumption has decreased, on average, by 1 PJ per year since the 1991 record-high level.

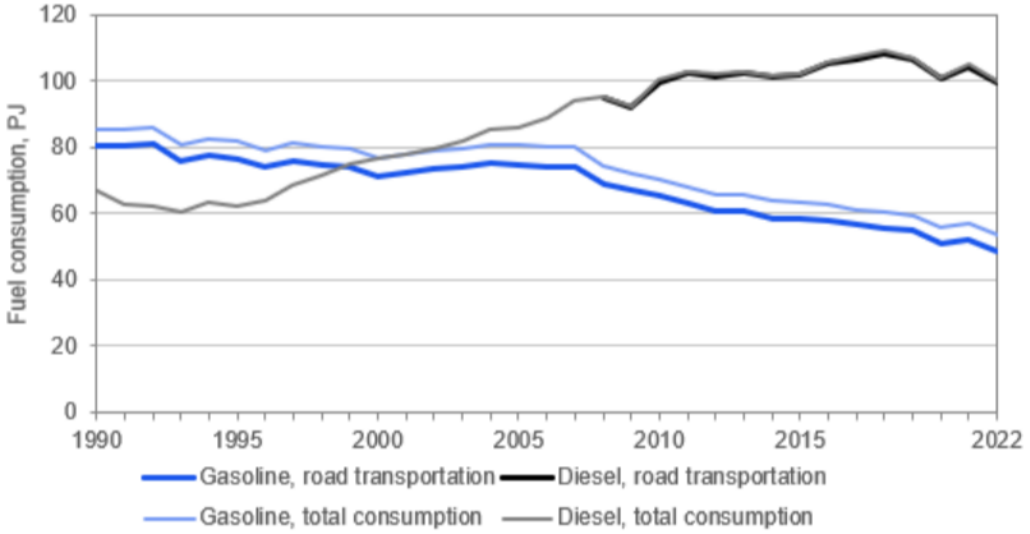


Figure 3.2-13 Consumption of diesel oil and gasoline (including bioshares) in road transportation in 1990 to 2022 (Energy Statistics, Statistics Finland).

Methods

Emission estimations from road transportation are made using the road traffic emission model LIISA, which is a part of the model for all transport modes, LIPASTO of VTT Technical Research Centre of Finland Ltd. The calculations comprise the emissions of CO_2, CH_4 and N_2O. The same model is also used for the calculation of SO_2, CO, NMVOC, NO_2 and PM emissions.

N_2O emission factors comply with both 2006 IPCC Guidelines and EMEP/EEA 2019 because the factors are the same in both documents. CH_4 emission factors comply with EMEP/EEA 2019 where factors are based on emission factor database HBEFA (The Handbook Emission Factors for Road Transport). Factors are basically the same as in 2006 IPCC Guidelines but in EMEP/EEA 2019 the emissions are speed dependent thus differing somewhat from 2006 IPCC Guidelines. In addition, EMEP/EEA 2016 contains factors for newer emission standard vehicles than 2006 IPCC Guidelines. Calculation of the CO_2 emissions is based on fuel consumption of road vehicles and country-specific emission factors. The calculation model is described in Appendix_3a at the end of Chapter 3. The definition of consumption of fuel at country level is based on fuel sales. The main fuels for Road transport in Finland are reformulated gasoline and diesel oil. Besides road transport use, the gasoline is also used in working machines and leisure boats. Diesel oil is used in road transport and leisure boats. Hence, the amounts of fuels used for other purposes than road transport are deducted from the total sales of fuels before the emission calculation (see Section Activity data). The amount of fuel imported in fuel tanks of vehicles from other countries is estimated to be small. The use of natural gas in road traffic in Finland is quite small.

N_2O and CH_4 emissions are based on kilometrage data (km/a) and calculated for gasoline and diesel vehicles separately. The kilometrage (km/a) of each automobile type and model year on different road types and in different speed classes are multiplied with the corresponding CH_4 and N_2O emission factors (g/km). Finally, all emissions are summed up. The calculation model is described in Appendix_3a at the end of Chapter 3.

The kilometrage [km/a] data for automobiles consist of two main categories: kilometrage on public roads (roads governed by the Finnish Transport Infrastructure Agency[19]) and kilometrage on streets (governed by municipalities).

Automobile kilometrage on public roads consists of aggregated kilometres driven by five vehicle types (cars, vans, buses and coaches, lorries and articulated vehicles) in six speed limit classes (50, 60, 70, 80, 100 and 120 km/h). The model uses municipality-level data which allow detailed calculations to be performed on smaller areas than the country. For nation-wide calculations the kilometrage is summed up.

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[19] The Finnish Transport Agency is from 1 January 2019 the Finnish Transport Infrastructure Agency (in Finnish, Väylä)

Street kilometrage is based on a total kilometrage estimation made by the Finnish Transport Infrastructure Agency and crosschecked by the studies made at inspection stations. The estimated street kilometrage data are further divided into street types (main street, collector street, residential street, local plan road) based on information from traffic calculations in some cities.

Both public road and street mileage are divided according to the vehicle technology for every vehicle type: vehicles with/without catalytic converters, diesel, and gas (CNG). Part of the diesel technology vehicles (light and heavy-duty vehicles) use SCR technology to lower NOx emissions by means of urea solution (AdBlue). The consumption of AdBlue is calculated separately for each vehicle category and reported in the subcategory 2.D.3 (See Section 4.5.4). The division of kilometrage by vehicle types and technologies is done by an ALIISA model, which is a vehicle fleet model and submodel to LIISA. The ALIISA model has 45 different vehicle types including gasoline, diesel, FFV (Flexible-fuel vehicle), ED95 (ethanol-diesel vehicle), gas, PHEV (plug-in hybrid electric vehicle), BEV (battery electric vehicle) and FCEV (fuel cell electric vehicle, hydrogen). Besides kilometrage, the ALIISA model comprises data on vehicle sales, fleet, fuel consumption, biofuels, energy and CO_2 emissions. The ALIISA model ensures that all foreseeable technologies can be included in the emission calculations. Furthermore, kilometrage is divided according to vehicle age (model year) thus defining the emission standard (Euro class).

Motorcycle, moped and diesel microcar (light quadricycle) kilometrage is specified in a separate model using the number of motorcycles, mopeds and microcars (from Statistics Finland) and estimation of annual kilometrage of each vehicle type on two road types (roads and streets). Mopeds have only one engine type but kilometrage is further divided according to different emission standards (Euro 0 to Euro 5). Motorcycles have two main type of engines, two-stroke and four-stroke. Kilometrage is divided into these main types and further to three engine volumes (under 250 ccm, 251 to 750 ccm and over 750 ccm) and according to emission standards (Euro 0 to Euro 5). Diesel microcars (light quadricycles) are using diesel technology and the emission standards are Euro 2 to Euro 5.

For each automobile type, the cold driving emissions and fuel consumption surplus are calculated according to the EMEP/EEA emission inventory guidebook 2019 (EMEP/EEA GB2019).

Activity data

The activity data in CO_2 calculation are the amount of fuel consumed in road traffic. Total fuel sales are from statistics compiled by the Finnish Petroleum and Biofuels Association until 2018 and Statistics Finland from 2018 on. These data are compared to and supplemented with the data received from Tax administration. Unlike in many parts of Europe, where through traffic is heavy, in Finland, national fuel sales correspond well with the fuel used in Finland. Gasoline used in road transport in Finland was 49.0 PJ and in leisure boats and working machines 4.3 PJ (8.1% of total sales) in 2022. Diesel fuel used in road transport was 99.4 PJ and in leisure boats 0.4 PJ (0.4% of total sales). Biodiesel and biogasoline are included in these figures.

The amount of gasoline and diesel used in other purposes than for road transportation is deducted from the total sales of gasoline and diesel. Emissions from gasoline used in working machines are calculated with the TYKO model (See Section 3.2.5.7). Emissions from gasoline and diesel used in leisure boats are calculated with the MEERI model (See Section 3.2.5.6).

For modelling purposes, the fuel data are broken down into different vehicle types and road types. However, this does not affect the country-level CO_2 emission calculation because at the end, these sub-results are summed up and total fuel consumption remains unchanged.

For activity data for N_2O and CH_4 calculations, the Finnish Transport Infrastructure Agency has provided the kilometrage [km/a] on public roads as a database. Further division to subcategories is done at VTT. Data for total street kilometrage in Finland are obtained from the Finnish Transport Infrastructure Agency. Further division is made at VTT. Division of kilometrage to subcategories is based on vehicle fleet data from Statistics Finland and the vehicle fleet model ALIISA at VTT, street kilometrage systems of the cities of Helsinki and Espoo and population data of the cities.

The motorcycle, moped and microcars kilometrage is specified in a separate model (submodel to LIISA) using the number of motorcycles, mopeds and microcars (from Statistics Finland) and an estimation of the annual kilometrage of each vehicle type on two road types (roads and streets).

Road traffic kilometrage in Finland in 1990 to 2022 is presented in Table 3.2-17.

Table 3.2-17 Road traffic kilometrage in Finland [Million km/a] (LIISA)

Year	Cars	Light duty trucks	Heavy duty trucks and buses	MC+Mopeds+ Diesel microcars	Total
1990	35 757	3 593	3 440	448	43 237
1995	34 740	3 743	3 272	447	42 203
2000	38 699	4 266	3 412	556	46 934
2005	41 195	4 676	3 732	781	50 385
2010	40 991	5 136	3 835	1 045	51 007
2011	40 682	5 145	3 906	1 131	50 864
2014	41 064	5 306	3 974	1 205	51 549
2015	40 603	5 488	4 026	1 220	51 337
2016	40 682	5 511	4 128	1 226	51 547
2017	40 528	5 608	3 999	1 225	51 361
2018	40 537	5 686	4 022	1 194	51 439
2019	40 446	5 720	3 935	1 154	51 256
2020	38 622	5 655	3 768	1 125	49 169
2021	37 876	5 758	3 726	1 115	48 476
2022	36 822	5 560	3 659	1 092	47 134

note: figures do not include kilometrage of battery electric vehicles (BEV) and kilometres driven using electricity in plug-in hybrid electric vehichles (PHEV).

The source of the number, types and age of vehicles is the Finnish Transport Register (data obtained from Statistics Finland, the Finnish Transport and Communications Agency maintain the register, Traficom).

The activity data for natural gas, LNG, LBG and biomethane used in road transport are taken from Energy Statistics. Information about bioshares of transport fuels can be found in Section 3.2.5.2.

Emission factors and other parameters

Emission factors are determined for all the activity categories mentioned above. Country-specific CO_2 emission factors are shown in Table 3.2-4. They differ slightly from those in the 2006 IPCC Guidelines. CO_2 emission factors, as well as densities and NCVs for transport fuels have been estimated by Statistics Finland, based on product data received from refineries and the most important oil product importers.

Country-specific net calorific values and CO_2 emission factors are shown in Table 3.2-4. That table includes separate data for fossil and biogenic shares of blended liquid fuels.

CO_2 emission factors for biogenic additives and transport fuels have been discussed in Section 3.2.5.2. Emission factors for CH_4 and N_2O are based on the EMEP/EEA GB2019 report. Cold driving has been taken into account in defining the final factors.

EMEP/EEA GB2019 includes now emission factors for microcars (L6e-B light quadri-mobile, moped cars). Guidebook instructs to use emission factors of L-Category mini cars for microcars. However, in the separate factor file “1.A.3b.i-iv Road Transport Appendix 4 Emission Factors 2019” the right emission factors are under the name diesel microcar which are now used in the model.

The same CH_4 and N_2O emission factors are used for the fossil and biogenic shares of the same fuel type.

Uncertainty assessment and time series' consistency

Quantitative estimates of uncertainty are provided in Annex 2. The annex also documents assumptions made for the analysis.

A summary of the uncertainty analysis methodology used in the inventory is given in Section 1.6. The Monte Carlo simulation has been used to combine the uncertainties of each calculation parameter in order to get the total uncertainty of the category.

The activity data for fuels used in road transportation are very accurate due to accurate total fuel sales statistics. For the purposes of the uncertainty estimate, road transportation is divided into gasoline, diesel and natural gas driven vehicles. For the estimation of N_2O emissions, gasoline driven cars are divided into cars with and without catalytic converters.

Emissions of CH_4 and N_2O depend on driving conditions and hot and cold start-ups, for example, and vary greatly during the driving cycle and between different vehicles. Emission estimates also depend on the vehicle kilometrage estimates and are, thus, more uncertain than CO_2 emissions. CH_4 emission factors are estimated to contain uncertainty of around ±60%.

N_2O emissions vary more than CH_4 emissions and are highly dependent on the type and age of the catalytic converters used. N_2O emission factors are estimated to contain uncertainty of 150%.

The properties of fuels and hence the CO_2 emissions factor change over time. In some cases, small annual changes are identified and taken into account only afterwards, e.g. when measurements become available on the impacts.

Category-specific QA/QC and verification

The quality management process and the QA/QC plan for the whole inventory are presented in Section 1.5. The QA/QC plan for the transport sector includes the QA/QC measures based on 2006 IPCC Guidelines. These measures are implemented every year during the transport sector inventory. Potential errors and inconsistencies are documented and corrections are made, if necessary. A bilateral quality meeting is held annually between the inventory unit and the sectoral expert.

Total diesel oil and gasoline consumption taken as a sum from the LIPASTO transport submodels is annually compared with total fuel sales data taken from the Energy Statistics. Only small differences (average between 2014 to 2022 -0.02% and between 1990 to 2013 -0.6%) have been identified (see also Section 3.2.5.2). Reasons for larger differences have been explained and necessary updates are made to the inventory figures and to the LIPASTO submodels in order to ensure consistency between ILMARI system, energy statistics and LIPASTO models.

Category-specific recalculations

No recalculations were done in this category.

Category-specific planned improvements

There are no category-specific planned improvements.

3.2.5.5 Railway transportation

Railway transportation is a minor emission source in the transport sector. The emissions of railway transportation were 0.06 Mt (CO_2 eq.) in 2022, which was 0.6% of the transport category's emissions. Emissions decreased 17% from the previous year. The emissions were 0.19 Mt (CO_2 eq.) in 1990 (Figure 3.2-14). Greenhouse gas emissions from diesel trains have decreased since 1994, because the electrification of railway lines has progressed and transportation in minor, non-electrified railway lines has ceased. The recession and the rapid restructuring in Finland's forest industry significantly reduced freight carryings on rail in 2008 and 2009. There was a decrease to a lower transport volume level in 2015 due to the economic situation in Finland and Russia. Since, the situation has stabilized with minor fluctuations. In 2022, transport activity (gross tonne kilometres) reduced substantially especially in diesel-powered freight transport (-15%) mainly due to the economic sanctions against Russia.

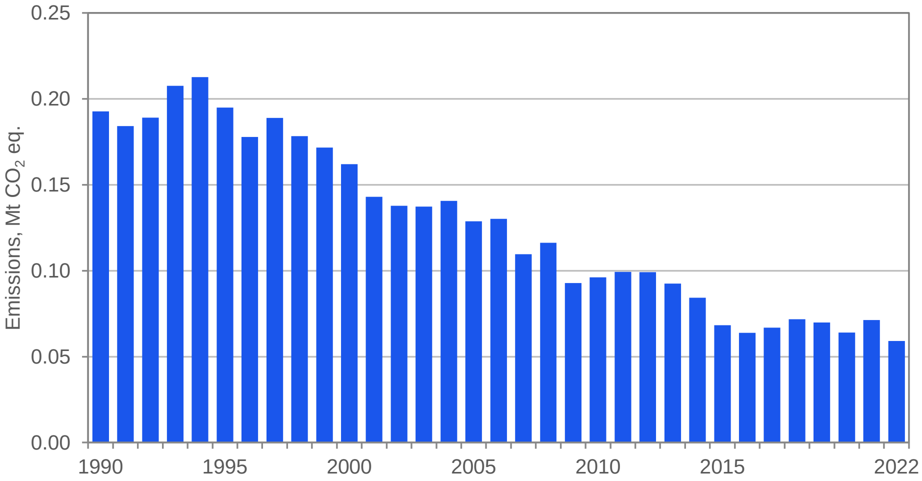


Figure 3.2-14 Emissions from railway transportation (Mt CO_2 eq.)

Methods

In Finland, railway emissions are calculated using the RAILI model developed by VTT Technical Research Centre of Finland Ltd. Gross tonne kilometres for each train and locomotive type and rail section (in total 602 sections) are used as activity data. Activity data is needed in determining the regional emissions and in the detailed calculation of consumption of trains by weight category. Fuel consumption of a train is calculated by multiplying activity data with the specific fuel consumption of the locomotive. In Finland there are three railway operators. The calculated fuel consumption figures are calibrated to be consistent with the total reported consumption by the operators. This ensures that the consumption results are consistent with the reality. Calibration is particularly important as the specific consumption figures for new locomotive types can only be obtained from the technical specifications given by the manufacturers.

The amount of fuel used is calculated separately for passenger transport, freight transport and locomotives without wagons, and for rail yard operations. To include the mobilisation time of the fleet, preparation and finishing times, extra transfer, wagon heating and use of aggregates for electricity production the amount of fuel is multiplied by factors defined by VR-Group Ltd (the main operator in Finland). In Finland, all diesel locomotives use gasoil for non-road use, which is technically the same product as sulphur free diesel oil.

In general, emissions are calculated by multiplying the amount of fuel used (kg) with the specific emission factor (g/kg fuel). In the RAILI model the relevant emission compounds are CO, HC, NOx, PM, SO_2, CH_4, N_2O, CO_2 and thereto fuel consumption and energy usage. Time series of the model results are available for 1990-2050. For national purposes, also the energy use of electric trains is calculated. The formula for diesel trains in the RAILI model is described in Appendix_3a at the end of Chapter 3. The calculation method is consistent with the 2006 IPCC Guidelines (corresponds to the Tier 2 level method).

Activity data

The activity data in the RAILI model consisting of gross tonne kilometres of all operators is collected by the Finnish Transport Infrastructure Agency (the national authority) and stored in their database. In detail, the gross tonne kilometre data used in the RAILI model is segregated by the operator, train type, locomotive type (5 diesel locomotive types), train weight (10 weight categories) and gross tonne kilometres hauled by rail section (in total 602 rail sections). Also, information on locomotives driving without wagons is included. Shunting locomotive use (by VR-Group Ltd) is expressed as time (h/a) in all rail yards. In addition, railway operators' reports on their fuel consumption are essential for the calibration (described above).

In the calculation of CO_2 emissions from railway transportation terajoules (TJs) received from RAILI model have been used as activity data. Gasoil consumption in railway transportation in Finland is presented in Table 3.2-13.

Emission factors and other parameters

The specific fuel consumption of locomotives of the largest operator, VR-Group Ltd, has been defined by measuring the actual fuel consumption of locomotives hauling trains of different weights. The specific consumption of locomotives of the two new operators, Fenniarail and Operail, was defined based on the total consumption of the first year of their operation, in 2017 and 2020 respectively, and the gross tonne kilometres hauled.

In the calculation of CO_2 emissions from railway transportation terajoules (TJs) received from the RAILI model have been used as activity data. The country-specific CO_2 emission factor follows Table 3.2-4 (Gasoil for non-road use, 73.1 g/MJ in 2021).

In 2022, the bio share of gasoil was 3.9% for all users.

CH_4 emission factors have been taken from IPCC 2006 Guidelines. N_2O EFs have been chosen based on an expert estimate to get consistent time series and comparable results to other relevant subcategories of mobile sources (non-road machinery, domestic navigation, fishing boats, etc.), which are basically using the same kind of diesel engines and the same type of fuel (non-road gasoil). The N_2O emission factor for wagon heating (0.0071 g/kg fuel) is derived from U.S. EPA (2010) (residential furnace).

Emission factors other than CH_4 and N_2O for the new operators (Fenniarail and Operail) are based on the information of locomotive manufacturers that they meet the Stage III A level.

Uncertainty assessment and time series' consistency

Quantitative estimates of uncertainty are provided in Annex 2. The annex also documents assumptions made for the analysis. A description of the uncertainty analysis is included in Section 1.6.

A summary of the uncertainty analysis methodology used in the inventory is given in Section 1.6. The Monte Carlo simulation has been used to combine the uncertainties of each calculation parameter in order to get the total uncertainty of the category.

All non-electric locomotives in Finland use gasoil as fuel. As the fuel quality is rather constant and carbon in the fuel is nearly completely oxidised, uncertainty in CO_2 emissions is estimated to be low. This was also shown in a measurement project of Kymenlaakso Polytechnic (Korhonen & Määttänen, 1999). In the current inventory, CO_2 uncertainties are estimated at CRF category level 1.A.

Uncertainties of CH_4 and N_2O emission factors are larger than those of CO_2. These emissions vary depending on engine design and maintenance, and the start-ups and shutdowns of the engines are likely to affect emissions. Uncertainty in the emission factor for CH_4 was estimated based on the variation in hydrocarbon emissions in a measurement project (Korhonen & Määttänen, 1999). Uncertainty in the N_2O emission factor was based on expert judgement (see Monni et al., 2003) and on uncertainty in emission factors for diesel engines used for other purposes.

Category-specific QA/QC and verification

The quality management process and the QA/QC plan for the whole inventory are presented in Section 1.5. The QA/QC plan for the transport sector includes the QA/QC measures based on 2006 IPCC Guidelines. These measures are implemented every year during the transport sector inventory. Potential errors and inconsistencies are documented and corrections are made, if necessary. A bilateral quality meeting is held annually between the inventory unit and the sectoral expert.

The calculated fuel consumption results are calibrated to be consistent with the operators’ yearly consumption reports. This ensures that the consumption calculations are consistent with the reality.

Statistics Finland crosschecks the fuel consumption data calculated within the RAILI model.

Category-specific recalculations

No recalculations were done in this category.

Category-specific planned improvements

There are no category-specific planned improvements.

3.2.5.6 Domestic navigation

Domestic navigation includes the most important domestic waterway transport in Finland: sea-going ships, icebreakers, working boats, cruisers (sightseeing), ferryboats and leisure boats. Fishing boat emissions are included in the Agriculture, forestry and fisheries’ sector (CRF 1.A.4c).

Domestic navigation is a minor emission source in Transport category. The emissions of domestic navigation were 0.35 Mt (CO_2 eq.) in 2022, which was 4% of the sector’s emissions. Emissions decreased 4% compared to 2021 (Table 3.2-12). The emissions were 0.45 Mt (CO_2 eq.) in 1990. Emissions from domestic navigation by ship types are presented in Figure 3.2-15.

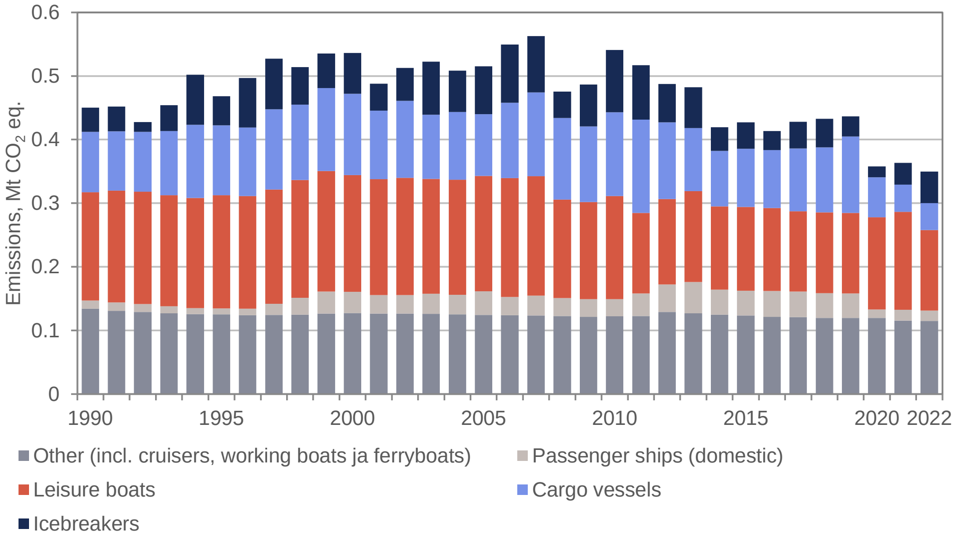


Figure 3.2-15 Emissions from domestic navigation by ship types (Mt CO_2 eq.)

The emissions from leisure boat increased little but steadily from 1990 to 2007. In 2008, two contemporaneous changes concerning leisure boating took place, namely a significant increase in fuel price and a change in legislation stating that all diesel driven boats had to use higher taxed diesel fuel instead of lower taxed gasoil. All this led up to a lower use of leisure boats. In 2021, the second pandemic year, the leisure boating continued to increase, while cargo vessel traffic continued to decrease. In 2022, the registration numbers of leisure boats began to stabilize towards the pre-pandemic levels. Before the crisis, emission from passenger ships showed a stable increasing trend for the whole time series. For cargo vessels the upward trend since 1990 changed to a downward trend in 2012 due to the prolonged economic downturn. The situation had stabilized to a lower level with a little increase, until the drop in 2020 due to the crisis. Depending on the ice conditions at the Baltic Sea, the fuel consumption of icebreakers can vary substantially as can be seen in Table 3.2-18.

Methods

Calculations of emissions from domestic navigation are made with the waterway traffic emission model MEERI, which is a part of the model for all transport modes LIPASTO. Calculation comprises emissions of CO_2, CH_4 and N_2O. The same model is also used for the calculation of SO_2, CO, NMVOC, NO_2 and PM emissions. Calculation methods are different depending on the vessel category. The methods are described below.

In the MEERI model, emissions are calculated by multiplying the amount of energy used (kWh) by the corresponding emission factors (g/kWh). However, emissions from icebreakers, working boats, cruisers and ferryboats are calculated by multiplying the amount of fuel used (kg/a) by emission factors (g/kg fuel). The methods for calculating emissions from domestic navigation are equivalent with the IPCC Tier 2 method.

The activity data of ships driving in shipping channels outside ports (km/a) are calculated using the number of port visits and the distances between the ports (km). The total energy use (kWh) is calculated for every ship type using the data on engine power (kW), engine load (%) and speed (km/h). There are nine different ship types in the model. Ships are further divided into different engine types (two-stroke and four-stroke). These are further divided into different emission levels, at the moment from Tier 0 to Tier 2. Ships have seven size categories. Emissions are calculated based on the fuels ships are using: Heavy fuel oil (HFO), HFO + scrubber, Marine diesel oil / Marine gas oil (MDO/MGO), Diesel and LNG.

For calculating emissions in ports, the time (h) of manoeuvring and berthing is determined. Using engine power (kW), engine load (%) and time (h) taken for manoeuvring and berthing, the total energy use in ports (kWh) is calculated for every ship type. Total emissions are obtained by multiplying the total energy use (kWh) of ships by the emission factors (g/kWh) of different engine types (2-stroke and 4-stroke and auxiliary engines) (g/kWh).

Icebreaker and ferryboat emissions are calculated using total fuel consumption (from operator statistics, icebreaker consumption from Arctia Shipping Oy and ferryboat consumption from Destia) and corresponding emission factors.

Leisure boat emission estimations are based on the use of energy (kWh) and corresponding emission factors (g/kWh). Energy use is calculated by boat category (six), engine type (four), average engine power class (10) (kW), engine load (%) and average operation time per year (h/a). Total emissions are calculated by multiplying total energy use (kWh) of engine types with corresponding emission factors (g/kWh).

Total emissions of working boats and cruisers are calculated by multiplying the total fuel use (kg/a) of boats by emission factors (g/kg fuel). Fuel consumption of these boats is calculated using the number of boats in different boat categories, engine power classes (kW) and average fuel consumption of a corresponding boat per year (kg/boat/a).

Calculation models are described in Appendix_3a at the end of Chapter 3.

Activity data

For the MEERI model, a detailed database on every ship visit in Finnish ports is obtained from the Finnish Transport Infrastructure Agency. The database includes data on ship type, age, size (GT = gross tonnage), engine power, speed, engine load, port, previous port, destination, nationality, and trip type (domestic/international). In the database the accurate and detailed ship movement division to domestic and international transportation enables the calculation of domestic transportation based on this data. Ferry traffic between Finland and Sweden is very frequent. Since 1999, all ferries have put in at the ports of Åland (which is an archipelago between Sweden and Finland belonging to Finland) but only a very small portion of passengers on these ferries are actually travelling between the mainland and Åland (e.g. 0.2% of all passengers using the Helsinki to Sweden lines travel between Helsinki and Åland in 2015). The method used to separate domestic ferry traffic from international traffic to Sweden is to define domestic ship kilometres according to the share of passengers travelling to the archipelago of Åland.

Data on total fuel consumption of icebreakers are obtained from Arctia Shipping Ltd.

Data on total fuel consumption of ferryboats and small ferries are acquired from road authorities (Ferryboats are used to transport road vehicles across narrow water straits on the public road network and small ferries are used for transport connections between islands in the Finnish Archipelago). The amount of fuels used by ship type are described in Table 3.2-18.

The number of working boats is obtained from different official organisations (e.g. customs, sea rescue).

The number of cruisers (sightseeing boats, etc.) comes from the Finnish Transport Infrastructure Agency.

The number of bigger leisure boats is received from the Transport Register in the Finnish Transport and Communications Agency (Traficom), the number of smaller boats (under 20 hp) is an estimation based on a thorough study made by VTT in 2004. The Transport Register data include information on the type of engine(s), engine power and age.

The database from the Finnish Transport Infrastructure Agency is analysed to produce power and speed classes for the ships. In addition, origin-destination matrices are produced using the data.

The Finnish Transport Infrastructure Agency’s database is very accurate and detailed. The Transport Register is the best available source for boats.

Amount of fuels used (TJ) taken from MEERI have been used as activity data to calculate CO_2 emissions of domestic navigation.

Liquefied natural gas (LNG) data (consumption, import and export) for energy balance are collected by Statistics Finland directly from the terminals, from the information on related fuel taxes and from point sources in energy and manufacturing industries. This, the best available data, is also used for LNG consumption in domestic and international navigation as activity data.

The Finnish Meteorological Institute has a world leading ship emission model STEAM, where the ship emission calculations are based on data from AIS (Automatic Identification System) on the entire Baltic Sea. The detailed results of this model have been used to estimate characteristics of ships, auxiliary engines, speeds and fuel types.

Table 3.2-18 Amount of fuels used in domestic navigation by ship type, PJ (MEERI)

	Leisure boats	Passenger ships (domestic)	Cruisers	Cargo vessels	Working boats	Ferryboats	Icebreakers
1990	2.25	0.16	0.10	1.19	1.42	0.27	0.48
1995	2.35	0.12	0.10	1.39	1.27	0.31	0.58
2000	2.43	0.42	0.15	1.63	1.26	0.29	0.82
2005	2.40	0.47	0.12	1.24	1.26	0.28	0.98
2010	2.24	0.34	0.12	1.69	1.27	0.27	1.28
2013	2.00	0.64	0.12	1.29	1.27	0.31	0.85
2014	1.84	0.52	0.12	1.15	1.27	0.28	0.49
2015	1.92	0.52	0.09	1.22	1.28	0.31	0.56
2016	1.84	0.54	0.08	1.23	1.27	0.29	0.40
2017	1.83	0.53	0.08	1.33	1.27	0.29	0.57
2018	1.84	0.52	0.08	1.38	1.27	0.27	0.60
2019	1.85	0.51	0.08	1.64	1.27	0.27	0.42
2020	2.12	0.18	0.08	0.88	1.27	0.27	0.23
2021	2.33	0.23	0.08	0.62	1.27	0.27	0.46
2022	1.92	0.22	0.08	0.60	1.26	0.27	0.67

Emission factors and other parameters

The CO_2 emission factors are presented in Table 3.2-4. They are based on national data which differ slightly from those in the 2006 IPCC Guidelines.

In 2021 bioshares of gasoline and diesel oil were 9.8% and 17.7% respectively (calculated from TJ). The bioshare of gasoil was 3.9% in 2022.

The CH_4 and N_2O emission factors for ships are the IPCC default values for ocean-going ships (2006 IPCC Guidelines).

The CH_4 and N_2O emission factors for working boats, cruisers, ferryboats and leisure boats are not available in the 2006 IPCC Guidelines or EMEP/EEA GB2019. Therefore CH_4 factors are based on EMEP/EEA GB2019 locomotive values and N_2O on EMEP/EEA GB2019 HDV values (see also description in Section 3.2.5.5).

Uncertainty assessment and time series’ consistency

Quantitative estimates of uncertainty are provided in Annex 2. The annex also documents assumptions made for the analysis. A description of the uncertainty analysis is included in Section 1.6.

The Monte Carlo simulation has been used to combine the uncertainties of each calculation parameter in order to get the total uncertainty of the category. A detailed description of the uncertainty analysis method has been presented in Monni & Syri (2003) and Monni (2004).

In Finland, fuels used in waterborne navigation include residual oil, gasoil and gasoline and starting from 2008, diesel oil. Diesel oil and gasoline are used mainly by leisure boats. The share of fuels sold for leisure boats is rather poorly known due to lack of consumer surveys. Use of LNG in navigation started in 2016.

Uncertainties in CH_4 and N_2O emission factors are larger than those in CO_2. These emissions vary depending on engine design and maintenance, and the start-ups and shutdowns of the engines are likely to affect emissions. Measurements done for diesel engines in ships have shown that variation in N_2O emissions is larger than in CH_4 emissions. Reduction of uncertainty in CH_4 and N_2O emission estimates would require more measurement data and more information on the use of engines in ships (frequency of start-ups, shutdowns, etc.).

Category-specific QA/QC and verification

The quality management process and the QA/QC plan for the whole inventory are presented in Section 1.5. The QA/QC plan for the transport sector includes the QC measures based on 2006 IPCC Guidelines. These measures are implemented every year during the transport sector inventory. Potential errors and inconsistencies are documented and corrections are made, if necessary. Also, a bilateral quality meeting is held annually between the inventory unit and the sectoral expert.

Statistics Finland crosschecks the fuel consumption data calculated within the MEERI model. Gasoline, gasoil and heavy fuel oil consumption data taken from MEERI are summed up in the ILMARI system with other user’s estimated consumption and the calculated totals are compared to total sales of these fuels.

The above-mentioned STEAM model results have been used to verify the emission calculation of the MEERI model. Also, ship emission experts from the Finnish Meteorological Institute (Dr. Jukka-Pekka Jalkanen, February 2014) have been used to verify the calculation methods of the MEERI model.

Category-specific recalculations

No recalculations were done in this category.

Category-specific planned improvements

No sector-specific improvements are planned.

3.2.5.7 Other transportation

Emission sources of other transportation include pipeline transport (fuel used in compressor units in natural gas transmission grid). The data is reported in 1.A.5a due to confidentiality.

The trend follows loosely total consumption of natural gas: until 2003 the consumption increases (also the grid is expanding), but from 2003 the consumption starts to decrease, thus emissions are also decreasing due to lower running time of compressors. A new compressor unit supporting the natural gas grid was started in 2005. This new unit is an internal combustion CHP-engine while all previous compressor units are gas turbines. These units have different CH_4 emission factors and natural gas consumption in different parts of the grid varies annually resulting interannual fluctuations in the CH_4 implied emissions factor.

Methods

Emission data from pipeline transportation are received from the YLVA system (Annex 6), ETS and partly directly from companies. The data are included in the ILMARI calculation system (Section 3.1.4).

Uncertainty assessment and time series’ consistency

Quantitative estimates of uncertainty are provided in Annex 2. The annex also documents assumptions made for the analysis. A description of the uncertainty analysis is included in Section 1.6.

The Monte Carlo simulation has been used to combine the uncertainties of each calculation parameter in order to get the total uncertainty of the category.

Category-specific QA/QC and verification

The quality management process and the QA/QC plan for the whole inventory are presented in Section 1.5. The QC measures based on 2006 IPCC Guidelines implemented in the sector other transportation are described in Section 3.2.4.4.

Category-specific recalculations

There were no category-specific recalculations done.

Category-specific planned improvements

There are no category-specific planned improvements.

3.2.5.8 Off-road vehicles and other machinery

Emissions of off-road vehicles and other machinery are allocated to CRF categories 1.A.2gvii Manufacturing industry and Construction, 1.A.4aii Commercial/Institutional, 1.A.4bii Residential, and 1.A.4cii Agriculture/Forestry/Fisheries. A complete list of machine types included in each CRF category is presented in Table 3.2-20. The emissions from off-road vehicles and other machinery amounted 2.4 Mt (CO_2 eq.) in 2022, they were 5% of total greenhouse gas emissions. In 2022 emissions were 2% lower than in 2021 and 1% than in 1990. Total emissions from by CRF categories in are presented in Mt CO_2 eq. in Table 3.2-19.

The economic depression at the beginning of the 1990s can be seen in the emission trend of off-road vehicles and other machinery as slightly decreasing emissions. After that, especially emissions from leisure time activities have increased (gasoline; ATV (all-terrain vehicle), snowmobiles), while emissions from business activities have decreased (gasoil/diesel). The economic depression that started in 2008 has lowered leisure time activity and hence the emissions in 2008. In 2010, the market began to recover and the use of these vehicles and other machinery increased. Market has been fairly stable including some fluctuation.

Table 3.2-19 Greenhouse gas emissions from the TYKO model by CRF categories (Mt CO_2 eq.)

	1990	1995	2000	2005	2010	2013	2014	2015	2016	2017	2018	2019	2020	2021	2022
Off-road vehicles and other machinery	**2.45**	**2.38**	**2.55**	**2.60**	**2.56**	**2.57**	**2.52**	**2.55**	**2.47**	**2.62**	**2.58**	**2.68**	**2.70**	**2.48**	**2.47**
1.A 2gvii Manufacturing and construction	0.94	0.93	1.02	1.07	1.16	1.12	1.08	1.02	0.95	1.10	1.13	1.13	1.17	1.14	1.13
1.A 4aii Commercial/Institutional	0.43	0.41	0.45	0.43	0.37	0.37	0.37	0.36	0.35	0.34	0.33	0.33	0.32	0.30	0.29
1.A 4bii Residential	0.14	0.16	0.18	0.19	0.19	0.21	0.21	0.20	0.20	0.19	0.18	0.18	0.17	0.17	0.16
1.A 4cii Agriculture/Forestry	0.94	0.88	0.91	0.91	0.84	0.88	0.86	0.96	0.97	0.99	0.94	1.05	1.04	0.87	0.89

Methods

The TYKO model from VTT Technical Research Centre of Finland Ltd. estimates emissions and energy consumption of non-road machinery, which are reported in the Finnish inventory under sectors 1.A.2gvii Manufacturing industry and Construction, 1.A.4aii Commercial/Institutional, 1.A.4bii Residential and forest machinery reported under 1.A.4cii Agriculture/Forestry/Fisheries. Emissions and energy consumption of agricultural machinery (reported also under 1.A.4cii Agriculture/Forestry/Fisheries) are based on TYKO model until 2014. From 2015 on information from other sources were used as additional sources to estimate revised fuel consumption in agriculture.

The machinery included in the TYKO model is divided into five main categories: Drivable diesel, drivable gasoline, moveable diesel, moveable gasoline and handheld gasoline, totalling 51 different machine types. The model calculates the machinery in the categories mentioned above. The division into different CRF source categories is made afterwards for the ILMARI system (see Section 3.1.4) by Statistics Finland. As the TYKO model calculates emissions of non-road machinery in Finland, this model description is valid for all source categories, except agriculture from 2015 on, that deal with machinery. Emissions by CRF subcategories are presented in Table 3.2-19.

Emissions are calculated separately for gasoline, diesel and LPG machinery. The main method is to sum up the product of the machinery population, engine power, load factor, activity hours and emission factors. The machinery population is based on the previous year's population, wastage factor and sales.

The calculation formula, which applies to all non-road machinery in the TYKO model, is presented in Appendix_3a at the end of Chapter 3.

The calculation method is in general consistent with the 2006 IPCC Guidelines (corresponds to the Tier 2 level method). The method is widely used, for example, in the U.S. EPA Nonroad model (1998) and CORINAIR Off-Road vehicle and Machines model (Andrias et al., 1994). The emission factors of CH_4 and N_2O are based on EMEP/EEA GB2019.

Activity data

In the TYKO model, data on machine population are based on national machinery registrations, sales figures and knowledge on the life expectancy of machinery. Activity data include yearly usage hours separately for each machine type. This basic machine-specific hourly data of certain machine types are adjusted according to the annual index on working hours, combined from civil engineering and mining and quarrying statistics. The activity data in TYKO are based on national and international research as well as national expert estimations. Starting from 2023 submission, some additional sources of information were used to produce a revised fuel consumption estimate for agricultural machinery from 2015 on. These new sources include fuel survey for agriculture (every 3 – 4 years) and annual profitability survey, both by Natural resources Institute Finland annual energy tax refund data and national accounts data.

Emission factors and other parameters

The CO_2 emission factors for off-road vehicles and other machinery are presented in Table 3.2-4. In 2022, the bioshare of gasoline was 9.8% and diesel oil 17.8% (calculated from TJ). The bioshare of gasoil was 3.9% in 2022.

The emission factors of CH_4 and N_2O are based on EMEP/EEA GB2019 (see also description in Section 3.2.5.5).

Uncertainty assessment and time series' consistency

Quantitative estimates of uncertainty are provided in Annex 2. The annex also documents assumptions made for the analysis. A description of the uncertainty analysis is included in Section 1.6.

The Monte Carlo simulation has been used to combine the uncertainties of each calculation parameter in order to get the total uncertainty of the category.

Category-specific QA/QC and verification

The quality management process and the QA/QC plan for the whole inventory are presented in Section 1.5. The QA/QC plan for the transport sector includes the QC measures based on 2006 IPCC Guidelines. These measures are implemented every year during the transport sector inventory. Potential errors and inconsistencies are documented and corrections are made, if necessary. Also, a bilateral quality meeting is held annually between the inventory unit and the sectoral expert.

Statistics Finland crosschecks the fuel consumption data calculated within the TYKO model. Gasoline, gasoil and LPG consumption data taken from TYKO are summed up in the ILMARI system with other user's estimated consumption and the calculated totals are compared to total sales of these fuels.

Table 3.2-20 Breakdown of different machine types in the TYKO model to CRF subcategories

CRF subcategory	Type of machine	Fuel
1.A 2gvii Off-road vehicles and other machinery (in Manufacturing and construction)	Cranes	diesel
	Bulldozers	diesel
	Rollers	diesel
	Wheel loaders	diesel
	Backhoe loaders	diesel
	Excavators, skid steer	diesel
	Excavators, rubber tire	diesel
	Tractors in industry	diesel
	Dumpers	diesel
	Telehandlers	diesel
	Generator sets	diesel, gasoline
	Compressors	diesel
	Compactors	diesel
	Plate compactors	diesel
	Other lifts	diesel
	Forklift	gasoline
	Forklift	gas
	Mini excavators, skid steer	diesel
	Other moveable machines	diesel
1.A 4aii Off-road vehicles and other machinery (in Commercial/Institutional)	Graders	diesel
	Maintenance tractors	diesel
	Skid steer loaders	diesel
	Forklifts	diesel
	ATV, 2-stroke, professional	gasoline
	ATV, 4-stroke, professional	diesel, gasoline
	Snowmobiles, 2-stroke professional	gasoline
	Snowmobiles, 4-stroke professional	gasoline
	Other drivable machines	diesel
1.A 4bii Off-road vehicles and other machinery (in Residential)	Other tractors	diesel
	Riding mowers	gasoline
	Lawn tractor	diesel
	Lawn movers, handheld	gasoline
	ATV, 2-stroke, leisure	gasoline
	ATV, 4-stroke, leisure	gasoline
	Snowmobiles, 2-stroke leisure	gasoline
	Snowmobiles, 4-stroke leisure	gasoline
	Other movable machines	gasoline
	Snow blowers	gasoline
	Chain saws, hobby	gasoline
	Trimmers	gasoline
	Other drivable	gasoline
	Other handheld machines	gasoline
1.A 4cii Off-road vehicles and other machinery (in Agriculture)	Farm tractors	diesel
	Combine harvesters	diesel
	Soil cultivator	gasoline
1.A 4cii Off-road vehicles and other machinery (in Forestry)	Forest harvesters	diesel
	Forwarders (forest tractors)	diesel
	Professional chain saws	gasoline
	Clearing saws	gasoline

Category-specific recalculations

No recalculations were done in this category.

Category-specific planned improvements

There are no category-specific planned improvements.

3.2.6 Other sectors and Other (CRF 1.A.4, CRF 1.A.5)

3.2.6.1 Category description

Subcategory CRF 1.A.4 includes emissions from stationary combustion and off-road vehicles and other machinery in commercial, institutional and residential sectors. In addition, emissions from heating of agricultural buildings, non-road machinery in agriculture and forestry, as well as fishing boats are included in this category. Subcategory CRF 1.A.5 includes emissions from non-specified consumption of fuels, military use and statistical corrections of fuel consumption. In addition, emissions from CRF 1.A.3e pipeline transport (fuel used in compressor units in natural gas transmission grid) are reported in 1.A.5a due to confidentiality reasons.

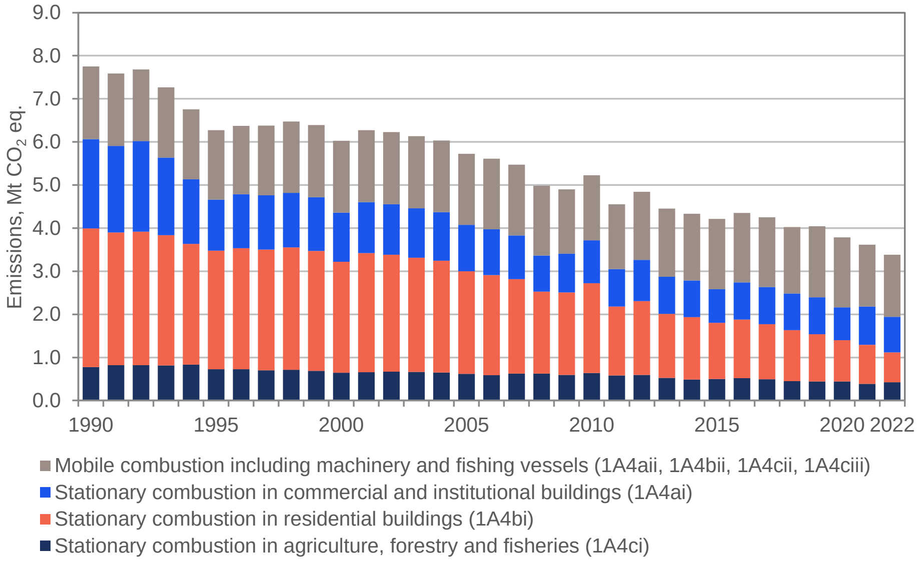


Figure 3.2-16 Emissions from stationary and mobile sources in the Other Sector (CRF 1.A.4)

The emissions of Other sectors (1.A.4) were 3.4 Mt and Other (1.A.5) 0.8 Mt (CO_2 eq.) in 2022. The emissions of these subcategories covered 13% of the energy sector's emissions and 9% of total greenhouse gas emissions of Finland. Emissions of these two sectors (1.A.4 and 1.A.5) have fallen by 2% since 2021 and 53% since 1990. The main reason for decrease from 1990 is the increased use of district and electric heating in residential, commercial and public buildings. The peak in 2010 heating energy consumption is due to exceptionally high heating degree days.

Emissions from stationary combustion (1.A.4ai, 1.A.4bi, 1.A.4ci) accounted for 57% of the emissions in the Other sectors (1.A.4) in 2022. 26% of sectors' emissions arose from the mobile combustion in agriculture and forestry (1.A.4cii), 24% from the stationary combustion in commercial and institutional buildings (1.A.4ai) and 20% from the stationary combustion in residential buildings (1.A.4bi).

Emissions from these sectors in 1990 to 2022 by subcategory are presented in Table 3.2-21.

Table 3.2-21 Emissions from sectors 1.A.4 Other sectors and 1.A.5 Other by subcategory (Mt CO_2)

	1990	1995	2000	2005	2010	2013	2014	2015	2016	2017	2018	2019	2020	2021	2022
CO_2															
4. Other sectors	**7.49**	**6.02**	**5.77**	**5.42**	**4.89**	**4.16**	**4.04**	**3.93**	**4.05**	**3.96**	**3.74**	**3.76**	**3.54**	**3.35**	**3.14**
a. Commercial and institutional	2.47	1.58	1.57	1.48	1.34	1.22	1.21	1.13	1.20	1.19	1.17	1.17	1.06	1.17	1.09
i. stationary	2.05	1.17	1.13	1.06	0.98	0.85	0.84	0.77	0.85	0.85	0.84	0.84	0.75	0.87	0.81
ii. mobile	0.42	0.41	0.44	0.42	0.36	0.37	0.37	0.36	0.35	0.34	0.33	0.32	0.31	0.29	0.28
b. Residential	3.15	2.69	2.53	2.31	1.98	1.44	1.39	1.26	1.29	1.20	1.11	1.02	0.91	0.84	0.64
i. stationary	3.01	2.54	2.36	2.13	1.80	1.24	1.19	1.07	1.10	1.02	0.94	0.85	0.75	0.68	0.48
ii. mobile	0.14	0.15	0.17	0.19	0.19	0.20	0.20	0.19	0.19	0.18	0.17	0.17	0.17	0.16	0.16
c. Agriculture, forestry and fisheries	1.87	1.74	1.67	1.63	1.57	1.50	1.44	1.55	1.56	1.56	1.46	1.57	1.57	1.34	1.40
i. stationary	0.77	0.72	0.63	0.61	0.63	0.51	0.48	0.49	0.51	0.48	0.44	0.43	0.43	0.37	0.42
ii-iii. mobile	1.10	1.03	1.04	1.02	0.95	0.99	0.96	1.06	1.06	1.08	1.02	1.14	1.13	0.96	0.98
5. Other	**1.13**	**1.32**	**1.40**	**1.49**	**1.20**	**1.01**	**0.95**	**0.96**	**0.89**	**0.93**	**0.73**	**0.76**	**0.69**	**0.69**	**0.83**
CH_4															
4. Other sectors	**0.18**	**0.19**	**0.19**	**0.23**	**0.26**	**0.23**	**0.23**	**0.22**	**0.24**	**0.24**	**0.23**	**0.23**	**0.19**	**0.21**	**0.19**
i. stationary	0.01	0.004	0.004	0.004	0.004	0.003	0.004	0.003	0.004	0.004	0.004	0.004	0.003	0.004	0.004
ii-iii. mobile	0.176	0.18	0.19	0.23	0.26	0.23	0.23	0.22	0.24	0.23	0.23	0.22	0.19	0.21	0.19
5. Other	**0.004**	**0.004**	**0.004**	**0.005**	**0.004**	**0.003**	**0.003**	**0.003**	**0.003**	**0.003**	**0.003**	**0.002**	**0.002**	**0.003**	**0.002**
N_2O															
4. Other sectors	**0.078**	**0.067**	**0.065**	**0.068**	**0.070**	**0.061**	**0.060**	**0.056**	**0.060**	**0.058**	**0.057**	**0.055**	**0.052**	**0.055**	**0.050**
i. stationary	0.016	0.010	0.009	0.009	0.009	0.007	0.007	0.007	0.007	0.007	0.007	0.007	0.007	0.008	0.007
ii-iii. mobile	0.062	0.057	0.056	0.059	0.062	0.053	0.053	0.049	0.052	0.051	0.049	0.048	0.045	0.047	0.043
5. Other	**0.008**	**0.009**	**0.009**	**0.009**	**0.007**	**0.006**	**0.006**	**0.006**	**0.006**	**0.006**	**0.004**	**0.005**	**0.004**	**0.004**	**0.005**

Table 3.2-22 Fuel consumption in CRF categories 1.A.4 and 1.A.5 (PJ)

		1990	1995	2000	2005	2010	2013	2014	2015	2016	2017	2018	2019	2020	2021	2022
Liquid fuels	Heavy fuel oil	19.2	7.5	6.7	7.0	5.4	3.6	3.1	3.1	2.7	2.7	2.3	1.9	1.7	1.9	1.7
	Light fuel oil	85.7	78.3	74.5	68.9	57.9	50.5	49.6	48.0	48.9	47.2	44.0	44.5	42.9	40.1	38.0
	LPG	2.0	2.4	2.8	3.0	3.4	3.3	3.0	3.2	2.6	3.0	3.6	3.8	3.9	4.4	6.0
	Other liquid fuels	3.5	4.5	5.2	5.9	6.0	5.6	5.1	5.0	5.5	5.2	4.7	5.1	4.9	4.0	4.0
Solid fuels	Hard coal	0.52	0.29	0.21	0.17	0.19	0.11	0.11	0.11	0.11	0.09	0.11	0.09	0.08	0.10	0.08
Gaseous fuels	Natural gas and other gaseous fuels	3.1	5.8	7.6	8.1	8.1	6.5	6.3	6.5	6.3	7.4	4.6	4.7	3.7	4.0	4.2
Biomass	Woodfuels and other biofuels	45.3	45.6	46.8	59.4	71.6	63.9	64.0	60.0	65.4	64.6	63.7	62.6	57.3	65.8	60.5
Peat	Peat	1.4	1.0	1.3	1.6	2.6	2.1	2.0	2.0	2.3	2.3	2.3	2.3	1.3	1.5	1.4
Other	Mixed fuels and waste	0.003	0.001	0.001	0.0003	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO

3.2.6.2 Methodological issues

Methods

Emissions from stationary sources of subcategories 1.A.4 and 1.A.5 are calculated within the ILMARI system, which has been described in Section 3.1.4,

Table 3.**1-6** and Figure 3.1-5. Calculation of the greenhouse gas emissions from stationary sources in 1.A.4 and 1.A.5 is mostly based on a Tier 2 method using fuel consumption data and fuel-specific emission factors. Emission factors are either country-specific or default depending on a fuel. There are parts of the calculation, which are more likely Tier 3 and some parts Tier 1, but in general Tier 2 seems to be the best corresponding choice.

Emissions from off-road vehicles and other machinery, which are reported in 1.A.4aii and 1.A.4bii are calculated with the TYKO model of VTT Technical Research Centre of Finland Ltd. Calculation method for agricultural off-road vehicles and other machinery (1.A.4cii) is described in Section 3.2.5.8. Emissions from fishing (1.A.4ciii) derive from the MEERI model of VTT (See descriptions in Section 3.2.5.6). Emission data from pipeline transportation (1.A.3e) are received from the YLVA system, ETS and partly directly from companies (See descriptions in Section 3.2.5.7).

Activity data

The activity data for stationary sources of category CRF 1.A.4 are taken from annual energy statistics. Only a small part of the emissions is based on actual installation bottom-up data (depending on fuel type). The fuel consumption data for CRF 1.A.4 are presented in Table 3.2-22. It covers fuels used for the heating of commercial, institutional and residential buildings, which are estimated by the space heating estimation model (Raklam) maintained by Statistics Finland. Fuel consumption data are estimated using building stock statistics, average specific consumption ($MJ/m^3/a$) and annual heating degree days.

The Raklam model takes into account secondary heating systems in residential buildings, which are increasingly popular in Finland. For example, the number of air-to-air heat pumps has grown rapidly in the last few years; they are used as a secondary heat source, substituting fuel or electricity consumption of the primary heating system.

Activity data for off-road vehicles and other machinery in residential and commercial/institutional sectors are taken from the TYKO model of VTT. Activity data for off-road vehicles and other machinery in agriculture and forestry is based on TYKO model until 2014. From 2015 to 2021 information also from other sources were used to estimate the fuel consumption (See descriptions in Section 3.2.5.8). Activity data for fishing derive from the MEERI model of VTT (See descriptions in Section 3.2.5.6.

Activity data for category CRF 1.A.5 include military fuel consumption, which are partly based on estimates. The category also includes residuals of certain commercially traded fuels (light fuel oil, heavy fuel oil, natural gas and LPG). Statistical corrections are taken into account in these residuals.

Emission factors

The CO_2 emission factors are presented in Table 3.2-4.

In 2022 bioshares of gasoline and diesel oil were 9.8% and 17.8% respectively (calculated from TJ). The bioshare of gasoil was 3.9% in 2022 both in off-road vehicles and machinery and heating.

The other emission factors used are partly IPCC default from 2006 and 1996 guidelines and partly based on national sources (Table 3.2-23).

Table 3.2-23 Emission factors of small combustion in the ILMARI calculation system

Small combustion boilers < 1 MW	**CH_4 kg/TJ**	**N_2O kg/TJ**
Oil	10 [b, a]	2 [b]
Coal, residential buildings	300 [a]	4 [b]
Natural gas	3 [b]	1 [b]
Peat	50 [b]	4 [e]
Wood, commercial buildings and agriculture	3 [c, d]	1.73-1.8 [c, d]
Wood, residential buildings	129-146 [c, d]	2.08-2.16 [c, d]

References:, [a.] 2006 IPCC Guidelines (Table 2.4), [b.] Boström (1994), [c.] Tsupari et al. (2005, 2006), [d.] Savolahti et al. (2019), Syke 2022, [e] 1996 IPCC Guidelines (Table 1–7)

As described earlier in Section 3.2.4.2 (subtitle: “Factors affecting implied emission factors”), annual variation can be seen in implied emission factors, as there are changes in the shares of different fuel/technology combinations. This is true also in subcategories 1.A.4 and 1.A.5, because part of the activity data is plant-specific; thus there are different emission factors for different type of plants (fuel/technology combinations). Especially this involves peat and wood fired boilers, which are typical in Finland in these subsectors.

3.2.6.3 Uncertainty assessment and time series' consistency

Quantitative estimates of uncertainty are provided in Annex 2. The annex also documents assumptions made for the analysis. A description of the uncertainty analysis is included in Section 1.6.

Uncertainties in activity data were based on energy statistics expert estimates.

In general, the uncertainties in subcategories 1.A.4 and 1.A.5 are clearly higher (±10% to 50% depending on a sector and fuel) than in other subcategories of the Energy sector. In the case of natural gas, the uncertainties are slightly lower, ±5% to 15%.

Uncertainties in emission factors for CH_4 and N_2O are high, because these emissions vary largely between different boilers, furnaces, etc. Especially in biomass combustion in small-scale applications, CH_4 emissions depend much on the fuel and furnace used. There is also very little information available about the emissions from these sources. International data cannot be applied directly, because the design of furnaces, fuel used and the means of combustion vary. To decrease uncertainty, more measurement data would be needed from different types of furnaces. In addition, more data on currently used furnaces and small-scale boilers, and about the amount and type of fuels used, would be needed. Results from a research study done by VTT in 2005 are used as a data source for CH_4 and N_2O emission factors, as well as uncertainties of these emission factors. Emission factors for small scale wood combustion are taken from Syke model (Syke 2022), which includes estimated annual shares of different furnaces.

The Monte Carlo simulation has been used to combine the uncertainties of each calculation parameter in order to get the total uncertainty of the category.

The consistency of time series of stationary sources of subcategory 1.A.4 is fairly good. The space-heating model (Raklam) of Statistics Finland includes years starting from 1995. Prior to that year, fuels for different subsectors of space heating are based on estimated disaggregation. As a result of a model revision, there is a break in the time series of the residential heating model results between 2007 and 2008. This affects mostly electricity consumption for heating. Heating oil consumption has been corrected for the GHG inventory by interpolation between 2005 and 2008.

Category 1.A.5 includes residuals and statistical corrections, which reflect the problems in the energy balance in some years. Some fuel consumption figures have been adjusted to prevent negative consumption figures, as well as to correct too big annual changes in this category's total emissions. A part of these adjustments may reflect not-so-well-known customers' annual stock changes. All and all, it can be said that the consistency of the original data in this subcategory is not as good as in other subcategories of the energy sector, but it has been improved using the adjustments mentioned above. These adjustments are checked annually by cumulative sums to prevent systematic continuous over or under estimations.

3.2.6.4 Category-specific QA/QC and verification

There are numerous automatic and manual QC procedures used in the ILMARI system (see Section 3.2.4.4).

Each year, the latest inventory calculations (activity data and CO_2 emissions) are crosschecked against the national energy balance (Annex 3). This reference calculation is based on the energy balance, showing activity data (PJ) and CO_2 emissions.

The allocation of different working machine types was checked against the CLRTAP reporting in order to improve consistency between the greenhouse gas and air pollutant inventory for the 2020 submission.

3.2.6.5 Category-specific recalculations

No recalculations for 1990 nor 2005 were performed. For 2021 following recalculations were performed:

Gasoil used for agricultural dryers and plant residues used for heating were updated resulting recalculations in 1.A.4ci (-50 kt CO_2 eq. in 2021). This also results allocation changes between 1.A.4 and 1.A.5 subcategory.

Total use of liquid fuels, mainly gasoil was updated to correspond data in energy statistics. This change reflected as a recalculation in category 1.A.5, which include residuals of gasoil (-107 kt CO_2 eq. in 2021).

Corrections in other categories' fuel data are reflected as a recalculation in this category (CRF 1.A.5), which includes residuals of certain fuels. These corrections include minor corrections in the point sources' data (activity, combustion technology or allocation) to remove inconsistencies in plant level time series. In most cases, the reasons for these corrections are updates in the latest years' source data or minor, previously undetected, errors in the older data.

3.2.6.6 Category-specific planned improvements

There are no category-specific planned improvements.

3.3 Fugitive emissions from solid fuels and oil and natural gas and other emissions from energy production (CRF 1.B)

3.3.1 Fugitive emissions from solid fuels (CRF 1.B.1)

There are no emissions reported under this sector in Finland. Emissions from peat production are reported in the LULUCF sector (category Wetlands, CRF 4.D) consistent with the *2006 IPCC Guidelines* (see Section 6.7).

There are no coal mines in Finland.

3.3.2 Fugitive emissions from oil and natural gas (CRF 1.B.2)

3.3.2.1 Category description

This category includes CO_2, CH_4 and N_2O emissions from flaring at oil refineries and in the petrochemical industry and at LNG terminals from 2016 on, fugitive methane emissions from oil refining and methane emissions from natural gas processing, transmission and distribution. Reasons behind the emission trends are addressed in Section 3.1.2.2. Fugitive CO_2 emissions from natural gas transmission and distribution are estimated to be insignificant (see Section 3.3.2.2 and Section 1.7.5).

Methane emissions from oil refining result from evaporation during the refining and storage of oil and from processing of liquified natural gas (LNG). Some of the emissions from gas transmission are caused by the normal running of older compressor stations in the transmission network. Another source of emissions in transmission is the emptying of pipelines during maintenance breaks and extension work. The emissions of distribution originate from leaks from valves in certain old pipeline types.

Flaring is a part of the safety system in refineries and the petrochemical industry and in a normal situation gases are recovered, not flared. Carbon dioxide from flaring is emitted in emergency situations when pressure in any production equipment has risen over the permissible pressure and, therefore, gases are burned in flares. Flaring is not conditional on output and the attempt is to minimise the amount of it and, therefore, flaring it is always related to problems in the process and it is more cost effective to generate energy or products to sell. Some of the refinery plants have been modernised during the time series.

There are no emissions from venting, since all process gases are directed to a fuel gas system during normal function and burned in different process heaters and boilers and reported as Fuel Combustion in the Energy sector. There are, however, other types of fugitive or venting emissions, which are reported as NMVOC emissions in '1.B.2'. These include, for example, venting of oil storages, drainage systems, etc.

In 2022, the combined fugitive and flaring emissions from oil refining (and flaring emissions from the petrochemical industry), and emissions of natural gas transmission and distribution totalled 0.09 Mt CO_2 eq. This is about 0.2% of Finland's total emissions. Emissions decreased by 2% compared to 2021 and they are 27% lower than in 1990.

Other NMVOC emissions originate from storage of chemicals at the refineries, road traffic evaporative emissions from cars, the gasoline distribution network and refuelling of cars, ships and aircrafts and natural gas transmission. The indirect CO_2 emissions from NMVOCs and CH_4 are reported separately and aggregated as one category in the national totals (see Chapter 9).

There is no exploration or production of oil or natural gas in Finland. Also transport of crude oil in pipelines does not take place in Finland. All our crude oil is shipped to the refinery ports and used nearby.

Table 3.3-1 Fugitive emissions from oil and gas (Mt CO_2 eq.)

	1990	1995	2000	2005	2010	2013	2014	2015	2016	2017	2018	2019	2020	2021	2022
CO_2															
1.B.2c Flaring	0.111	0.075	0.058	0.070	0.096	0.079	0.084	0.109	0.104	0.147	0.091	0.065	0.076	0.068	0.065
1.B.2d Distribution of town gas	0.001	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO
CH_4															
1.B.2a Oil refining	0.007	0.008	0.009	0.009	0.009	0.010	0.010	0.009	0.010	0.010	0.010	0.010	0.009	0.007	0.008
1.B.2b* Natural gas	0.005	0.096	0.061	0.072	0.041	0.034	0.026	0.032	0.027	0.024	0.023	0.020	0.015	0.018	0.017
1.B.2c Flaring	0.00006	0.00004	0.00003	0.00004	0.00005	0.00006	0.00004	0.00006	0.00005	0.00007	0.00005	0.00003	0.00004	0.00004	0.00004
1.B.2d Distribution of town gas	0.001	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO
N_2O															
1.B.2c* Flaring	0.0011	0.0007	0.0006	0.0007	0.0009	0.0011	0.0008	0.0011	0.0010	0.0014	0.0009	0.0006	0.0007	0.0007	0.0007
Total Mt CO_2 eq.	**0.13**	**0.18**	**0.13**	**0.15**	**0.15**	**0.12**	**0.12**	**0.15**	**0.14**	**0.18**	**0.12**	**0.10**	**0.10**	**0.09**	**0.09**

* CH_4 emissions from 1B2b Natural gas includes also emissions from LNG processing for 2010-2017

3.3.2.2 Methodological issues

Methods

Oil refining (CRF 1.B.2a)

The fugitive methane emissions from the refining and storage of oil have been calculated on the basis of 2006 IPCC Guidelines using the default emission factors for oil refining and data from Energy Statistics on oil refining activities.

Flaring (CRF 1.B.2c)

Flaring takes place at oil refineries and in the petrochemical industry and since 2016 also in LNG terminals. Estimates of carbon dioxide emissions from flaring are for the recent years calculated using data from the EU ETS and earlier the YLVA (formerly VAHTI) system and fuel-specific emission factors in the ILMARI calculation system.

Natural gas processing and storage (CRF 1.B.2b3)

Estimates of methane emissions from liquefied natural gas (LNG) processing and storage are reported by the company to the YLVA system. A company informed that the LNG processing has been ended in September 2017 (Gasum, 2018) and therefore there are no emissions from LNG processing since 2018. This category includes also fugitive CH_4 emissions in LNG terminals.

Natural gas transmission (CRF 1.B.2b4)

Fugitive CH_4 emissions from gas transmission are calculated by Gasgrid Oy (Tolonen M, 2023). Calculations are based on measurements for 1996 to 2022. Emissions of earlier years have been estimated with Gasum Oy (Slioor S, 2004) at Statistics Finland based on the volume of transmitted gas and knowledge of malfunctions and repairing works resulting in gas releases. According to Gasgrid Oy, the data of composition of natural gas used in Finland has only 0.5% by volume CO_2, therefore, these emissions are estimated to be insignificant (see Section 1.7.5 and Tolonen M, 2022).

Distribution (CRF 1.B.2b5)

Methane emissions from natural gas distribution are based on measurements (leakage in the distribution network) for the years since 1996. For the years 1996 to 2015 the measurements were made by Gasum Oy and since 2015 they have been made by Auris Kaasunjakelu Oy (Harju T, 2023). For the earlier years (1991 to 1995), the emissions are rough estimates based on the volume of total distributed gas. The amount of distributed gas has increased and CH_4 emissions decreased due to less leakage in the distribution network, which led to a reduction of the IEF, see Section 3.1.2.2.

Since 1974 natural gas has been distributed in “newer parts” of pipeline in the Southern Finland. These pipes are made of polyethylene and no leaks nor emissions are expected (Slioor S, 2004).

The distribution of town gas (LPG, butane) started in 1973 and it continued until 1993. Town gas was distributed only in Helsinki area. Distribution of town gas was gradually replaced by natural gas between 1991 and 1994. Since 1994, only natural gas was distributed in Helsinki area. This pipeline in Helsinki area is made of steel, cast iron and polyethylene and some leakage is expected to happen.

Town gas contained greenhouse gases, 1% methane and 20% carbon dioxide (Neste, 1993), and these emissions are included in the inventory for years 1990 to 1993. Methane and carbon dioxide emissions are calculated using leakage of town gas in the distribution network and percentage of them in town gas.

Emission factors and other parameters

Emission factors for calculating emissions from the refining and storage of oil are based on the default factor given in 2006 IPCC Guidelines, since country-specific factors are not available. The IPCC Guidelines offer a wide range for emission factors. Due to lack of knowledge on the applicability of the factors to Finnish circumstances, the mean value of the factors is used.

Plant and fuel-specific emission factors are used for calculating emissions from flaring. They can be found in Table 3.2-4. Flaring consists of refinery gases and a very small amounts of LPG, natural gas and gasoil, used in pilot flame, and from 2016 also LNG.

Percentage of methane and carbon dioxide in town gas are used to calculate emissions of town gas distribution (1% methane and 20% carbon dioxide).

Activity data

Activity data for oil refining are taken from Energy Statistics, indicating the quantity of refined oil.

The amounts of flared fuels are reported to the YLVA system, and these data are used as activity data in calculating emissions from flaring also ETS data have been used in the most cases from 2005. Activity data are received from refineries and petrochemical plants, including point source data for each plant either by plant or by each flare. Flaring includes both the pilot flame and the burning of process gases released in start-ups, shutdowns and malfunctions.

No activity data are used in calculating the emissions from gas transmission and distribution because estimates are based on measurements and expert estimates. However, the quantity of gas transmitted and distributed is reported as background information in the CRF tables. For the 2023 submission data on transmitted natural gas were harmonised with the Energy Statistics for the whole time series.

Town gas sales has been used as activity data. The average of leakage percentages (20%) of natural gas has been used to estimate leakage of town gas for years 1990 to 1993.

3.3.2.3 Uncertainty assessment and time series' consistency

Quantitative estimates of uncertainty are provided in Annex 2. The annex also documents assumptions made for the analysis. A description of the review and update of uncertainty analysis is included in Section 1.6.

Sources of uncertainty for estimates concerning 2022 are:
Oil refining: • Accuracy of activity data, which introduces only a small uncertainty
• Accuracy of default emission factors, which introduces a very large uncertainty
Uncertainty in emissions from oil refining was estimated to be 90%.

Gas transmission and distribution:
• Accuracy of measurements, which introduces only a small uncertainty.
Uncertainty in emissions from gas transmission was estimated to be ±5% and uncertainty in emissions from gas distribution ±3%.

Flaring: • Uncertainties as in the ILMARI system, see Section 3.2.4.3.

Transmission of gas: the figures concerning 1990 to 1995 are not based on measurements; instead, they are estimated by experts within the industry.

For gas distribution the emission estimates of 1991 to 1995 are also more uncertain than the measurement-based estimates of later years.

The methane emissions from oil refining and storage are calculated with the same method for the whole time series. In addition, the accuracy of activity data for oil refining and storage remains constant over all inventory years.

Emission estimations for all subcategories under Fugitive emissions from fuels are calculated using the same methodology for the whole time series.

3.3.2.4 Category-specific QA/QC and verification

The quality objectives and the QA/QC plan for the Finnish greenhouse gas inventory at the national inventory level are presented in Section 1.5. The QC procedures are performed according to the QA/QC plan in order to attain these quality objectives. In 2024 a quality meeting was held between the inventory unit and the sectoral expert.

In the calculation of fugitive methane emissions from oil refining and methane emissions from gas transmission and distribution, several general inventory quality control procedures have been done as mentioned in 2006 IPCC Guidelines (Chapter 1.6, Table 6.1). Some of the checks are performed annually, like comparing with previous emissions of the subcategory of the calculated emissions and ensuring that there are no transcription errors in calculations and some when the calculation method has been developed.

Quality control procedures, which are mentioned in Section 3.2.4 are also used in the calculation of emissions from flaring.

3.3.2.5 Category-specific recalculations

Point source emissions in 1.B.2a were corrected for 2021 (-2.5 kt CO_2 eq.). Two LNG storage were included to the inventory, CH_4 emissions were increased 2017 to 2021 by 0.6 kt CO_2 eq./a.

3.3.2.6 Category-specific planned improvements

No improvements are planned.

3.4 CO_2 transport and storage (CRF 1.C)

3.4.1 CO_2 capture, transfer and storage in PCC

3.4.1.1 Category description

In Finland, at this moment two pulp and paper mills and one paper mill are capturing and directing a part of their fuel combustion-based CO_2 emissions to PCC (Precipitated Calcium Carbonate) plants nearby via pipelines between CO_2 producer and user. There used to be six pulp and paper mills in Finland at the beginning of the 2000s, but since that three plants have ceased operation in 2011, 2019 and 2021. The CO_2 capture in pulp production takes place in the lime kiln and in paper production in associated industrial power plants. There are also two hydrogen producing plants, which capture their process-based CO_2 emissions and transport part of it to PCC producing plants. The first PCC plant using transferred CO_2 in Finland started operating in 1993.

In the Finnish system the CO_2 producers, which transfer their CO_2 to PCC production, report their emissions as total CO_2 emissions minus CO_2 emissions calculated from the amount of PCC produced. The calculation process is similar for both pulp and paper mills as well for hydrogen plants. This way any losses during the capture, transfer and production are accounted for as only the amount of CO_2 that has been converted to PCC is deducted from the total emissions. Therefore, fugitive emissions from pipeline transport (1.C.1.a) are reported as IE in the inventory.

PCC is widely used in different kind of paper and paperboard as filling or coating material. PCC in paper and paperboard will form a long-term storage for the captured CO_2 except in cases where the paper or sludge from recycled paper is combusted. The emissions from combustion are taken into account separately under relevant categories in the energy sector (in emissions factors (fossil/biological part) of paper or sludge) and in the Industrial Processes and Product use (2.A.4d Other; limestone containing sludge). Long-term storage is the main criteria used for inclusion of CO_2 capture and storage in the inventory.

3.4.1.2 Methodological issues

In the lime kilns of the pulp production process lime mud (basically $CaCO_3$) is burned back to lime ($CaCO_3$ --> $CaO + CO_2$) and after that, the lime is reused in causticising. The lime kiln has been chosen for the CO_2 source of PCC production because an excess amount of CO_2 is produced in the process. This is captured and transferred to the PCC plant and used in the production of PCC. In addition, a part of the CO_2 comes from fuels used in the kilns.

In hydrogen production hydrocarbons react with water and CO_2 and hydrogen are produced (see Section 4.3.6.2). The formed CO_2 is captured, a small part of it is bottled and transported to PCC plants. Most of the CO_2 captured from hydrogen production is used in other applications from which the captured CO_2 is released on short term and this part is therefore not deducted from emissions reported for hydrogen production. For example, the CO_2 is widely used in food processing for cooling, preservation and pH control. It is also used to blanket chemicals, control of pH in water treatment, as a shield gas in metal welding, to stimulate biological growth and as a fire-extinguishing agent.

The amount of CO_2 transferred to PCC production is estimated based on the amount of PCC produced, because the pulp and paper plants do not measure their CO_2 emissions or the amount of CO_2 captured. This way any losses during the capture, transfer and production are accounted for.

Finland exports more than 90% of paper and paperboard. In addition, the PCC included in these products is exported. Possible emissions from PCC in exported paper are not taken into account, as these emissions are not occurring within the national borders of Finland.

$CO_{2\,\textit{captured and stored}} = PCC_{\textit{production}} * [CO_2]/[CaCO_3]$

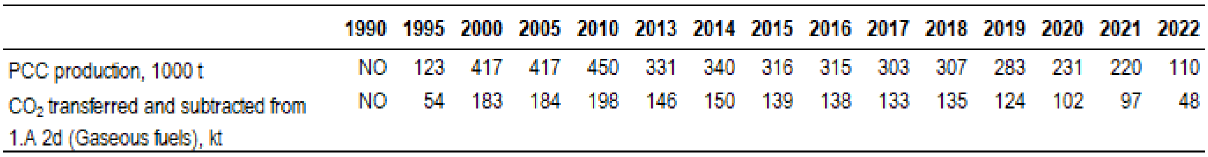
The calculated amount of stored CO_2 is subtracted from gaseous fuels in subcategory 1.A.2d as a major part of transferred CO_2 is from combustion of natural gas. Also the amount of CO_2 from hydrogen production is included in the same subcategory due to confidentiality reasons. The calculations are presented in more detail in Appendix_3c. These are in accordance with the guidance for reporting given in the 2006 IPCC Guidelines.

The characteristics of the captured CO_2 were clarified from the calculation of the emissions of plants capturing CO_2 for PCC production.

- Before 2011, in 2013 and after 2017, part of the fuel used in the plants capturing CO_2 from lime kilns in pulp production is of biogenic origin, the biogenic share of total transferred CO_2 is less than 30%. Finland deducts all captured CO_2 from the emissions in accordance with the guidance in the 2006 IPCC Guidelines, which states that once captured, there is no differentiated treatment between biogenic carbon and fossil carbon.
- In the paper mills, one of the power plants capturing CO_2 has used exclusively fossil fuels for the whole time series. The other power plant has used fossil fuels until 2001 and thereafter the share of biofuels was about 60%. The operation of this power plant ended in 2013.
- In hydrogen producing plants the hydrogen has been produced from natural gas (fossil fuel)
- Since 2012 one pulp plant which is transferring a part of its CO_2 emissions to PCC production is not included in the EU ETS. In 2018, the same plant started using only biomass in its lime kiln.

Statistics Finland has calculated the share of fossil CO_2 used in PCC production on the above-described plant-specific information since 2000 (plant-level PCC production data were available only since 2000). For plants using fossil and biomass fuels, the share was calculated assuming that CO_2 captured would be proportional to the amount of fossil and biomass fuels used at a plant. Of the total transferred CO_2 amount, the average share of fossil CO_2 is 86% for 2000 to 2011. In 2012, 2014, 2015 and 2016, all transferred CO_2 was of fossil origin. In 2013, and since 2017 a bigger part of transferred CO_2 has been of biogenic origin (since 2017 the average of share of biogenic origin has been about 20%). More details can be found in Appendix_3c.

Table 3.4-1 PCC production and transferred CO_2



	1990	1995	2000	2005	2010	2013	2014	2015	2016	2017	2018	2019	2020	2021	2022
PCC production, 1000 t	NO	123	417	417	450	331	340	316	315	303	307	283	231	220	110
CO_2 transferred and subtracted from 1.A 2d (Gaseous fuels), kt	NO	54	183	184	198	146	150	139	138	133	135	124	102	97	48

A small amount of carbonate (either PCC or other carbonates) based CO_2 is released in the combustion of recycling sludge as well as part of MSW or REF (mostly in subsectors 1.A.1a, 1.A.2d and 1.A.2g). These emissions are taken into account in the Energy sector in the corresponding emission factors. When deinking sludge is combusted, the CO_2 emissions from carbonates included in PCC are reported in 2.A.4d Other Process Uses of Carbonates. The emissions are reported under industrial processes because the fuel (deinking sludge) does not contain fossil energy but the fossil CO_2 emissions are generated from PCC. No distinction is made whether the carbonates originate from a process using fossil or biomass-based CO_2 when the CO_2 emissions from combustion of PCC are reported.

3.4.1.3 Category-specific QA/QC and verification

Statistics Finland clarified the characteristics of CO_2 storage in PCC in 2008 through literature and discussions with experts. According to the Finnish experts[20], PCC in paper and recycled sludge disposed in landfills or used in landscaping constitute a long-term storage for CO_2. Support for the long-term nature of storage when the recycled sludge is disposed in landfills or used in landscaping is also given in the following references: Appelo and Postma, 1996, Garrels and Christ, 1965. However, CO_2 will be released when PCC containing paper or sludge is burned.

The PCC production data have been crosschecked with other data sources. Statistics Finland has collected plant-specific data on the production amounts by PCC plant for the relevant years from the YLVA (formerly

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[20] Prof. Eero Hanski, University of Oulu, prof. Olli Dahl, Helsinki University of Technology and Docent Kauko Kujala, University of Oulu (see Appendix_3d).

VAHTI) system (national environmental permit registry), from PCC plants and the production statistics (plant-specific data from Statistics Finland’s manufacturing industry surveys). The data have also been crosschecked with the amount of captured and transferred CO_2 reported under the EU ETS. These data exist since 2005 and include the captured and transferred amount of CO_2 by plant.

The differences in the PCC production data from the various sources have been very small. The emission data reported to EU ETS 2008 to 2012 have been approximately 94% of the amount calculated and reported by Statistics Finland in the greenhouse gas inventory. The amount reported to EU ETS 2013 to 2022 is about 99% of the data reported to the greenhouse gas.

3.4.1.4 Category-specific recalculations

There were no category-specific recalculations done.

3.4.1.5 Category-specific planned improvements

No planned improvements.

Appendix_3a

The formulas used in calculating yearly emissions from the transport sector (1.A 3)

Road transportation LIISA model

Formula for CO_2 emissions in the LIISA model:

$$E^{CO2} = \sum_{f=1}^{N_f} \left(S_f - O_f\right) e^{CO2}$$

E^{CO2}	total CO_2 emissions
f	fuel type
N^f	number of fuel types
S	total sales of fuel
O	total use of fuel for other purposes than road traffic
e^{CO2}	CO_2 emission factor

Formula for N_2O and CH_4 emission estimation in the LIISA model:

$$E^c = \sum_{r=1}^{6}\sum_{v=1}^{6}\sum_{l=1}^{5}\sum_{x=1}^{6}\sum_{f=1}^{6}\sum_{y=1}^{7}\left(M_{r,v,l,x,f,y}\left(e^{c,h}_{r,v,l,x,f,y}+e^{c,s}_{r,v,l,x,f,y}\right)\right)$$

E^c	total emissions of compound c
c	compound
r	road type (6 types)
v	speed limit class (6 classes)
l	type of vehicle (5 types)
x	type of driving power (6 types)
f	fuel type (6 types)
y	emission standard level (Euro) (7 classes)
M	kilometrage (given by road type, speed limit class and main type of vehicle, and divided to vehicle subclasses using a car fleet model called ALIISA)
$e^{c,h}$	emission factor for hot driving
$e^{c,s}$	emission factor for cold start-ups

Railway transportation RAILI model

Formula for diesel trains in the RAILI model (for years 1990 to 2018):

$$E^c = \sum_{x=1}^{2}\left(\left(\sum_{l=1}^{4}\sum_{w=1}^{10} d_{x,l,w} f^{d}_{x,l,w}\right) g_x e^{c,f}_x + d_x\left(f^h_x e^{c,h} + f^a_x e^{c,a}\right) + \left(\sum_{r=1}^{N}\sum_{l=1}^{4} t_{x,l,r} f^t_{x,l}\right) e^{c,f}_x + \left(\sum_{l=1}^{4} k_l f^k_l\right) e^{c,f}_x\right)$$

E^c	total emissions of compound c
c	compound
x	train type: person/freight train
l	type of locomotive (4 types)
w	train weight class (10 classes)

d	gross tonne kilometre
g	a factor for extra fuel consumption of non-line driving *
r	rail yard
N	number of rail yards
t	shunting time
k	locomotive kilometre
f^d	specific fuel consumption per gross tonne kilometre
f^t	specific fuel consumption per hour
f^h	specific fuel consumption of heating per gross tonne kilometre
f^a	specific fuel consumption of aggregate per gross tonne kilometre
f^k	specific fuel consumption per locomotive kilometre
$e^{c,f}$	emission factor of compound c per fuel used
$e^{c,h}$	emission factor of compound c per fuel used for wagon heating
$e^{c,a}$	emission factor of compound c per fuel used for aggregates
*	mobilisation time of the fleet, preparation and finishing times and extra transfer of the fleet

Civil navigation MEERI model

Formula for all ships in the MEERI model (icebreakers excluded):

$$E^c = \sum_{x=1}^{2}\sum_{l=1}^{9}\sum_{w=1}^{7}\left(\frac{\sum_{i=1}^{N_{l,w}} d_{l,w,i}}{v_{l,w}^{a}} g_{l,x}^{d} p_{l,w,x}^{a} \sum_{y=1}^{10}\sum_{f=1}^{5}\left(r_{x,y} s_{x,f} e_{x,l,w,y,f}^{c,d}\right) + N_{l,w}\left(t_{l,w}^{m} g_{l,x}^{m} p_{l,w,x}^{a} \sum_{y=1}^{10}\sum_{f=1}^{5}\left(r_{x,y} s_{x,f} e_{x,l,w,y,f}^{c,m}\right) + t_{l,w}^{b} g_{l,x}^{b} p_{l,w,x}^{a} \sum_{y=1}^{10}\sum_{f=1}^{5}\left(r_{x,y} s_{x,f} e_{x,l,w,y,f}^{c,b}\right)\right)\right)$$

E^c	total emissions of compound c
c	compound
x	engine function type (2 types): main engine / auxiliary engine
l	type of ship (9 types)
w	gross register ton (GRT) class (7 classes)
N	number of trips / port visits
d	distance of an individual trip
v^a	average design speed
p^a	average nominal engine power
g^d	engine load factor during driving
g^m	engine load factor during manoeuvre
g^b	engine load factor during berthing
y	engine type by two/four-stroke engine and emission standard level (Tier) (10 combined types)
r	share of engines by engine type
f	fuel type of engine (5 types)
s	share of engines by fuel type
t^m	time used for manoeuvre
t^b	time used for berthing
$e^{c,d}$	emission factor of compound c for driving
$e^{c,m}$	emission factor of compound c for manoeuvre
$e^{c,b}$	emission factor of compound c for berthing

Formula for icebreakers:

$$E^c = \sum_{f=1}^{N^f} S_f e_f^c$$

E^c	total emissions of compound c
c	compound
f	fuel type
N^f	number of fuel types
S	total fuel use by fuel type
e^c	emission factor for compound c

Formula for (diesel) working boats:

$$E^c = \sum_{l=1}^{3} N_l s_l e^c$$

E^c	total emissions of compound c
c	compound
l	type of working boat (3 types)
N	number of working boats
s	average fuel use of a working boat per year
e^c	emission factor for compound c

Formula for leisure boats:

$$E^c = \sum_{l=1}^{6} \sum_{y=1}^{3} \sum_{r=1}^{10} N_{l,y,r} p_r \, g_{l,y,r} t_l e_y^c$$

E^c	total emissions of compound c
c	compound
l	type of leisure boat (6 types)
y	engine type and fuel: gasoline two/four-stroke engine and diesel engine (3 combined types)
r	engine power class (10 classes)
N	number of boats
p	nominal engine power (class centre)
g	engine load factor
t	activity (hours in use per year)
e^c	emission factor for compound c

Other transportation TYKO model

Formula for all off-road machinery in the TYKO model:

$$E^c = \sum_{l=1}^{N^l} g_l \sum_{r=1}^{4} p_{l,r} \sum_{x=1}^{3} \sum_{f=1}^{3} \sum_{s=1}^{6} \left(\sum_{u=1}^{3} \sum_{a=1}^{40} N_{l,r,x,f,s,u,a}^{m} t_{l,r,x,f,s,u,a} \right) e_{l,r,x,f,s}^{c}$$

E^c	total emissions of compound c
c	compound
l	type of machinery
N^l	number of machinery types (presently 50)

g	engine load factor by machinery type
r	engine power class (4 classes)
p	nominal engine power (class centre)
x	engine type (presently 3: two/four-stroke gasoline and diesel engines)
f	fuel type (3 types)
s	emission standard level (Stage) by model year of machinery (6 classes)
u	type of usage (3 types: professional/leisure/both)
a	age of machine (max 40)
N^m	number of machines by detail (machinery fleet in the calculation year by age)
t	activity (hours in use per year)
e^c	emission factor for compound c

Formula for detailed machinery fleet calculation:

$$N_y^m = N_{y-1}^m\left(1 - w_y^m\right) + S_y^m$$

$N^m{}_y$	machinery fleet by type (detailed) in the year y
$w^m{}_y$	scrapping factor of machinery in the year y
$S^m{}_y$	new sales of machinery in the year y

Appendix_3b

Fuel combusted, greenhouse gas emissions and implied emission factors for CO_2 from combustion by fuel

Table 1_App_3b. Fuel combustion by fuel, PJ

	1990	1995	2000	2005	2010	2013	2014	2015	2016	2017	2018	2019	2020	2021	2022
Solid fuels	**145.1**	**142.6**	**122.4**	**104.4**	**164.8**	**131.0**	**104.9**	**79.4**	**99.5**	**88.7**	**85.9**	**69.3**	**48.0**	**55.2**	**61.1**
Hard coal	128.1	122.6	98.5	80.6	144.8	114.3	87.3	62.2	81.3	71.6	68.0	53.3	32.1	36.5	45.1
Coke	5.87	4.89	5.45	5.65	4.57	1.24	1.18	1.10	1.06	0.93	1.06	1.02	0.96	0.95	0.83
Blast furnace gases	6.9	7.5	11.2	11.0	8.6	7.7	8.2	9.2	9.8	9.2	9.9	8.0	8.5	11.0	8.3
Coke oven gas	4.16	7.21	7.14	7.01	6.60	6.59	6.81	6.86	7.30	7.00	6.87	6.95	6.39	6.79	6.76
Other coal	0.02	0.38	0.08	0.13	0.26	1.17	1.39	0.04	0.02	0.03	0.07	0.06	0.07	0.01	0.02
Liquid fuels	**369.5**	**342.2**	**345.4**	**353.1**	**338.6**	**306.7**	**286.9**	**285.0**	**306.7**	**294.7**	**292.2**	**286.9**	**268.1**	**254.5**	**264.4**
Heavy fuel oil	71.1	58.0	48.7	43.8	35.8	20.0	19.3	19.6	18.1	15.8	11.5	10.6	9.0	9.5	9.8
Light fuel oil	105.7	98.7	96.5	90.5	80.0	72.1	70.5	68.3	68.8	69.7	68.0	68.0	65.4	64.5	67.4
Motor gasoline	85.6	81.7	76.7	80.7	67.5	63.0	60.7	60.3	59.9	57.6	56.7	55.4	51.5	51.9	48.1
Diesel oil	66.9	62.1	76.5	86.2	97.6	96.1	83.7	84.1	101.1	94.2	97.1	92.8	88.4	81.7	82.1
LPG	6.7	7.1	11.0	12.9	12.7	11.5	11.6	11.8	11.6	11.4	11.6	7.8	7.5	8.0	9.3
Refinery gases	21.0	22.6	22.0	24.2	27.3	27.1	25.8	25.7	29.5	27.8	29.1	31.4	29.1	24.4	30.4
Town gas	0.14	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO
Recycled waste oil	0.52	0.52	0.93	1.34	1.20	0.61	0.76	0.47	0.50	0.61	0.43	0.40	0.70	0.46	0.56
Petroleum coke	4.9	4.9	4.7	5.5	5.2	6.5	6.1	5.5	6.1	5.7	5.0	5.3	5.7	4.8	5.3
Jet fuel	5.5	4.9	6.8	6.3	5.8	4.5	4.1	4.1	4.8	4.8	4.7	5.2	3.4	2.5	3.4
Aviation gasoline	0.17	0.13	0.14	0.15	0.08	0.05	0.04	0.04	0.04	0.03	0.04	0.04	0.04	0.03	0.03
Process gases	0.08	0.31	0.34	0.29	3.97	4.11	3.15	3.83	4.98	5.82	5.09	5.39	4.45	4.17	4.25
Other oil	1.22	1.21	0.95	1.27	1.29	1.09	1.12	1.11	1.20	1.25	2.94	4.74	3.01	2.54	3.67
Gaseous fuels	**90.8**	**117.6**	**141.9**	**149.1**	**148.7**	**107.0**	**95.7**	**82.4**	**72.3**	**65.8**	**75.6**	**73.3**	**74.3**	**74.4**	**38.5**
Natural gas	90.8	117.6	141.9	149.1	148.7	106.9	95.6	82.4	71.9	65.3	74.2	68.0	68.3	68.0	32.7
LNG	NO	NO	NO	NO	NO	0.1	0.1	0.1	0.3	0.5	1.4	5.3	6.0	6.4	5.8
Peat	**53.3**	**79.4**	**63.3**	**70.9**	**97.8**	**57.6**	**61.1**	**58.0**	**56.3**	**53.9**	**61.9**	**56.7**	**42.9**	**38.3**	**36.7**
Other	**1.1**	**1.5**	**3.3**	**3.9**	**5.2**	**9.2**	**10.4**	**10.4**	**11.5**	**12.8**	**12.9**	**13.4**	**13.0**	**14.5**	**14.0**
Mixed fuels (MSW/REF /RDF/PDF etc.)	0.2	0.5	1.7	2.5	4.2	7.2	8.3	8.8	10.0	10.9	11.1	11.6	11.1	12.3	11.9
Other fossil wastes etc.	0.89	0.99	1.67	1.37	0.99	1.98	2.08	1.63	1.52	1.84	1.84	1.76	1.96	2.19	2.09
Biomass	**179.3**	**218.9**	**275.3**	**293.4**	**340.1**	**364.3**	**377.0**	**369.6**	**377.5**	**400.9**	**412.9**	**420.1**	**392.7**	**456.1**	**414.8**
Black/sulphite liquor	87.4	111.1	139.8	129.4	135.7	140.7	141.9	142.1	146.3	154.8	167.0	169.7	158.1	166.2	142.4
Other woodfuels	90.5	105.4	132.2	156.4	185.6	197.8	197.4	188.9	203.8	204.5	203.2	205.7	191.9	231.7	220.6
Biogas[1]	0.09	0.65	0.86	1.75	1.69	2.43	2.55	2.66	2.63	7.15	7.80	7.85	7.08	8.14	7.33
Bio diesel	NO	NO	NO	NO	2.6	6.8	17.9	18.0	4.5	12.9	11.8	14.2	12.6	23.2	17.7
Bio gasoline	NO	NO	NO	NO	3.04	2.94	3.08	2.90	3.01	3.59	3.74	3.92	4.14	5.00	5.22
Bio gasoil	NO	NO	NO	NO	1.7	NO	NO	NO	NO	NO	NO	NO	NO	2.2	2.7
Bio mixed fuels	0.62	0.88	1.11	3.86	6.56	8.79	9.75	10.97	12.18	12.89	13.81	13.60	13.16	14.34	13.83
Hydrogen	0.62	0.95	1.10	1.13	1.10	1.05	1.04	0.97	1.00	1.08	1.34	1.10	1.44	1.52	0.88
Other non-fossil fuels	0.07	0.03	0.3	0.9	2.2	3.8	3.3	3.2	4.1	4.0	4.2	4.0	4.2	3.8	4.0
Bunker fuels	**37.3**	**26.1**	**40.9**	**38.2**	**31.1**	**31.4**	**29.7**	**38.6**	**38.3**	**42.8**	**45.7**	**48.7**	**24.6**	**22.7**	**36.2**
Jet fuel	13.8	12.3	14.5	17.6	22.6	26.6	26.2	26.8	26.9	28.7	32.6	35.2	11.9	11.3	22.3
Light fuel oil	5.1	6.6	6.7	2.0	2.6	1.7	1.1	1.5	1.4	2.6	2.1	2.7	3.0	4.2	5.8
Heavy fuel oil	18.4	7.3	19.7	18.6	5.9	3.1	2.5	10.3	10.0	11.4	10.9	10.8	9.7	7.3	8.1
LNG	NO	NO	NO	NO	NO	NO	NO	NO	0.01	0.20	0.05	0.02	0.06	0.05	0.07

[1] Includes biomethane and LBG

Table 2_App_3b. CO_2 emissions from combustion by fuel, Mt

	1990	1995	2000	2005	2010	2013	2014	2015	2016	2017	2018	2019	2020	2021	2022
Solid fuels	**14.5**	**14.2**	**12.9**	**11.1**	**16.2**	**12.8**	**10.5**	**8.3**	**10.1**	**9.1**	**8.9**	**7.1**	**5.2**	**6.3**	**6.4**
Hard coal	12.0	11.5	9.2	7.5	13.4	10.6	8.1	5.7	7.5	6.6	6.3	4.9	3.0	3.4	4.2
Coke	0.63	0.52	0.58	0.60	0.49	0.13	0.13	0.12	0.11	0.10	0.11	0.11	0.10	0.10	0.09
Blast furnace gases	1.73	1.86	2.79	2.72	2.03	1.78	1.90	2.12	2.22	2.11	2.26	1.77	1.90	2.53	1.90
Coke oven gas	0.17	0.30	0.29	0.29	0.27	0.27	0.28	0.28	0.30	0.29	0.28	0.29	0.26	0.28	0.28
Other coal	0.002	0.037	0.008	0.013	0.024	0.106	0.125	0.004	0.002	0.003	0.007	0.006	0.007	0.001	0.002
Liquid fuels	**27.3**	**25.2**	**25.3**	**25.8**	**24.3**	**21.7**	**20.4**	**20.1**	**21.6**	**20.7**	**20.5**	**20.1**	**18.8**	**17.9**	**18.6**
Heavy fuel oil	5.6	4.6	3.8	3.5	2.8	1.6	1.5	1.6	1.4	1.3	0.9	0.8	0.7	0.7	0.8
Light fuel oil	7.8	7.3	7.2	6.7	5.9	5.3	5.2	5.0	5.0	5.1	5.0	5.0	4.8	4.7	4.9
Motor gasoline	6.2	6.0	5.6	5.9	4.9	4.5	4.3	4.3	4.3	4.1	4.1	4.0	3.7	3.7	3.4
Diesel oil	4.9	4.6	5.6	6.3	7.2	7.0	6.1	6.1	7.4	6.9	7.1	6.8	6.5	6.0	6.0
LPG	0.43	0.46	0.72	0.84	0.82	0.74	0.75	0.77	0.76	0.74	0.75	0.51	0.48	0.52	0.60
Refinery gases	1.2	1.3	1.3	1.4	1.5	1.5	1.4	1.4	1.6	1.5	1.6	1.7	1.6	1.3	1.7
Town gas	0.009	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO
Recycled waste oil	0.04	0.04	0.07	0.11	0.09	0.05	0.06	0.04	0.04	0.05	0.03	0.03	0.06	0.04	0.04
Petroleum coke	0.48	0.47	0.46	0.56	0.50	0.66	0.62	0.55	0.59	0.56	0.51	0.49	0.51	0.44	0.52
Jet fuel	0.40	0.36	0.50	0.46	0.43	0.33	0.30	0.30	0.35	0.35	0.34	0.38	0.25	0.18	0.25
Aviation gasoline	0.01	0.01	0.01	0.01	0.01	0.004	0.003	0.003	0.003	0.002	0.003	0.003	0.003	0.002	0.002
Process gases	NO	NO	NO	NO	0.02	0.01	0.01	0.01	0.02	0.01	0.01	0.01	0.01	0.00	0.00
Other oil	0.09	0.09	0.07	0.10	0.10	0.09	0.09	0.09	0.09	0.10	0.23	0.37	0.23	0.20	0.28
Gaseous fuels [1]	**5.0**	**6.4**	**7.6**	**8.0**	**8.0**	**5.8**	**5.1**	**4.4**	**3.9**	**3.5**	**4.0**	**3.9**	**4.0**	**4.0**	**2.1**
Natural gas	5.0	6.5	7.8	8.2	8.2	5.9	5.3	4.6	4.0	3.6	4.1	3.8	3.8	3.8	1.8
LNG	NO	NO	NO	NO	NO	0.003	0.003	0.003	0.02	0.03	0.08	0.29	0.33	0.35	0.32
Peat	**5.6**	**8.3**	**6.6**	**7.4**	**10.2**	**6.1**	**6.5**	**6.1**	**6.0**	**5.7**	**6.5**	**5.9**	**4.5**	**4.0**	**3.9**
Other	**0.10**	**0.15**	**0.27**	**0.33**	**0.44**	**0.69**	**0.79**	**0.80**	**0.89**	**0.99**	**0.99**	**1.03**	**1.01**	**1.13**	**1.10**
Mixed fuels (MSW/REF/ RDF/PDF etc.)	0.01	0.04	0.11	0.19	0.34	0.58	0.67	0.70	0.81	0.88	0.89	0.93	0.90	0.99	0.96
Other fossil wastes etc.	0.09	0.11	0.17	0.14	0.10	0.12	0.12	0.10	0.09	0.11	0.10	0.10	0.11	0.14	0.14
Biomass	**18.3**	**22.2**	**27.9**	**30.1**	**34.8**	**37.2**	**38.2**	**37.4**	**38.7**	**40.7**	**41.9**	**42.6**	**39.8**	**46.1**	**42.2**
Black/sulphite liquor	8.2	10.5	13.2	12.2	12.8	13.3	13.4	13.4	13.8	14.6	15.8	16.0	14.9	15.7	13.4
Other woodfuels	10.0	11.6	14.5	17.2	20.4	21.7	21.7	20.8	22.4	22.4	22.3	22.5	21.1	25.4	24.3
Biogas [2]	0.005	0.035	0.047	0.10	0.09	0.13	0.14	0.15	0.14	0.58	0.68	0.69	0.61	0.71	0.63
Bio diesel	NO	NO	NO	NO	0.2	0.5	1.3	1.3	0.3	0.9	0.9	1.0	0.9	1.7	1.3
Bio gasoline	NO	NO	NO	NO	0.21	0.21	0.22	0.20	0.19	0.25	0.26	0.27	0.28	0.32	0.33
Bio gasoil	NO	NO	NO	NO	0.12	NO	NO	NO	NO	NO	NO	NO	NO	0.16	0.20
Bio mixed fuels	0.08	0.11	0.13	0.43	0.76	1.06	1.20	1.35	1.51	1.61	1.71	1.70	1.64	1.79	1.73
Hydrogen	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO
Other non-fossil fuels	0.007	0.003	0.028	0.09	0.20	0.33	0.27	0.26	0.34	0.33	0.34	0.34	0.34	0.31	0.32
Bunker fuels	**2.8**	**2.0**	**3.1**	**2.9**	**2.3**	**2.3**	**2.2**	**2.9**	**2.9**	**3.2**	**3.4**	**3.6**	**1.8**	**1.7**	**2.7**
Jet fuel	1.0	0.9	1.1	1.3	1.7	1.9	1.9	2.0	2.0	2.1	2.4	2.6	0.9	0.8	1.6
Light fuel oil	0.38	0.49	0.50	0.15	0.19	0.12	0.08	0.11	0.10	0.19	0.15	0.20	0.22	0.30	0.42
Heavy fuel oil	1.45	0.57	1.55	1.47	0.47	0.25	0.19	0.81	0.79	0.89	0.86	0.84	0.76	0.57	0.63
LNG	NO	NO	NO	NO	NO	NO	NO	NO	0.000	0.011	0.003	0.001	0.003	0.003	0.004

[1] Sum of gaseous fuels includes amount of captured CO_2 which is reported in 1A2d

[2] Includes biomethane and LBG

Table 3_App_3b. Implied CO_2 emission factors

	1990	1995	2000	2005	2010	2013	2014	2015	2016	2017	2018	2019	2020	2021	2022
Solid fuels	**100.1**	**99.6**	**105.3**	**106.6**	**98.2**	**98.1**	**100.4**	**104.0**	**101.9**	**102.2**	**104.0**	**101.8**	**109.0**	**113.5**	**105.2**
Hard coal	93.6	93.7	93.7	93.1	92.4	92.4	92.8	92.2	92.3	91.8	92.2	91.8	92.2	92.1	92.2
Coke	106.7	106.8	106.8	106.7	106.8	106.3	106.4	105.9	105.9	105.9	105.9	105.9	105.9	105.9	105.9
Blast furnace gases	250.6	247.0	248.2	247.9	237.3	231.8	230.9	229.6	227.6	230.3	229.0	220.8	223.9	229.7	227.8
Coke oven gas	41.1	41.1	41.1	41.1	41.1	41.1	41.1	41.1	41.1	41.1	41.1	41.1	41.1	41.1	41.1
Other coal	106.9	97.0	97.1	98.0	91.4	90.0	90.0	106.6	106.9	106.9	106.9	106.9	106.9	106.8	106.9
Liquid fuels	**73.8**	**73.6**	**73.3**	**73.1**	**71.7**	**70.8**	**71.0**	**70.7**	**70.3**	**70.3**	**70.2**	**70.0**	**70.0**	**70.2**	**70.2**
Heavy fuel oil	78.8	78.8	78.8	78.8	78.8	79.1	79.1	79.1	79.1	79.0	78.8	78.7	78.7	78.5	78.4
Light fuel oil	74.1	74.1	74.1	74.1	73.9	73.1	73.1	73.1	73.1	73.1	73.1	73.1	73.1	73.1	73.1
Motor gasoline	72.9	72.9	72.9	72.9	72.9	71.5	71.5	71.5	71.5	71.5	71.5	71.5	71.5	71.5	71.5
Diesel oil	73.6	73.6	73.6	73.6	73.6	72.9	72.9	73.0	73.0	73.3	73.4	73.3	73.3	73.3	73.3
LPG	65.0	65.0	65.0	65.0	65.0	64.9	64.9	64.9	64.9	64.9	64.9	64.9	64.9	64.9	64.9
Refinery gases	57.2	57.2	56.8	55.8	53.9	54.1	54.8	53.8	53.2	54.7	54.3	55.0	54.0	53.9	56.2
Town gas	59.4	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO
Recycled waste oil	78.8	78.8	78.8	78.8	78.8	78.8	78.8	78.8	78.8	78.8	78.8	78.8	78.8	78.8	78.8
Petroleum coke	97.5	97.5	97.5	102.0	95.7	100.7	101.5	99.6	97.5	99.7	101.4	93.5	90.4	92.3	97.0
Jet fuel	73.2	73.2	73.2	73.2	73.2	73.2	73.2	73.2	73.2	73.2	73.2	73.2	73.2	73.2	73.2
Aviation gasoline	71.3	71.3	71.3	71.3	71.3	71.3	71.3	71.3	71.3	71.3	71.3	71.3	71.3	71.3	71.3
Process gases	NA	NA	NA	NA	4.4	3.0	4.4	3.1	3.7	1.8	1.7	1.9	2.8	0.3	0.6
Other oil	77.7	78.1	78.7	77.1	78.8	79.3	81.3	77.6	78.8	79.4	79.6	78.3	76.2	77.9	77.2
Gaseous fuels [1]	**55.0**	**54.6**	**53.7**	**53.8**	**53.7**	**53.8**	**53.7**	**53.6**	**53.4**	**53.3**	**53.5**	**53.6**	**54.0**	**54.0**	**54.1**
Natural gas	55.0	55.0	55.0	55.0	55.0	55.2	55.2	55.3	55.3	55.3	55.3	55.3	55.4	55.3	55.4
LNG	NO	NO	NO	NO	NO	55.8	55.8	55.8	55.8	55.8	55.8	55.3	55.3	55.3	55.3
Peat	**104.4**	**104.4**	**104.5**	**104.6**	**104.5**	**106.1**	**105.9**	**105.7**	**106.1**	**106.1**	**105.5**	**104.9**	**105.0**	**105.4**	**105.1**
Other	**95.6**	**99.7**	**82.5**	**84.4**	**84.5**	**75.6**	**76.0**	**76.7**	**77.4**	**77.2**	**76.9**	**77.2**	**77.5**	**78.3**	**78.4**
Mixed fuels (MSW/REF/ RDF/PDF etc.)	79.2	78.7	65.3	75.3	80.7	80.2	80.3	80.2	80.3	80.3	80.3	80.3	81.0	80.5	80.4
Other fossil wastes etc.	98.9	110.9	99.5	101.2	100.7	58.6	59.0	58.3	58.4	58.6	55.9	57.2	57.8	65.7	66.9
Biomass	**102.1**	**101.5**	**101.5**	**102.4**	**102.2**	**102.1**	**101.3**	**101.2**	**102.5**	**101.6**	**101.5**	**101.4**	**101.3**	**101.1**	**101.7**
Black/sulphite liquor	94.3	94.3	94.3	94.3	94.3	94.3	94.3	94.3	94.3	94.3	94.3	94.3	94.3	94.3	94.3
Other woodfuels	110.2	110.0	110.0	110.2	109.9	109.8	109.9	109.9	109.9	109.8	109.6	109.6	109.7	109.8	109.9
Biogas [2]	54.6	54.6	54.6	54.6	54.6	54.6	54.6	54.6	54.6	81.8	86.8	87.4	86.1	87.7	85.7
Bio diesel	NO	NO	NO	NO	71.4	72.2	71.9	72.1	71.9	72.1	73.0	72.9	73.4	72.2	72.2
Bio gasoline	NO	NO	NO	NO	69.8	70.2	69.8	68.1	64.2	68.5	69.3	68.7	66.5	64.0	64.0
Bio gasoil	NO	NO	NO	NO	70.9	NO	NO	NO	NO	NO	NO	NO	NO	71.6	71.6
Bio mixed fuels	121.7	128.3	118.9	111.1	115.9	121.0	123.0	123.2	124.2	125.0	124.0	124.7	124.4	124.6	125.4
Hydrogen	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
Other non-fossil fuels	99.0	99.0	94.5	96.5	89.2	86.2	82.3	80.9	81.3	82.1	81.8	83.7	81.9	81.5	79.4
Bunker fuels	**76.1**	**75.0**	**76.0**	**76.0**	**74.3**	**73.7**	**73.6**	**74.6**	**74.6**	**74.5**	**74.4**	**74.3**	**75.2**	**74.8**	**74.3**
Jet fuel	73.2	73.2	73.2	73.2	73.2	73.2	73.2	73.2	73.2	73.2	73.2	73.2	73.2	73.2	73.2
Light fuel oil	74.1	74.1	74.1	74.1	74.1	73.1	73.1	73.1	73.1	73.1	73.1	73.1	73.1	73.1	73.1
Heavy fuel oil	78.8	78.8	78.8	78.8	78.8	78.4	78.4	78.4	78.4	78.4	78.4	78.4	78.4	78.4	78.4
LNG	NO	NO	NO	NO	NO	NO	NO	NO	55.8	55.8	55.8	55.3	55.3	55.3	55.3

[1] amount of captured CO_2 not included in the IEF calculation

[2] Includes biomethane and LBG

Table 4_App_3b. CH_4 emissions from combustion by fuel, t

	1990	1995	2000	2005	2010	2013	2014	2015	2016	2017	2018	2019	2020	2021	2022
Solid fuels	**286**	**181**	**146**	**123**	**184**	**154**	**124**	**91**	**112**	**99**	**103**	**83**	**56**	**64**	**68**
Hard coal	269	161	122	99	163	135	105	72	93	81	84	65	38	43	50
Coke	6.0	4.9	5.5	5.7	4.7	1.3	1.2	1.1	1.1	0.9	1.1	1.0	1.0	1.0	0.8
Blast furnace gases	6.9	7.5	11.2	11.0	9.1	9.6	9.6	10.4	10.9	9.9	11.4	9.6	10.2	12.6	9.8
Coke oven gas	4.2	7.2	7.1	7.0	6.6	6.6	6.8	6.9	7.3	7.0	6.9	7.0	6.4	6.8	6.8
Other coal	0.02	0.38	0.17	0.29	0.32	1.21	1.42	0.10	0.04	0.09	0.12	0.10	0.10	0.03	0.04
Liquid fuels	**5 875**	**4 687**	**3 526**	**2 618**	**1 889**	**1 612**	**1 549**	**1 477**	**1 440**	**1 362**	**1 299**	**1 239**	**1 184**	**1 143**	**1 075**
Heavy fuel oil	257	134	126	120	98	62	54	52	48	45	36	32	27	28	27
Light fuel oil	802	744	701	659	568	490	480	451	454	445	426	412	392	389	370
Motor gasoline	4 205	3 266	2 296	1 493	971	854	838	808	765	722	694	661	646	624	566
Diesel oil	546	480	337	270	173	129	104	94	98	75	66	54	46	34	30
LPG	29.6	27.8	30.2	34.8	32.4	30.7	29.4	29.5	27.3	27.0	28.2	25.1	25.3	28.8	32.7
Refinery gases	21.8	22.4	21.5	24.7	27.9	27.0	25.8	25.7	29.5	28.0	29.5	31.8	29.6	24.5	30.4
Town gas	0.43	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO
Recycled waste oil	0.53	0.52	0.94	1.36	1.22	0.63	0.77	0.48	0.51	0.62	0.44	0.41	0.71	0.47	0.56
Petroleum coke	4.90	4.86	4.69	5.50	5.24	6.53	6.14	5.51	6.08	5.84	5.02	5.27	5.67	4.78	5.33
Jet fuel	5.80	5.16	7.14	7.39	7.21	5.61	5.08	5.12	5.99	5.84	5.68	6.26	3.82	2.84	4.28
Aviation gasoline	0.17	0.13	0.14	0.15	0.08	0.05	0.04	0.03	0.03	0.02	0.03	0.03	0.03	0.02	0.03
Other oil	2.38	1.59	1.09	1.29	1.29	0.75	1.13	1.12	1.21	1.37	3.16	5.38	3.19	2.56	3.94
Process gases	NO	NO	NO	NO	4.32	5.23	4.28	4.80	5.15	5.94	5.19	5.52	4.60	4.19	4.29
Gaseous fuels	**111**	**193**	**260**	**338**	**228**	**137**	**123**	**109**	**97**	**92**	**110**	**105**	**108**	**128**	**64**
Natural gas	111	193	260	338	228	131	117	102	91	84	92	85	82	87	47
LNG	NO	NO	NO	NO	NO	6.5	5.8	6.9	6.2	7.7	17.9	20.1	25.7	41.1	17.2
Peat	**231**	**306**	**292**	**353**	**510**	**354**	**358**	**341**	**373**	**366**	**391**	**374**	**278**	**266**	**266**
Other	**5.3**	**3.2**	**7.7**	**13.5**	**14.9**	**32.7**	**45.1**	**36.1**	**34.2**	**37.1**	**33.2**	**34.4**	**32.9**	**40.1**	**40.7**
Mixed fuels (MSW/REF/ RDF/PDF etc.)	0.2	1.3	2.5	10.3	13.1	29.1	41.8	33.4	31.4	33.7	29.8	31.3	29.4	36.1	36.1
Other fossil wastes etc.	5.1	1.9	5.3	3.2	1.8	3.6	3.3	2.7	2.8	3.3	3.4	3.0	3.5	3.9	4.6
Biomass	**5 703**	**6 313**	**6 530**	**8 097**	**9 543**	**8 730**	**8 896**	**8 446**	**9 158**	**9 173**	**9 047**	**8 965**	**7 705**	**8 700**	**8 029**
Black/sulphite liquor	87	111	140	129	136	141	142	142	146	155	167	170	158	166	142
Other woodfuels	5 610	6 140	6 308	7 878	9 128	8 220	8 325	7 872	8 589	8 570	8 463	8 393	7 161	8 113	7 496
Biogas[1]	0.37	59	76	75	191	275	309	322	328	341	312	295	275	278	251
Bio diesel	NO	NO	NO	NO	4.64	9.10	22.06	20.23	4.39	10.33	8.02	8.24	6.49	9.72	6.55
Bio gasoline	NO	NO	NO	NO	44.22	40.57	42.96	38.82	38.41	44.98	45.74	46.74	51.97	60.11	61.48
Bio gasoil	NO	NO	NO	NO	13.40	NO	NO	NO	NO	NO	NO	NO	NO	13.44	15.00
Bio mixed fuels	3.8	2.3	4.9	10.8	20.1	35.2	47.1	41.2	37.2	39.1	37.4	36.6	35.6	41.8	41.9
Hydrogen	0.6	1.0	1.1	1.1	1.1	1.2	1.2	1.1	1.1	1.2	1.5	1.2	1.5	1.6	0.9
Other non-fossil fuels	0.30	0.11	0.74	1.93	5.02	8.65	6.99	8.96	12.44	11.96	12.49	13.56	15.11	15.74	13.87
Bunker fuels	**136**	**74**	**156**	**129**	**64**	**60**	**64**	**113**	**108**	**131**	**118**	**121**	**112**	**109**	**123**
Jet fuel	0	1	1	5	13	29	42	33	31	34	30	31	29	36	36
Light fuel oil	22	29	31	10	13	9	6	9	8	14	12	15	15	21	29
Heavy fuel oil	113	45	123	114	38	21	17	71	69	79	75	74	67	51	56
LNG	NO	NO	NO	NO	NO	NO	NO	NO	0.2	4.5	1.2	0.4	1.4	1.3	1.6

[1] Includes biomethane and LBG

Table 5_App_3b. N_2O emissions from combustion by fuel, t

	1990	1995	2000	2005	2010	2013	2014	2015	2016	2017	2018	2019	2020	2021	2022
Solid fuels	**293**	**274**	**240**	**241**	**257**	**253**	**196**	**180**	**248**	**216**	**207**	**193**	**134**	**146**	**147**
Hard coal	274	248	215	215	233	229	173	157	224	195	182	171	112	121	125
Coke	6.6	5.3	6.1	6.4	5.3	1.8	1.6	1.4	1.2	1.1	1.2	1.2	1.1	1.1	1.0
Blast furnace gases	7.1	7.5	11.2	11.2	10.3	13.7	12.7	13.4	14.0	12.2	15.1	13.5	14.1	16.6	13.1
Coke oven gas	4.2	7.9	8.0	7.9	7.3	7.3	7.5	7.5	8.0	7.7	7.5	7.4	6.9	7.5	7.3
Other coal	0.60	5.05	0.24	0.41	0.37	1.28	1.49	0.23	0.09	0.20	0.22	0.17	0.17	0.05	0.09
Liquid fuels	**958**	**891**	**786**	**663**	**571**	**504**	**478**	**468**	**512**	**490**	**514**	**509**	**467**	**428**	**455**
Heavy fuel oil	154	119	101	92	75	40	38	36	33	28	20	18	15	16	16
Light fuel oil	210	197	190	168	140	122	119	110	112	111	109	105	99	102	106
Motor gasoline	300	321	281	196	108	74	68	62	56	51	47	43	41	38	37
Diesel oil	220	179	129	112	141	166	156	163	202	192	205	205	209	185	190
LPG	10.1	10.2	16.0	18.7	17.6	16.2	16.4	16.3	16.3	15.2	15.6	11.8	10.8	11.5	12.3
Refinery gases	40.2	43.3	42.4	48.9	55.4	52.9	50.5	50.5	57.7	54.9	57.7	61.7	57.4	47.7	57.6
Town gas	0.14	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO
Recycled waste oil	0.54	0.52	1.22	2.27	2.44	1.24	1.44	0.82	0.91	1.18	0.79	0.70	1.30	0.86	1.03
Petroleum coke	9.8	9.7	9.4	11.0	10.5	13.0	12.3	11.0	12.2	11.7	10.0	10.5	11.3	9.6	10.7
Jet fuel	11.1	9.9	13.7	12.7	11.7	9.1	8.3	8.2	9.6	9.6	9.3	10.3	6.9	5.0	6.9
Aviation gasoline	0.34	0.26	0.29	0.30	0.17	0.11	0.08	0.08	0.08	0.07	0.08	0.07	0.07	0.06	0.06
Other oil	1.8	1.7	1.5	1.7	1.7	0.9	1.7	1.6	1.8	4.3	29.9	31.4	5.6	2.9	9.8
Process gas	NO	NO	NO	NO	7.9	8.2	6.4	7.7	9.9	11.6	10.2	10.8	8.9	8.4	8.5
Gaseous fuels	**103**	**130**	**163**	**166**	**164**	**122**	**110**	**96**	**86**	**80**	**90**	**87**	**89**	**88**	**48**
Natural gas	103	130	163	166	164	122	109	96	85	78	88	81	81	80	40
LNG	NO	NO	NO	NO	NO	0.17	0.17	0.12	0.65	1.13	2.24	6.29	7.63	8.26	7.15
Peat	**169**	**290**	**259**	**312**	**421**	**244**	**250**	**248**	**241**	**225**	**276**	**244**	**186**	**171**	**177**
Other	**2.1**	**3.5**	**5.1**	**12.0**	**18.0**	**27.7**	**27.1**	**28.5**	**32.3**	**37.5**	**39.5**	**37.9**	**38.2**	**44.6**	**41.6**
Mixed fuels (MSW/REF/RD	0.18	1.30	1.01	8.7	16.2	22.3	22.9	25.1	28.7	33.0	35.0	34.0	33.5	39.3	36.4
Other fossil wastes etc.	1.96	2.21	4.04	3.30	1.74	5.38	4.17	3.38	3.65	4.52	4.46	3.83	4.70	5.32	5.26
Biomass	**288**	**364**	**534**	**594**	**751**	**805**	**815**	**792**	**802**	**829**	**861**	**875**	**832**	**1016**	**955**
Black/sulphite liquor	88	111	140	129	136	141	142	142	147	155	167	170	158	166	143
Other woodfuels	197	249	388	442	569	606	596	567	594	587	602	611	582	726	703
Biogas[1]	0.10	0.67	0.89	1.83	1.75	2.79	2.96	3.09	2.99	7.52	8.25	8.28	7.41	8.50	8.05
Bio diesel	NO	NO	NO	NO	3.78	11.64	32.97	34.97	9.08	26.37	24.86	31.37	29.78	52.71	40.99
Bio gasoline	NO	NO	NO	NO	4.94	3.58	3.53	2.99	2.83	3.15	3.07	3.07	3.30	3.70	4.02
Bio gasoil	NO	NO	NO	NO	3.03	NO	NO	NO	NO	NO	NO	NO	NO	3.53	4.29
Bio mixed fuels	0.98	2.28	3.15	16.30	24.30	29.28	28.04	33.20	37.18	40.04	44.46	41.49	40.47	46.00	42.57
Hydrogen	0.63	1.07	1.22	1.33	1.20	1.12	1.11	1.04	1.08	1.16	1.44	1.19	1.54	1.63	0.97
Other non-fossil fuels	0.52	0.20	1.08	2.90	6.61	9.64	8.33	7.08	8.68	8.38	9.01	9.09	9.16	7.99	8.44
Bunker fuels	**48**	**29**	**55**	**49**	**32**	**31**	**29**	**46**	**49**	**58**	**59**	**58**	**56**	**60**	**61**
Jet fuel	0	1	1	8	16	22	23	25	29	33	35	34	33	39	36
Light fuel oil	10	13	13	3.9	5.0	3.2	2.0	2.9	2.6	4.8	3.8	5.0	5.5	7.6	10.5
Heavy fuel oil	38	15	41	37	11	6	4	19	18	21	20	19	18	13	15
LNG	NO	NO	NO	NO	NO	NO	NO	NO	0.00	0.06	0.02	0.01	0.02	0.02	0.02

[1] Includes biomethane and LBG

Appendix_3c

Data on CO_2 capture and transfer to PCC production from lime kilns, industrial power plants and hydrogen production

Table 1_App_3c Amount of produced PCC.

	1993	1995	2000	2005	2010	2011	2012	2013	2014	2015	2016	2017	2018	2019	2020	2021	2022
Produced PCC using transferred CO_2, kt	2.0	123.2	417.2	417.4	449.8	409.7	334.8	331.1	340.5	316.3	314.9	303.4	307.0	282.6	230.9	220.0	110.3

The Finnish Forest Industries collected the total produced amount of PCC for years 1993 to 2007. Statistics Finland have collected PCC data for years since 2008 from Production statistics (plant specific data from Statistics Finland's manufacturing industry surveys), from YLVA database or from PCC producing plants directly. Annual production (years 1993 to 2007) has been compared with added up plant level PCC data received from production statistics, only small differences (+/-2%) were noticed (years 2000 to 2007).

Table 2_App_3c The share of fossil fuels of total transferred CO_2.

	1993	1995	2000	2005	2010	2011	2012	2013	2014	2015	2016	2017	2018	2019	2020	2021	2022
The share of biological emission of total transferred CO_2 (%)			8	14	19	11	0*	1**	0	0	0	12***	28***	40***	40***	39***	58***
The share of fossil fuels and other emissions of total transferred CO_2 (%)			92	86	81	89	100	99	100	100	100	88	72	60	60	61	42

All fuels used in the lime kilns and industrial power plants for the whole time series have been collected unit level and the percentage of emissions from fossil fuels have been calculated separately.

* A plant using wood fuels was closed down
** One plant combusted tall-oil pitch
*** One plant combusted tall-oil and barks

Table 3_App_3c Reported (negative emission figure in 1.A 2d Transferred CO_2) emissions in the inventory.

	1993	1995	2000	2005	2010	2011	2012	2013	2014	2015	2016	2017	2018	2019	2020	2021	2022
Reported transferred CO_2, kt	0.9	54.2	183.4	183.5	197.8	180.1	147.2	145.6	149.7	139.1	138.4	133.4	135.0	124.3	101.5	96.7	48.5

Statistics Finland has received kiln and plant level data of transferred CO_2 from 2005 to 2022 from the Energy Authority (one company is not in EU ETS anymore, the data on transferred CO2 are received from the company). The pulp and paper companies do not measure the amount of transferred CO_2 but calculate it based on the amount of produced PCC. The amount of transferred CO_2 from 1993 to 2004 has been calculated at Statistics Finland using the total amount of produced PCC (based on production data received from the Finnish Forest Industries). The amount of transferred CO_2 for 2013 to 2022 has been calculated at Statistics Finland using the amout of produced PCC (Production statistics as mentioned in Table 1_3c). Statistics Finland has also checked that CO_2 amount of every single plant (years 2005 to 2012) summed up is the same as the amount calculated from the total amount of PCC production.

Appendix_3d

Statement on potential CO_2 emissions from Calcium Carbonate in fibre sludge

Concerning the potential emission of CO_2 from calcium carbonate-water interaction in fibre sludge-bearing earth structures, we state the following:

Precipitated Calcium Carbonate, also known as PCC, is a widely used artificial additive in paper making processes, particularly as a filler in fine paper production. Depending on the material efficiency in papermaking, minor amounts of PCC will be carried along to effluent, where PCC will be recovered mainly by using a simple external purification method based on gravity. Since the essential part of papermaking is the use of chemical pulp, certain amounts of wood-based fibres can also be found from this recovered fraction.

PCC-bearing fibre sludge is nowadays mainly utilised in many earth construction applications, e.g., as a hydraulic barrier in landfill cover structures, in impermeable reactive walls and in the sub-base filter in roads and sport areas. Under these circumstances, it will be occasionally exposed to acid rainwater. Infiltration of water into a fibre sludge layer depends on its hydraulic conductivity, which is typically lower than 10-9 m/s.

The crystal forms of PCC are aragonite and calcite, depending upon manufacturing conditions. Typical for aragonite are needles and aggregates of needles, whereas calcite precipitates as scalenohedral or rhombohedral agglomerates, or prismatic particles. PCC is a very stable compound in moisture-free, neutral or alkaline conditions. When the pH of water containing calcium carbonate is between 8.4 and 9.9, the solubility of calcium carbonate as such is very small, only 25 mg/dm^3. However, the solubility in that case is also greatly dependent on the content of dissolved carbon dioxide in water. With very high carbon dioxide concentration, the solubility could even be 1,500 mg/dm^3. This is due to the decomposition of the bicarbonate formed in the solution. If the pH drops below 6.5–7.0, the solubility increases dramatically. A complex mixture is formed, including different soluble calcium cations and carbonate anions, depending on pH, concentration, and time.

Equilibrium relations between CO_2 in atmosphere, pH and carbonic acid components in water and precipitation/dissolution of calcium carbonate can be calculated using the following reactions and related equilibrium constants (Appelo and Postma, 1996, Garrels and Christ, 1965):

CO_2 (gas) + H_2O = H_2CO_3 (aq)	$KCO_2 = 10^{-1.47}$ (1)
$H_2CO_3 = HCO_3^- + H^+$	$K1 = 10^{-6.35}$ (2)
$CO_3^{2-} + H^+ = HCO_3^-$	$K_2 = 10^{10.33}$ (3)
$CaCO_3$ (s) = $Ca^{2+} + CO_3^{2-}$	$K_{sp} = 10^{-8.3}$ (4)
$H_2O = H^+ + OH^-$	$K_w = 10^{-14}$ (5)

By summing up equations one to four, the following net carbonate dissolution reaction is obtained:

$CaCO_3$ + CO_2 (gas) + H_2O = Ca^{2+} + $2HCO_3^-$ $K = 10^{-5.8}$ (6)

From the above equation, important stoichiometric conditions can be seen:

1) For two bicarbonate ions that are formed, one carbon ion is from calcium carbonate and the other one is from CO_2

2) For one Ca^{2+} ion dissolved one CO_2 molecule is consumed from the solution. In the open system, this CO_2 is replaced from the CO_2 in the atmosphere. In other words, dissolution of calcium carbonate contributes to the atmospheric CO_2 sink rather than causes emission of CO_2 gas.

What happens when rainwater is equilibrated with calcium carbonate in soil or sediment? This is demonstrated below under two different conditions:

1) A contact with atmospheric CO_2 is retained (open system) or

2) The system becomes closed to atmosphere before the reaction with calcium carbonate is started.

Results are shown in Table 1_App_3d. Rainwater, which is in equilibrium with the present CO_2 pressure of the atmosphere (10–3.5 atm) has a pH value of 5.66 and a total dissolved carbon content (CT) of 10–4.9 mol. In an open soil system, calcium carbonate will dissolve until the Ca^{2+} concentration of pore water reaches a value of around 20 mg/l and the total carbon content 10–3.0 mol. As far as calcium carbonate is present, the pH value of water is buffered by this reaction at 8.3. In a closed system, the dissolution of calcium carbonate is more restricted resulting in a Ca^{2+} concentration of around 6 mg/l, pH of 9.9 and a lower CT content compared to the open system. Evidently, the external source of atmospheric CO_2 in the open system promotes the solution reaction.

Table 1_App_3d. Contents of carbon species (mol) and Ca^{2+} (mg/l), pH, and PCO2 (atm) in rainwater before and after equilibration in soil with calcium carbonate in open and closed systems

	Rainwater	Carbonate-water Open system	Carbonate-water Closed system
logPCO_2	-3.5	-3.5	-6.0
pH	5.7	8.3	9.9
logH_2CO_3	-5.0	-5.0	-7.5
logHCO_3^-	-5.7	-3.0	-4.0
log CO_3^{2-}	-10.3	-5.0	-4.4
logCT	-4.9	-3.0	-3.9
Ca^{2+}	-	20	5.7

In conclusion, based on the above discussion, no CO_2 emission to the atmosphere can be expected from the dissolution of PCC if fibre sludge is used as a material in earth construction.

References

Appelo, C.A.J., Postma, D. 1996. Geochemistry, Groundwater and Pollution. A.A. Balkema, Rotterdam, 536 p.

Garrels, R.M., Christ, C.L., 1965. Solutions, Minerals, and Equilibria. Harper and Row, New York, 450 p.

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Appendix_3e

Quality assurance of emissions trading data (emissions and energy)

An installation under the EU emissions trading System requires an emission permit, on the basis of which it has the right to release greenhouse gases to the atmosphere. The permits are granted by the Energy Authority. In the emission permit application, the operator presents a monitoring plan showing the monitoring methods for the installation's greenhouse gas emissions. The European Commission has issued Regulation (EU) No 2018/2066 on the monitoring and reporting of greenhouse gas emissions, where the monitoring requirements and accuracy levels of emission data are defined. The operators report on their emissions by submitting annual emission reports to the Energy Authority for accounting the installations' emission volumes in the previous year. The emission reports must be verified before submitting them to the emissions trading authority. Verification is made by independent actors approved by the Energy Authority.

For monitoring the installation's emissions, the operator must decide whether to apply calculation-based methodology (standard and mass-balance methodology) or measurement-based methodology (CEMS, Continuous Emission Measurement Systems) for the monitoring. In special cases, emissions can be defined with a method that is not based on determination levels (the so-called fall-back methodology).

In the standard methodology, emissions caused by the combustion of each fuel are calculated based on the amount of fuel used. The net calorific value, emission factor and oxidation factor are used in calculating emissions. The used values are mainly fuel-specific values according to the classification of fuels published by Statistics Finland or the installation's fuel/fuel load-specific values determined in accredited laboratories.

In the methodology based on mass balance, the amount of the entering and leaving material is compared, and the carbon content of the material is taken into account in determining emissions. The mass-balance methodology is used in the steel industry, for example, where carbon is bound to products manufactured in the production process.

In methodology based on continuous emission measurement systems (CEMS), emissions must be determined by direct or indirect content measurement from flue gases. The measurement must be made with a method based on standards and the operator must ensure that the calibration of the measurement equipment is performed according to the standards.

Measuring equipment approved in the monitoring plan is used in determining the volume of fuel used or emissions. In the monitoring plan, requirements are set for determining emissions (and the measurement equipment) concerning calibration and the highest allowed uncertainty, for example. The requirement level depends on the installation's total emission volume and the annual emission volume of the fuel in question, so with larger emission volumes, the measurement accuracy must be better. For example, the highest allowed uncertainty for combustion plants can be, depending on what was mentioned above, ±7.5/5.0/2.5/1.5%. Determining the quantity of fuel can take place when the fuel arrives at the installation (e.g. weighing with a weighbridge) or closer to the actual use (e.g. flow measurement of boiler fuel).

In verifying the emission report, the operator must use a verifier approved and accredited in Finland on the basis of the Emissions Trading Act. The verification concerns the reliability, credibility and accuracy of the monitoring system and the reported emission figures and data. The verifiers belonging to the scope of the Emissions Trading Act are approved by the Energy Authority. The FINAS accreditation service acting as the external reviewer required by the act is responsible for assessing the competence of verifiers.

In the verification task, the verifier must comply with the Verification Regulation (EU) 2018/2067) issued by the European Commission. In the verification, the verifier examines that the operator has acted according to the requirements of the installation's monitoring plan and that the data reported in the emission report are accurate. The starting point is that the verifier visits each installation every year. In the verification, the calculation of the installation's emission data is reviewed and the reliability of the data is assessed. For example, the correctness of fuel volume data can be reviewed from indicators and correspondingly, the correctness of the emission factor/caloric value from the laboratory analysis certificate.

4 INDUSTRIAL PROCESSES AND PRODUCT USE (CRF 2)

4.1 Overview of the sector

4.1.1 Description and quantitative overview

The following problems caused by the CRF Reporter have been identified:

- *Empty cells of HFC, PFC, SF_6 and NF_3 in CRF tables in this sector should be NO and missing due to CRF Reporter problems.*
- *Notation key C prevents the aggregation in parent cells resulting incorrect emission figures. Finland does not consider manual input of emissions to these "pink cells" with the incorrect sums as a solution because it is time consuming and may result calculation or transfer errors easily. Therefore notation key IE is used instead of C for confidential data of F gases.*
- *Method and emission factors by sector in NID are not fully consistent with information in CRF tables. CRF Reporter is programmed in a way that method and emission factor information changes automatically to NA in categories, in which no emissions data is reported. NID includes correct method and emission factor information for subcategories in which emissions are reported as IE or C in order to improve transparency.*
- *Part of the NK explanations and official comments which are saved in the CRF Reporter are not visible in the CRF Tables. Explanations are included in the documentation boxes of CRF tables.*

Greenhouse gas emissions from Industrial Processes and Product Use contributed 11% to the total anthropogenic greenhouse gas emissions in Finland in 2022 (Figure 4.1-1), totalling 5.0 million tonnes of CO_2 equivalent (Mt CO_2 eq.).

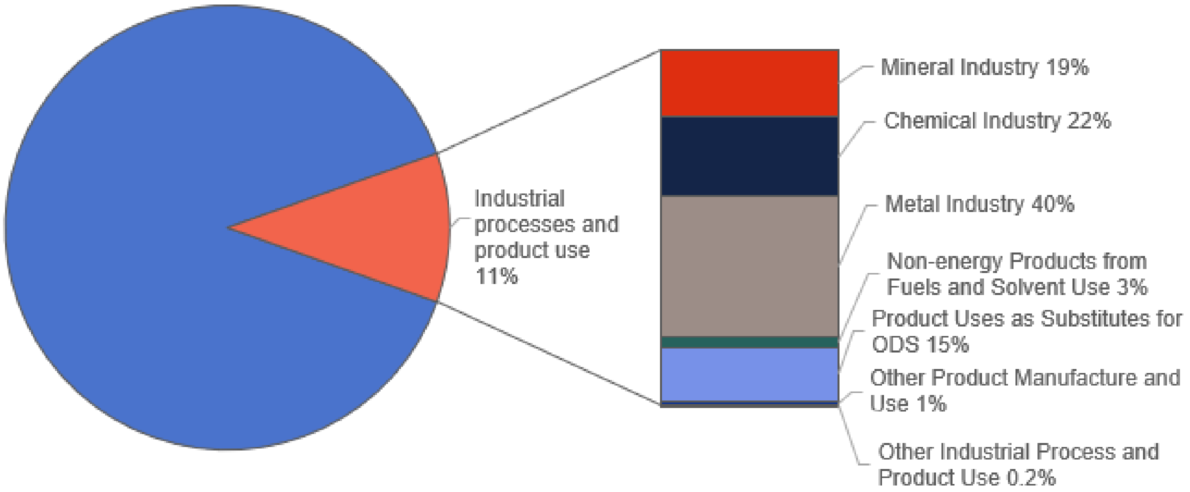


Figure 4.1-1 Emissions from Industrial Processes and Product Use compared with total emissions in 2022

Finnish greenhouse gas emissions from Industrial Processes and Product use are divided into the following emission categories:

- Mineral Products (CRF 2.A) includes CO_2 emissions from cement, lime and glass production, and other process uses of carbonates
- Chemical Industry (CRF 2.B) includes CO_2 emissions from hydrogen, phosphoric acid and formalin production and limestone and dolomite use in chemical industry, fugitive CH_4 emissions from ethylene production and N_2O emissions from nitric acid
- Metal Production (CRF 2.C) includes CO_2 emissions from coke and heavy bottom oil used in blast furnaces, zinc, copper and nickel production, and limestone and dolomite use and CH_4 emissions from coke production
- Non-energy Products from Fuel and Solvent Use (CRF 2.D) includes CO_2 emissions from lubricant, paraffin wax and urea use in NOx control and use of urea-based catalyst, also CH_4 and N_2O emissions are included from lubricant use
- All emissions from Electronics industry (2.E) are confidential and are, therefore, included in Other (2.H)
- Product Uses as Substitutes for ODS (CRF 2.F) covers emissions of F gases from refrigeration and air conditioning, foam blowing and aerosols. Emissions from some smaller sources, such as semiconductor manufacturing and fixed fire protection systems are reported in Other (2.H) due to confidentiality issues.
- Other Product Manufacture and Use (2.G) includes SF_6 emission from electrical equipment and N_2O emissions from Product uses. PFC emissions from electrical equipment and SF_6 emissions from other product use are reported in Other (2.H) due to confidentiality issues.
- Other (2.H) includes emissions of grouped confidential data of halocarbons and SF_6 (semiconductor manufacturing, fixed fire protection systems, magnesium die casting (until 2012), shoes (until 2007), ski wax (for 1999), research and other individual confidential emissions from 2.F and 2.G.1)

Emissions from limestone and dolomite use are reported in several CRF categories: 2.A.4a Other Process Uses of Carbonates; Ceramics, 2.A.4d Other Process Uses of Carbonates; Other, 2.B.10 Other; Limestone and Dolomite use and 2.C.1a Steel.

NMVOC emission from Industrial Processes and Product use are reported under CFR 2.B Chemical industry (2.B.10 Chemicals production), CRF 2.C Metal industry (2.C.7 Other), CRF 2.D Non-energy Products from Fuels and Solvent use (2.D.3 Other, Solvent use and Road paving with asphalt), 2.H Other (2.H.1 Pulp and paper and 2.H.2 Food and beverages industry). Indirect CO_2 emissions from NMVOC emissions are reported aggregated in national totals, see Chapter 9.

A general assessment of completeness can be found in Section 1.7 and a more detailed assessment is included in Annex 5.

The emissions from the Industrial Processes and Product Use sector have slightly decreased, by 5% since 1990 (Figure 4.1-2). Emissions of almost all categories of IPPU sector have decreased during time-series, only use of F gases (15-fold) have increased. The main reason for the growth is increased use of F gases in refrigeration and air-conditioning. The emissions from nitric acid production decreased rapidly due to the implementation of N_2O abatement technology in 2009. Emissions from the Industrial Processes and Product Use sector in decreased by 7% since 2021.

The most important greenhouse gas emission sources of Industrial Processes and Product Use in the Finnish inventory in 2022 were CO_2 emissions from iron and steel, hydrogen and cement production with 4.3%, 1.9% and 1.3% shares of the total national greenhouse gas emissions, respectively. F gas emissions comprised together 1.7% of the total greenhouse gas emissions in Finland.

Industrial CO_2 (4.0 Mt in 2022) emissions decreased considerably at the beginning of the 1990s, increased since 1996 until 2008, and fell by 25% in a year due to the economic turndown. In 2022, CO_2 emissions were 9% lower than in 2021 and 5% higher than in 1990.

N_2O emissions (0.2 Mt CO_2 eq. in 2022) have fluctuated during the period 1990 to 2022; the first significant decrease due to the closing of a plant and after that a slow increase of emissions, the second decrease originated from the above-mentioned implementation of N_2O abatement technology. On the whole, N_2O emissions have decreased by 89% since 1990. In 2022, emissions were 33% lower than in 2021.

Emissions of F gases (0.8 Mt CO_2 eq in 2022) have increased significantly since 1990 and were at the highest level in 2008 being then about 25-fold compared to 1990. Since 2008 F gas emissions have had a decreasing trend. In 2022, emissions were 8% lower than in 2021 but 15-fold compared to 1990. There are no fugitive emissions from manufacturing because F gases are not produced in Finland. There has not been any manufacturing of other fluorinated gases either, such as HCFCs or CFCs, which could lead to by-product emissions (e.g. HFC-23 from HCFC-22 manufacturing). Other point sources, which make a considerable contribution to F gas emissions elsewhere, but are absent in Finland, include the primary aluminium and magnesium industry.

CH_4 emissions (0.002 Mt CO_2 eq in 2022) have decreased by 71% since 1990 but their contribution to the total industrial emissions were only 0.03% in 2022.

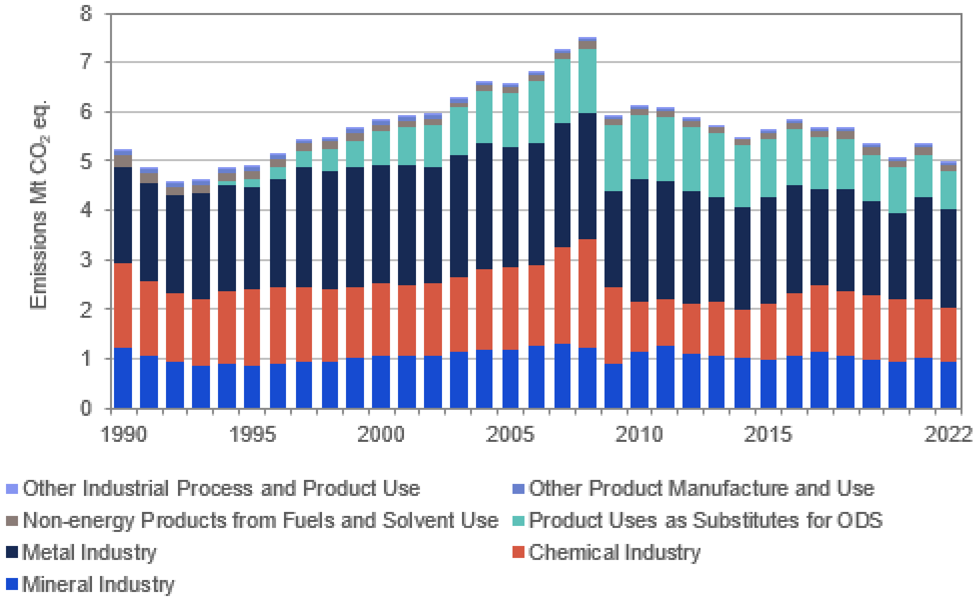


Figure 4.1-2 Total greenhouse gas emission from Industrial Processes and Product Use in Finland (Mt CO_2 eq.)

Total industrial emissions are divided between three sectors (Figure 4.1-3):

- Industrial process emissions are reported in sector 2: Industrial Processes and Product Use
- Emissions from fuel combustion in industry are reported in sector 1: Energy
- Waste and wastewater generated emissions in industry (except lime, dolomite and calcite use in wastewater treatment) are reported in sector 5. Emissions from combusted waste are reported in the energy sector.

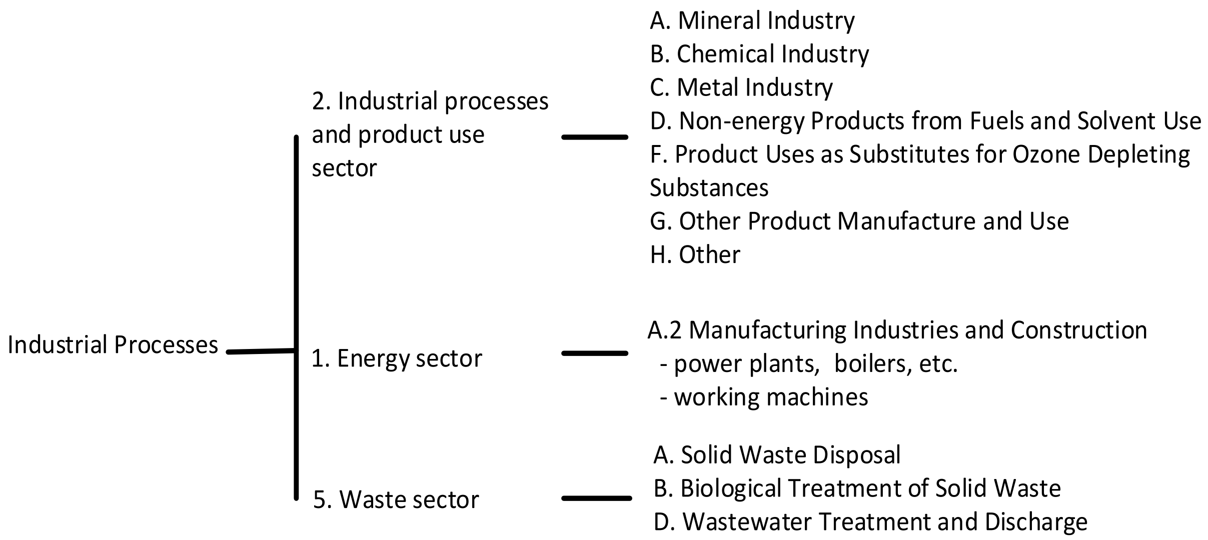


Figure 4.1-3 Reporting categories of emissions from industrial process sources in the national greenhouse gas inventory

4.1.2 Key categories

The key categories in Industrial Processes and Product Use are summarised in Table 4.1-1.

Table 4.1-1 Key categories in Industrial Processes and Product Use (CRF 2) in 1990 and 2022 (Approach 1 and Approach 2)

Category	Gas	Criteria	Method
2.A.1. Cement Production	CO_2	L, T	Tier 3 (1990 CS)
2.A.2. Lime Production	CO_2	L	Tier 3 (1990 CS)
2.B.2. Nitric Acid Production	N_2O	L, T	Tier 3 (1990 Tier 2)
2.B.10b Hydrogen Production	CO_2	L, T	Tier 2
2.C.1. Iron and Steel Production	CO_2	L, T	Tier 3, CS
2.C.7 Other Metal Industry	CO_2	L	Tier 3
2.D.1 Lubricant Use	CO_2	L	
2.F.1. Refrigeration and Air Conditioning	HFCs	L, T	Tier 2

Table 4.1-2 Trend in greenhouse gas emissions from Industrial Processes and Product Use (Mt CO_2 eq.)

	1990	1995	2000	2005	2010	2013	2014	2015	2016	2017	2018	2019	2020	2021	2022
CO_2															
A Mineral industry	1.22	0.87	1.08	1.18	1.17	1.06	1.03	0.97	1.08	1.14	1.06	0.97	0.95	1.02	0.94
B Chemical industry	0.28	0.27	0.28	0.30	0.87	0.91	0.77	0.91	1.03	1.14	1.10	1.14	1.05	0.96	0.97
C Metal industry	1.98	2.08	2.39	2.40	2.44	2.09	2.07	2.15	2.20	1.93	2.10	1.87	1.76	2.09	1.97
D Non-energy products from fuel and solvent use	0.22	0.19	0.14	0.10	0.11	0.13	0.11	0.14	0.14	0.14	0.16	0.15	0.13	0.15	0.13
CH_4															
B Chemical industry	0.0052	0.0052	0.0028	0.0027	0.0027	0.0016	0.0013	0.0020	0.0012	0.0041	0.0027	0.0010	0.0013	0.0016	0.0014
C Metal industry	1.4E-06	2.6E-06	2.5E-06	2.5E-06	2.3E-06	2.5E-06	2.5E-06	2.5E-06	2.1E-06	2.1E-06	2.2E-06	2.3E-06	2.1E-06	2.3E-06	2E-06
D Non-energy products from fuel and solvent use	0.00032	0.00027	0.0002	0.00013	0.00013	0.00016	0.00013	0.00017	0.00017	0.00016	0.00018	0.00018	0.00014	0.00016	0.00014
N_2O															
B Chemical industry	1.42	1.25	1.17	1.39	0.14	0.19	0.18	0.23	0.19	0.21	0.19	0.18	0.20	0.22	0.14
D Non-energy products from fuel and solvent use	0.0015	0.00129	0.00093	0.00062	0.00063	0.00074	0.00062	0.00079	0.0008	0.00077	0.00087	0.00084	0.00068	0.00078	0.00065
G Other product manufacture and use	0.057	0.057	0.049	0.043	0.029	0.024	0.024	0.021	0.022	0.023	0.020	0.016	0.014	0.030	0.021
HFCs	2E-05	0.149	0.693	1.123	1.321	1.291	1.258	1.193	1.134	1.064	1.015	0.969	0.904	0.837	0.763
PFC	0.00019	0.00152	0.00316	0.00358	0.00253	0.00419	0.00376	0.00139	0.00138	0.0015	0.00159	0.00177	0.00149	0.00159	0.00153
SF6	0.054	0.038	0.027	0.023	0.022	0.032	0.036	0.023	0.032	0.028	0.025	0.024	0.026	0.0279	0.0280
NF3	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO
Total	**5.22**	**4.91**	**5.82**	**6.57**	**6.11**	**5.74**	**5.49**	**5.63**	**5.84**	**5.67**	**5.67**	**5.34**	**5.04**	**5.34**	**4.98**

4.2 Mineral Industry (CRF 2.A)

4.2.1 Introduction

This category consists of non-fuel carbon dioxide emissions from cement, lime and glass production and other process uses of carbonates (Table 4.2-1 and Table 4.2-2) The use of limestone and dolomite other than for clinker and lime production are reported by branch of businesses according to the 2006 IPCC Guidelines. In Finland under the Mineral Industry, these emissions are reported from ceramics and mineral wool production, from wastewater treatment, from the neutralisation, from energy industry for sulphur dioxide control and use of soda ash and combustion of limestone content of de-inking sludge. Emissions from limestone and dolomite use in the chemical or metal industries are reported under corresponding categories.

Lime production includes lime production in the iron and steel industry. All soda ash is used in Finland are included in the inventory. All other uses of soda ash than use in glass production (2.A.3) are reported in CRF category 2.A.4b.

Production capacity of clinker in Finland at the end of the time series is about 1,300,000 t (1,600,000 t cement), but in 2022, altogether 1,180,000 t clinker were produced (EU ETS). The production capacity has been increasing during the time series when old cement kilns have been modernised or replaced.

Table 4.2-1 Reported emissions, calculation methods and type of emission factors for the subcategory Mineral Industry in the Finnish inventory

CRF	Source	Emissions reported	Method	Emission factor
2.A.1	Cement production	CO_2	Tier 3 (2005-2022) CS (1990-2004)	PS CS
2.A.2	Lime production	CO_2	Tier 3 (2008-2022) CS (1990-2007)	CS
2.A.3	Glass production	CO_2	Tier 3	CS
2.A.4	Other process uses of carbonates			
	- Ceramics	CO_2	Tier 3	CS
	- Other uses of Soda Ash	CO_2	Tier 1	D
	- Other	CO_2	Tier 3	CS

The emissions of the category Mineral Industry were 23% of the emissions of the Industrial Processes and Product Use sector in 1990 and 19% in 2022 as well as 2.0% of Finland’s total greenhouse gas emissions in 2022. The amount of emissions was 1.2 Mt in 1990 and 0.9 Mt in 2022 (Figure 4.2-1). The emissions in 2022 were 23% lower than in 1990 and 8% lower than in 2021. The main reasons for emission reduction since 1990 have been a closing down of a cement plant and glass plants in the beginning of the time series. In 2022 the decreased production of cement and lime had a significant impact on the fall of the emissions in Mineral Industry.

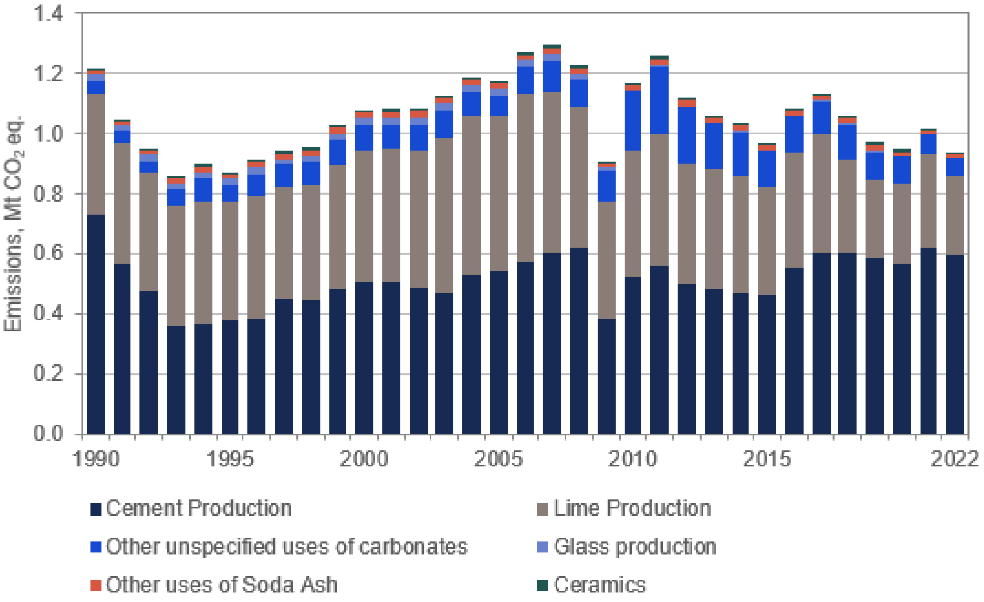


Figure 4.2-1 Greenhouse gas emission from Mineral Products (Mt CO_2 eq.)

Cement production is the biggest source of greenhouse gas emissions in the Mineral Industry category, being 0.6 Mt in 2022. Emissions were 14% in 1990 and about 12% in 2022 of the emissions in the Industrial Processes and Product Use sector and 1.3% of Finland’s total emissions in 2022. The production volume decreased rapidly at the beginning of the 1990s due to the reduced need for clinker during the recession and the closing down of a plant in 1993. The output grew slightly until 2008, but due to the economic downturn in 2009, the demand for clinker decreased fast and the output in 2009 was 40% smaller than in 2008. In 2022, there were 18% less emissions from cement production than in 1990 and 4% less emissions than in 2021.

Lime production is the second largest source in the Mineral Industry category, the emissions were 0.3 Mt in 2022. The emissions have been less than 9% of this sector’s emissions for the whole time series. Production of lime has been slowly increasing until 2006, but after that production has decreased by 53%. One lime plant was not used at all in 2011 due to decreased demand of lime, in 2012 the operation continued, but in 2019 the plant was closed down. The production of another lime plant ceased in 2014. In 2018 the competitive situation was very challenging, one plant lost a significant customer, therefore production was lower than in 2017. Demand of lime turned to a rise, but it folded in 2021 and emissions were in 2022 16% lower than in 2021. Emissions from lime production were 35% lower than in 1990.

Other process uses of carbonates is the third largest source in the Mineral Industry category, emissions were 0.08 Mt in 2022. Emissions of the most important sources were limestone and dolomite used in wastewater treatment and neutralisation 44%, soda ash use 19% and limestone and dolomite use in the energy industry for sulphur dioxide control 14% of emissions of this subcategory in 2022. Since 1990, emissions have increased 21%, the biggest reason were the increased use of carbonates in wastewater treatment. Emissions of other process uses of carbonates were 2% lower in 2022 than in 2021.

Glass production is a minor source in the category of Mineral Industry, emissions were 0.002 Mt in 2022. The emissions have been less than 0.5% of this sector’s emissions for the whole period. Due to the economic downturn in 2009, two plants in the Finnish glass industry were closed down. Emissions from glass production have decreased by 90% since 1990. In 2022, emissions from glass production were about 0.04% of the emissions of Industrial Processes and Product Use sector and 0.2% of the Mineral Industry category.

Table 4.2-2 CO_2 emissions from Mineral Products (Mt)

	1990	1995	2000	2005	2010	2013	2014	2015	2016	2017	2018	2019	2020	2021	2022
2.A 1 Cement production	0.73	0.38	0.50	0.54	0.53	0.48	0.47	0.46	0.55	0.60	0.60	0.58	0.57	0.62	0.60
2.A 2 Lime production	0.40	0.39	0.44	0.51	0.42	0.40	0.39	0.36	0.39	0.40	0.31	0.26	0.27	0.31	0.26
2.A 3 Glass production	0.021	0.020	0.021	0.020	0.002	0.002	0.003	0.002	0.002	0.003	0.003	0.002	0.002	0.002	0.002
2.A 4 Other process uses of carbonates	0.07	0.08	0.11	0.10	0.22	0.17	0.17	0.14	0.14	0.13	0.15	0.12	0.11	0.08	0.08
- Ceramics	0.007	0.007	0.011	0.009	0.007	0.006	0.006	0.004	0.005	0.006	0.006	0.009	0.007	0.007	0.006
- Other uses of soda ash	0.013	0.016	0.017	0.018	0.017	0.021	0.017	0.017	0.019	0.017	0.021	0.022	0.013	0.010	0.015
- Other unspecified uses of carbonates	0.047	0.060	0.085	0.072	0.200	0.147	0.148	0.123	0.120	0.109	0.121	0.094	0.090	0.066	0.060
Total of Mineral industry	**1.22**	**0.87**	**1.08**	**1.18**	**1.17**	**1.06**	**1.03**	**0.97**	**1.08**	**1.14**	**1.06**	**0.97**	**0.95**	**1.02**	**0.94**

4.2.2 Cement production

4.2.2.1 Category description

In the production of cement, CO_2 is emitted when an intermediate product, clinker, is produced. In that process, limestone is heated to a high temperature in rotary kiln ovens, which results in CO_2 emissions, as the main component of limestone, calcium carbonate breaks down, calcinates, into calcium oxide and carbon dioxide. Limestone also contains small amounts of magnesium carbonate ($MgCO_3$), which will also calcinate in the process causing CO_2 emissions (Slioor, 2004). In Finland average CaO content for clinker is 65% and MgO 3% (Leveelahti, 2015)

CRF category 2.A.1 covers CO_2 emissions from clinker production. Clinker is mixed with gypsum and other materials that together make up the cement.

The mixture of raw material fed into the oven is called the raw mix. The main carbonaceous components of the raw mix are limestone ($CaCO_3$) and dolomite ($CaCO_3$ * $MgCO_3$). When heated to 1,400 to 1,500 degrees centigrade, CO_2 is released. For example, the reaction for limestone is:

$$CaCO_3 \text{ --> } CaO + CO_2$$

There are currently two operating plants in Finland. Production at a third plant ceased in 1993.

4.2.2.2 Methodological issues

Emissions were calculated using the Tier 3 methodology from the 2006 IPCC Guidelines (Equation 2.3). Tier 3 is based on the collection of disaggregated data on the types and quantities of carbonates consumed to produce clinker using respective emission factors. The share of different types of carbonates in raw mix varies annually and therefore CO_2 IEF changes between years. Also emissions from other carbon bearing non-fuel materials were calculated. The Tier 3 approach includes emissions from cement kiln dust. At the moment cement kiln dust calcinates only at one plant as dust is removed before the calcination process at the other plant. The process was changed in 2004.

Correction factors for non-carbonate CaO or MgO sources (e.g. blast furnace slag, nickel granule slag, diabase, fly ash, gypsum, bauxite, mineral waste, Finnsementti Oy, 2021) in the raw mix are used in the calculations. Fly ash is the main substance of carbon bearing non-fuel materials used in the production process. The plant-specific correction factors differ but average value is about 0.88. (Leveelahti, 2016). This means that there is about 12% of CaO and MgO in clinker from non-carbonate raw materials and therefore IEF of cement production is lower than average.

Since 2005 (Emissions trading periods) data on the amount and emissions of produced clinker, cement kiln dust and used fly ash are available. Emissions for the inventory for these years are as reported to EU ETS. Emission factors are plant-specific.

For the years prior to 2005 data on emissions or amount of fly ash are not available, and data on cement kiln dust is not complete. Only clinker production data of all plants is available for the whole time series. Therefore, to calculate emissions for years 1990 to 2004 annual emission factors were calculated by dividing total emissions from EU ETS with amount of produced clinker by plant in a certain year. The average value of these plant-specific emission factors was multiplied with clinker data for 1990 to 2004 for the plant in question to calculate the plant-specific emissions. The average value of both plants was used to calculate emissions for the closed plant for years 1990 to 1993. This method is described as country-specific.

4.2.2.3 Uncertainty assessment and time series' consistency

Quantitative estimates of uncertainty are provided in Annex 2. The annex also documents assumptions made for the analysis. A description of uncertainty analysis is included in Section 1.6.

The uncertainty for activity data is 2% and for emission factors 5%.

All activity data (clinker data) for years 1990 to 2007 had been received directly from the company. After a comparison of directly received and EU ETS data for years 2005 to 2007, it was decided to give up separate inquiries because those data were equal. Time series of activity data are therefore proved to be consistent.

As two different methods are used to calculated emissions, country-specific method for 1990 to 2004 and Tier 3 for 2005 to 2016, question of time series' consistency arises. To check if the reported time series of emissions are consistent, the total time series were calculated using the country-specific method. The time series were proved to be consistent because the difference between these two calculations was 2% at most, average value being 1% (Figure 4.2-2).

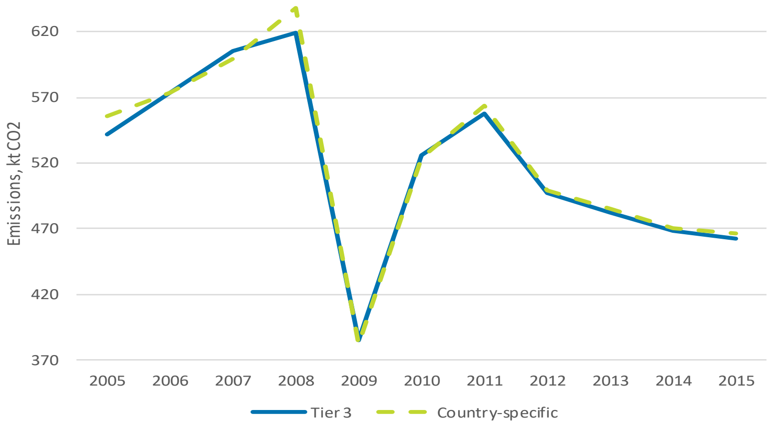


Figure 4.2-2 Time series' consistency of emissions from cement production

4.2.2.4 Category-specific QA/QC and verification

The quality objectives and the QA/QC plan for the Finnish greenhouse gas inventory at the national inventory level are presented in Section 1.5. The QC procedures are performed according to the QA/QC plan in the Mineral products sector in order to attain these quality objectives. A bilateral quality meeting or a quality desk review is held annually between the inventory unit and the sectoral expert. In the quality meeting in February 2024 the recalculations and improvement plans were discussed.

The auditing of working instructions by summer trainee in 2021 reassured the adequacy of written instructions to perform the calculation for the first time. The summer trainee found a couple of linking errors in the calculation sheets for 2020, these errors were corrected for the sheets used for reporting. The summer trainee also gave some suggestions for improvement for the working instructions to clarify the method of calculation.

Activity data have been checked using available independent sources and only slight differences between the data have been noticed. All activity data are site-specific, received from a company or reported due to monitoring of the environmental or emissions trading permit of a company. The sum of the individual plant-level emission estimates and emission estimates based on national clinker production figures and IPCC default Tier 1 factors were compared to verify emission calculation. Differences between these annual emission data were at average less than 5% which is even less than the uncertainty of emissions data of cement production.

4.2.2.5 Category-specific recalculations

There are no category-specific recalculations.

4.2.2.6 Category-specific planned improvements

There are no category-specific planned improvements.

4.2.3 Lime production

4.2.3.1 Category description

Limestone is a sedimentary carbonate rock consisting mainly of calcite mineral i.e. calcium carbonate. In Finland pure limestone contains 95% to 100% calcium carbonate. (Quick) Lime is produced by heating crushed and assorted limestone to a high temperature (about 1,000ºC) in a rotary or a shaft kiln. Lime (CaO) is granular or powdery, different products are made crushing, screening and grinding. The production process causes CO_2 emissions. Hydrated lime, $Ca(OH)_2$, is produced via (quick)lime by adding water to it.

At the moment there are four lime-producing plants in Finland, one plant was closed down at the end of 2014 and another one was closed down in 2019.

4.2.3.2 Methodological issues

Emissions are calculated using a Tier 3 methodology for since 2008, and for 1990 to 2007 using a country-specific method, which corresponds to the Tier 2 method. Plant-specific emissions from lime production are calculated by multiplying emission factors with lime production.

Activity data for the different plants for years 1990 to 1997 have been estimated by using the proportion of the production data of these plants in 1999 as only national total production data could be collected from the industrial statistics. For 1998 to 2004, production data have been partly collected from the industry and partly taken from industrial statistics and environmental permits or the YLVA (formerly VAHTI) system. Emissions from 2005 onwards have been calculated using production data reported to the EU ETS data. The total amount of produced lime has also been crosschecked with data from industrial statistics.

Plant-specific emission factors have been calculated dividing the EU ETS emissions (since 2008) with lime production data. All emissions from production processes have been taken into account; because emissions are generated not only from produced lime, but also from lime recovered from electric filter dust and downgraded lime which are generated as by-products during the process. Lime dust has normally been used in agriculture or in industry and downgraded lime has been dumped or used to fill up quarries, and amounts of lime dust or downgraded lime are not included in produced lime. Data on emissions or amounts of recovered lime and downgraded lime were not available prior to 2008. Therefore, only the emission data for 2008 to 2016 have been used to calculate plant-specific emission factors. The emission factor for a plant is an average of these annual emission factors.

For 1990 to 2007, the emissions for each plant have been calculated with the plant-specific emission factor multiplied with corresponding lime production data. Since 2008, the EU ETS data have been used for the emissions.

The implied emission factors and the total activity data of the time series can be found in Table 4.2-3.

4.2.3.3 Uncertainty assessment and time series’ consistency

Quantitative estimates of uncertainty are provided in Annex 2. The annex also documents assumptions made for the analysis. A description of the uncertainty analysis is included in Section 1.6.

For 2022, the uncertainty in lime production is partly due to the small margin of error associated with the measurements of lime produced. The uncertainty of the emission factors (to calculate emissions for 1990 to 2007) is slightly less than in those estimated using the earlier method as they are based on total emissions of a plant for nine years. Uncertainty for activity data were 2% and for emission factor 3%.

As two different methods are used to calculate the emissions, country-specific method for 1990 to 2007 and Tier 3 from 2008 on, the time series’ consistency was checked by calculating the 2008 to 2016 emissions also with the country-specific method. Results were compared with the emissions calculated with the Tier 3 method. Differences between the emissions were -0.2% to 0.8%. Therefore, the time series can be considered to be consistent.

4.2.3.4 Category-specific QA/QC and verification

The quality objectives and the QA/QC plan for the Finnish greenhouse gas inventory at the national inventory level are presented in Section 1.5. The QC procedures are performed according to the QA/QC plan in the Mineral products in order to attain these quality objectives. A bilateral quality meeting or a quality desk review is held annually between the inventory unit and the sectoral expert. In the quality meeting in February 2024 the recalculations and improvement plan were discussed.

In the calculation of emissions from lime production, general inventory quality control procedures have been done as mentioned in 2006 IPCC Guidelines, Table 6.1. Some of the checks are performed annually, like comparing with previous emissions of subcategory of the calculated emissions and ensuring that there are no transcription errors in calculations.

In addition, category-specific quality control procedures have been carried out during calculation. The used emission factors have been compared with the IPCC default emission factors. The used emission factors are based on accurate measurements of CaO and MgO content of lime, lime dust and downgraded lime and represent therefore the best possible knowledge of the plant-specific production processes and used raw materials. Activity data have been checked using available independent sources and only very small differences between figures have been noticed. All activity data are plant-specific and reported to industrial output statistics or reported due to monitoring of the environmental or emissions trading permits (EU ETS) of a company.

The sum of the plant level emissions calculated with the method introduced in 2018 submission and emission estimates based on total produced lime and IPCC default Tier 1 factors were compared to verify the emission calculation. Differences between these annual emission data were from 6% to 9% (default factor gives lower emissions), which can be explained with the information that the part of the emissions are not from the produced lime but from lime dust and downgraded lime which are generated as by-products during the process.

4.2.3.5 Category-specific recalculations

There were no category-specific recalculations.

4.2.3.6 Category-specific planned improvements

The calculation method will be checked due to changed production data of lime (this will not affect the emissions as they are as reported to EU ETS).

4.2.4 Glass production

4.2.4.1 Category description

The glass industry in Finland has produced a wide range of different glass types with different chemical compositions, for example container, flat, domestic and special glass and glass wool. Emissions are calculated using the use of carbonates as activity data.

Limestone, dolomite and soda ash are typically used in the glass industry. Barium and potassium carbonate are used as raw materials in the production of special glasses and lithium carbonate is used to strengthen glass products. Emissions from the use of barium, lithium and potassium carbonate in glass production are also included in the inventory.

In production, homogenous glass mixtures combining primary and secondary raw materials are melted down at temperatures of about 1,550ºC. The process-related CO_2 emissions are released from the raw material carbonates during the melting process in the furnace.

4.2.4.2 Methodological issues

Emissions are calculated using the Tier 3 method (Equation 2.12 from 2006 IPCC Guidelines), as various types of carbonates consumed for glass production have been collected at plant level. Process emissions in glass production are generated from limestone, dolomite, soda ash (= sodium carbonate), barium carbonate, lithium carbonate and potassium carbonate use, and they are calculated by multiplying emission factors with the amount of used carbonates.

Emission factors are the IPCC's default factors and stoichiometric ratio of chemical reactions. For barium carbonate the emission factor is 0.223 t CO_2/ t $BaCO_3$, lithium carbonate 0.595 t CO_2 / t Li_2CO_3 and potassium carbonate 0.318 t CO_2 / t K_2CO_3.

The consumption of limestone and dolomite has been used as activity data when calculating emissions from limestone and dolomite use. Activity data for 2022 are collected directly from individual companies and the EU ETS data. Most of the data for the earlier years have been received from individual companies, EU ETS and a smallish part has been estimated using industrial statistics.

Activity data of used sodium carbonate are collected directly from individual companies. For some early years not all activity data have been received directly from companies. In these cases, the data of industrial statistics or estimations based on the data of other years have been used.

Activity data for consumption of barium, lithium and potassium carbonate are collected from companies for years 1995 to 2004 and 2007 to 2022. Activity data for the remaining years are estimated using partly production data and partly activity data from other years (Forsell, 2012).

4.2.4.3 Uncertainty assessment and time series' consistency

Quantitative estimates of uncertainty are provided in Annex 2. The annex also documents assumptions made for the analysis. A description of the uncertainty analysis is included in Section 1.6.

The uncertainty for activity data were 5% and for emission factors 3%.

4.2.4.4 Category-specific QA/QC and verification

The quality objectives and the QA/QC plan for the Finnish greenhouse gas inventory at the national inventory level are presented in Section 1.5. The QC procedures are performed according to the QA/QC plan in the Mineral products sector in order to attain these quality objectives. A bilateral quality meeting or a quality desk review is held annually between the inventory unit and the sectoral expert. In the quality meeting in February 2024 the recalculations and improvement plan were discussed..

In the calculation of emissions from glass production, general inventory quality control procedures have been performed as mentioned in 2006 IPCC Guidelines, Table 6.1 Some of the checks are performed annually, like comparing with previous emissions of subcategory of the calculated emissions and ensuring that there are no transcription errors in the calculations. Some of the checks have been performed when the calculation method has been developed.

Also, category-specific quality control procedures have been carried out during calculation. The default emission factors have been defined to be adequate for Finnish circumstances and processes. Activity data have been checked using as many independent sources as possible and only small differences between figures have been noticed. All activity data are site-specific and reported to industrial output statistics or reported due to monitoring of the environmental permit of a company. The calculated emission data have been compared with ETS data and emissions have been found to be almost equal (+/-2%). Quality assurance of emissions trading data is described in Appendix 3e.

4.2.4.5 Category-specific recalculations

The use amount of $LiCO_3$ were corrected for 2021, emissions increased 1.0 t CO_2.

4.2.4.6 Category-specific planned improvements

No category-specific improvements have been planned.

4.2.5 Other process uses of carbonates

4.2.5.1 Category description

Other process uses of carbonates comprises limestone, dolomite, barium carbonate and sodium bicarbonate uses in ceramics and mineral wool production, in wastewater treatment, in neutralisation and in the energy industry for sulphur dioxide control and use of soda ash and clay. Also combustion of limestone content of de-inking sludge is included in Other process uses of carbonates. There is no non-metallurgical magnesia production in Finland.

4.2.5.2 Methodological issues

Ceramics

Emissions from limestone, dolomite, barium carbonate and clay use in production of light expanded clay aggregate (leca), tiles and porcelain are included in the subcategory of ceramics.

Emissions from limestone, dolomite and barium carbonate use are calculated using the Tier 3 method by multiplying emission factors with activity data. Activity data are collected mainly directly from the industry but industrial statistics have also been used to calculate emissions at the beginning of the time series.

The emission factors are default emission factors, for limestone 0.44 t CO_2/t carbonate, dolomite 0.48 t CO_2/t carbonate (Table 2.1, Vol 3. 2006 IPCC Guidelines) and barium carbonate 0.223 t CO_2/t carbonate. The correction factor from Equation 2.16 (2006 IPCC Guidelines) is 1.0. The C content and moisture of the clay has a big effect on the CO_2 emissions from use of clay. The EF varies highly between the loads of clay, for instance C content of a plant for one sort of clay it was 0.6% and for the other sort 1.2%. This leads to big variation of amount of CO_2 emissions in ceramics. If the emissions for clay were not available, emission were estimated using amount of wet clay, moisture content and EF (3.664 t CO_2/t C) (Forsell, 2019).

Emissions from the use of clay in ceramics production are since 2008 as reported for the EU ETS. Amounts of used clay in different plants for 1990 to 2007 were not available and therefore surrogate method (Equation 5.2, Vol 1, Chapter 5, 2006 IPCC Guidelines) was used to determine emissions from use of clay. Energy use of a plant was the only information available for the whole time series and therefore it was decided to use this information as a surrogate statistical parameter. Firstly, the ratio between emissions from the use of clay and amount of used energy of a plant was calculated for each year between 2008 and 2017. Secondly, the average of three plant level ratios and use of energy in a particular year were used to calculate emissions of the use of clay for 1990 to 2007.

In ceramics production, activity data available for the whole time series are limestone, dolomite, barium carbonate use. Data on the use of clay is available only since the start year of the EU ETS and these data are not coherent for all years. For some years they are reported only as carbon in clay and for other years as total use of clay. Therefore, the data on the use of clay is not reported. For 1990 to 2007, due to calculation of the emissions using surrogate method there are no activity data of clay available.

Other uses of soda ash

All uses of soda ash in Finland are assumed to release CO_2 emissions. However, the soda ash that is used in glass production is subtracted and corresponding emissions are reported under category 2.A.3. Even if this methodology may lead to a slight overestimation of emissions, Finland has not planned to clarify which soda ash uses are emissive and which non-emissive because it would be too resource demanding considering the size of this category.

CO_2 emissions from soda ash (Na_2CO_3) use are released when it is heated at high temperatures. Emissions are calculated by multiplying emission factors with the amount of used soda ash (Tier 1 method from Equation 2.14 (2006 IPCC Guidelines)).

The emission factor is the IPCC’s default factor, 0.415 t CO_2/ t carbonate (Table 2.1, Vol 3. 2006 IPCC Guidelines).

Activity data are calculated using Customs Statistics by subtracting annual export of soda ash from import (there is no production of soda ash in Finland). Also, the amount of soda ash, which is used in glass production, is subtracted from that amount. Imported and exported amounts are received from the Customs statistics database Uljas.

Other

In the category Other, Finland reports emissions from limestone, dolomite and sodium bicarbonate use in mineral wool production, in wastewater treatment, in neutralisation and in the energy industry for sulphur dioxide control. The ESD review of 2016 submission recommended that Finland allocate emissions of combustion of de-inking sludge containing PCC (see Section 3.4) to Industrial Processes and Product Use. Therefore, combustion emissions of de-inking sludge are included in the category Other and at the same time, the same amount of CO_2 emissions were subtracted from Energy (1.A.2d).

Emissions limestone, dolomite and sodium bicarbonate use are calculated using the Tier 3 method by multiplying emission factors with activity data. Activity data are collected mainly directly from the industry but industrial statistics have also been used to calculate emissions at the beginning of the time series.

The emission factors are default emission factors, for limestone 0.44 t CO_2/t carbonate, dolomite 0.48 t CO_2/t carbonate (Table 2.1, Vol 3. 2006 IPCC Guidelines) and sodium bicarbonate 0.524 t CO_2/t carbonate. The correction factor from Equation 2.16 (2006 IPCC Guidelines) is 1.0 if the fraction of calcination is unknown. For mineral wool production correction factor has been 0.90 to 0.96 and in energy industry 0.95 to 0.99. These correction factors have been used for plants for which emissions for EU ETS have been calculated using same correction factor.

Table 4.2-3 Activity data and emission factors for Mineral Products

	1990	1995	2000	2005	2010	2013	2014	2015	2016	2017	2018	2019	2020	2021	2022
2.A 1															
Clinker production, 1 000 t	1 470	760	1 017	1 110	1 049	973	941	934	1 117	1 181	1 187	1 142	1 141	1 220	1 185
EF t/t	0.496	0.497	0.496	0.488	0.501	0.495	0.498	0.495	0.495	0.511	0.507	0.511	0.499	0.510	0.504
2.A 2															
Lime production, 1 000 t	488	479	540	632	514	501	481	445	480	495	384	327	332	393	327
EF t/t	0.821	0.820	0.817	0.815	0.811	0.805	0.809	0.808	0.806	0.800	0.806	0.801	0.800	0.787	0.793
2.A 3															
Carbonate consumption, 1 000 t	44.7	39.5	44.1	47.4	4.1	5.1	6.4	5.1	5.3	6.3	7.2	5.0	4.0	4.5	4.9
EF t/t	0.469	0.494	0.487	0.430	0.389	0.402	0.404	0.404	0.402	0.405	0.408	0.402	0.400	0.398	0.411
2.A 4															
2.A 4a Ceramics															
Carbonate consumption, 1 000 t	6.9	8.6	13.6	10.5	6.5	4.4	4.9	3.2	3.6	3.9	4.6	5.0	5.5	6.1	4.8
EF t/t	1.064	0.797	0.793	0.866	1.016	1.322	1.307	1.139	1.332	1.558	1.272	1.809	1.310	1.198	1.323
2.A 4b Other uses of Soda Ash															
Soda ash consumption, 1 000 t	31.5	39.2	41.8	44.2	41.4	50.9	41.8	39.9	44.8	41.5	51.0	53.9	32.4	23.4	37.2
EF t/t	0.415	0.415	0.415	0.415	0.415	0.415	0.415	0.415	0.415	0.415	0.415	0.415	0.415	0.415	0.415
2.A 4d Other															
Other carbonate consumption, 1 000 t	107.9	140.0	201.5	167.9	457.3	335.3	338.0	279.7	271.9	248.4	274.2	213.0	203.7	151.1	135.0
EF t/t	0.436	0.431	0.421	0.426	0.437	0.438	0.439	0.439	0.440	0.440	0.440	0.439	0.440	0.439	0.442

4.2.5.3 Uncertainty assessment and time series' consistency

Quantitative estimates of uncertainty are provided in Annex 2. The annex also documents assumptions made for the analysis. A description of the uncertainty analysis is included in Section 1.6.

Uncertainty in activity data of limestone, dolomite, soda ash and other carbonate use of this category were estimated to be ±4% and uncertainty of emission factors of these emissions is 2%. The share of MgO in dolomite has been assumed to be constant and the possibility that limestone can also be include in a small amount of MgO has been taken into account. Another source of uncertainty is the amount of carbonates that actually reacts by releasing carbon dioxide in the various processes.

Due to lack of data concerning some earlier years, the time series are calculated using partly estimated data. For years prior to 2000, all activity data have not been gained directly from companies, but industrial statistics or estimations based on data from other years have been used. The time series are consistent.

4.2.5.4 Category-specific QA/QC and verification

The quality objectives and the QA/QC plan for the Finnish greenhouse gas inventory at the national inventory level are presented in Section 1.5. The QC procedures are performed according to the QA/QC plan in the Mineral products sector in order to attain these quality objectives. A bilateral quality meeting or a quality desk review is held annually between the inventory unit and the sectoral expert. In the quality meeting in February 2024 the recalculations and improvement plan were discussed.

In the calculation of emissions from limestone, dolomite and soda ash use, several general inventory quality control procedures have been performed as mentioned in 2006 IPCC Guidelines, Table 6.1. Some of the checks are performed annually, like comparing with previous emissions of subcategory of the calculated emissions and ensuring that there are no transcription errors in calculations. Some of the checks have been performed when the calculation method has been developed.

In addition, category-specific quality control procedures have been carried out during calculation. In use of limestone and dolomite, the default emission factor multiplied with the correction factor has been defined to be adequate for Finnish circumstances and processes, because default emission factors are stoichiometric; based on chemical equations and the content of carbonate in limestone and dolomite used in Finland is very high. The fluctuations in emission factors of limestone use have been checked, and the reason for it has been originated from different calcium carbonate content in used limestone. In the use of soda ash, the default emission factor has been defined to be adequate for Finnish circumstances and processes. The default emission factor is stoichiometric and the content of carbonate in sodium carbonate used in Finland is very high.

Activity data have been checked using as many independent sources as possible and only small differences between figures have been noticed, the results of the comparisons are included in the calculation sheets. This activity data are site-specific and reported to industrial output statistics or reported due to monitoring of the environmental or emissions trading permit of a company.

The calculated emission data of most plants have been verified with ETS data and differences have been found to be 1% to 2%. Quality assurance of emissions trading data is described in Appendix 3e.

4.2.5.5 Category-specific recalculations

Preliminary data on imported soda ash were corrected for 2021, emissions decreased 0.06 kt CO_2. Error in activity data reported of an energy plant were corrected for 2016 to 2021, emission data were already reported in 2023.

4.2.5.6 Category-specific planned improvements

No category-specific improvements have been planned.

4.3 Chemical Industry (CRF 2.B)

4.3.1 Introduction

In the Finnish inventory this category includes emissions of carbon dioxide from hydrogen, phosphoric acid, ammonia, formalin and certain chemicals production (use of limestone in the chemical industry is included this category), methane emissions from ethylene production (fugitive) and nitrous oxide emissions from nitric acid production. CO_2 emissions from titanium dioxide production are included in the Mineral industry category since emissions are from wastewater treatment not production of titanium dioxide. Ammonia was produced from hydrocarbons only in 1990 to 1992. The total time series of CO_2 emissions from formalin production were included in the inventory for the first time.

Table 4.3-1 Reported emissions, calculation methods and type of emission factors for the subcategory Chemical Industry in the Finnish inventory

CRF	Source	Emissions reported	Methods	Emission factors
2.B.1	Ammonia Production	CO_2	Tier 1	D
2.B.2	Nitric acid Production*	N_2O	Tier 3 (2009-2022) Tier 2 (1990-2008)	PS
2.B.6	Titanium Dioxide Production	NO		
2.B.8b	Ethylene Production	CO_2 (IE)		
		CH_4	Tier 2	PS
2.B.10	Other			
	- Hydrogen Production	CO_2	Tier 2	CS
	- Phosphoric acid Production	CO_2	CS	PS
	- Limestone and dolomite use	CO_2	Tier 3	CS
	- Formalin Production	CO_2	Tier 3	PS

* Emissions from nitric acid production also includes emissions from fertiliser production.

Nitric acid, hydrogen production and limestone and dolomite use are identified as key categories in 2022 using Approach 1 and Approach 2 assessment.

All emissions of this category are presented in Table 4.3-2 by gas and subcategory. Ammonia, adipic acid, caprolactam, glyoxal, glyoxylic acid, carbides, soda ash, carbon black, dichloroethylene, ethylene oxide, acrylonitrile and methanol are not produced in Finland. Ethylene is produced in Finland, methane produced during ethylene production is used as fuel in the ovens of cracking, in the benzene and cumene units. All CO_2 emissions are reported in the Energy sector, therefore CO_2 emissions from ethylene production are reported as IE. Fugitive CH_4 emissions from flanges, valves, and other process equipment from ethylene production are included in the inventory.

In 2021, process emissions of the chemical industry were 1.1 Mt CO_2 eq. and represented 22% of the sector's emissions and 2.4% of Finland's total emissions. Emissions from the chemical industry decreased by 56% between 2008 and 2010. The main reason for this was the installation of a new N_2O abatement system for all three nitric acid plants during 2009. Emissions of hydrogen production have increased by 54% from 2007 to 2022 and they are now four-fold compared to the time before the launching of the hydrogen plant in 2006 (Figure 4.3-1). Total emissions of the chemical industry in 2022 were 34% lower than in 1990 and 5% lower than in 2021. The biggest reason for increased emissions in the last few years has been the growth of production of hydrogen due to launching of new plants.

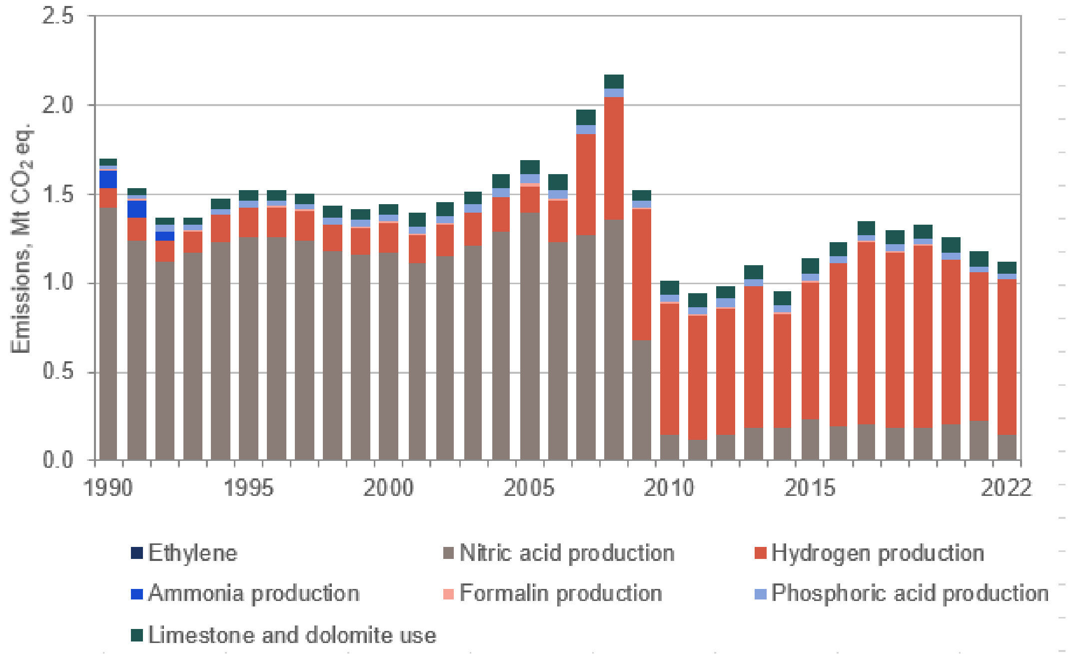


Figure 4.3-1 Greenhouse gas emission from the Chemical Industry (Mt CO_2 eq.)

Emissions of CO_2 from hydrogen production were about 0.9 Mt in 2022, which was 17% of emissions of IPPU sector. Not all hydrogen production causes CO_2 emissions. Emissions occur only processes in which hydrocarbons are used as feedstock. In Finland, natural gas is the most common feedstock in hydrogen production. Theoretically, all the carbon contained in hydrocarbons will be emitted as CO_2 in the processes but, in practice, a small amount of feedstock does not react. Two hydrogen producing companies capture formed carbon dioxide for recovery and bottle it, but only the amount used for PCC production has been subtracted from the total emissions (See Section 3.4.1). In 2022, emissions from hydrogen production were over seven-fold compared to emissions in 1990 and 4% higher than in 2021.

Phosphoric acid is produced from apatite and in the production process calcite, which is a host rock in apatite deposits, calcinates and emits CO_2. Calcite has also been used for neutralisation of wastewater in phosphoric acid plant. These emissions are calculated together and reported in this category due to confidentiality reasons, the emissions were approximately 0.03 Mt in 2022. In 2022, emissions from phosphoric acid production and neutralisation of wastewater were 31% higher than in 1990 and 10% lower than in 2021.

There are only few chemical production companies in Finland which use limestone or dolomite in their production processes. These CO_2 emissions were 0.07 Mt in 2022 and emissions were 78% higher than in 1990 and were 22% lower than in 2021.

Production of formalin and resin adhesives are now included in the inventory (Section 4.3.6). CO_2 emissions have been quite insignificant during the whole time series, they have fluctuated from 0.002 to 0.016 Mt in a year. In 2022 CO_2 emissions were 68% lower than in 1990 and 1% higher than in 2021.

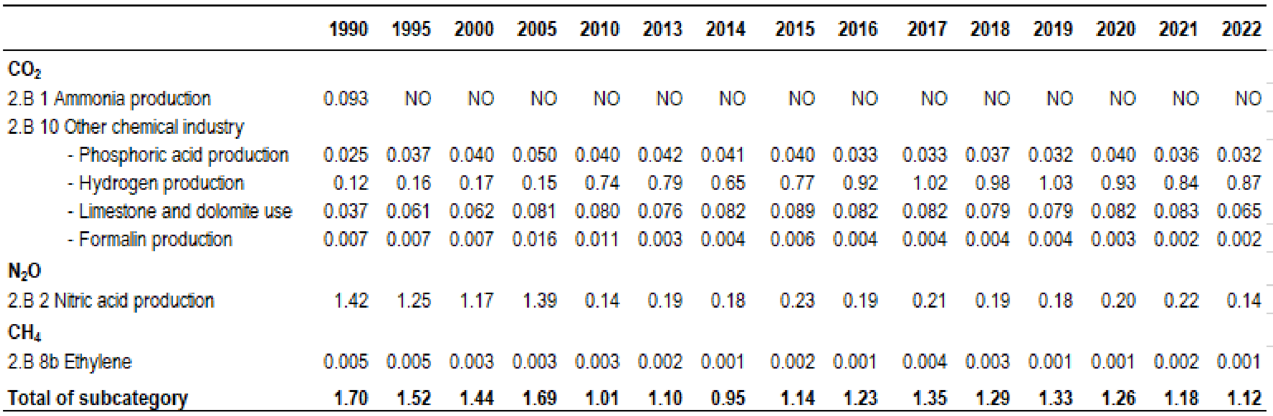
All ammonia currently used in Finland is imported. In 1990 to 1992 small amounts (12 to 30 kt per year) were produced using mainly peat and heavy oil as feedstock for the needed hydrogen. From 1993 on, there has been no ammonia production in Finland. The CO_2 emissions from these processes have been estimated and included in the inventory.

In the chemical industry there are only fugitive CH_4 emissions and they are formed in the ethylene production. Emissions were 0.001 Mt in 2022, they have decreased 72% since 1990 and 9% since 2021. According to the information received from the production plants they have paid attention to minimize VOC emissions over the years. For example, regular leakage measurements, low-emission equipment and better maintenance work have been introduced in recent years. The disturbance-free operation has also decreased emissions. Reasons for higher emissions in 1997 and 2017 are related to leakages in the production process and exhausts before shutdowns.

Emissions of N_2O from nitric acid production were approximately 0.6 kt (0.1 Mt CO_2 eq.) in 2022, which was 0.3% of Finland's total greenhouse gas emissions and 2.9% of emissions of the sector Industrial Processes and Product Use. In 1990, emissions from nitric acid production represented almost 30% of emissions of Industrial Processes and Product Use. Then there were four nitric acid plants in Finland. Emissions of this subcategory include also N_2O emitted from two fertiliser production plants. One nitric acid plant was closed down in 1992 that could be also seen in a rapid decrease of the emissions. In October 2004, a new plant (relocated from Belfast, Northern Ireland) was commissioned at an existing site and, therefore, the amount of produced nitric acid increased. The new plant replaced an older plant, which was closed in 2005. Finally, the N_2O abatement technology were installed in 2009, emissions decreased in all nitric acid plants, emissions are now approximately 89% less than the time prior to instalment. In 2015, the temporary increase in the IEF was due to malfunctions in the production process of fertilisers.

Emissions from nitric acid production have been a part of EU ETS since 2013. In 2022, emissions from nitric acid production were 90% lower than in 1990 and 34% lower than in 2021. Emissions by gas and subcategory of the Chemical industry are presented in Table 4.3-2.

Table 4.3-2 Emissions by gas and subcategory (Mt CO_2 eq.)



	1990	1995	2000	2005	2010	2013	2014	2015	2016	2017	2018	2019	2020	2021	2022
CO_2															
2.B 1 Ammonia production	0.093	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO
2.B 10 Other chemical industry															
- Phosphoric acid production	0.025	0.037	0.040	0.050	0.040	0.042	0.041	0.040	0.033	0.033	0.037	0.032	0.040	0.036	0.032
- Hydrogen production	0.12	0.16	0.17	0.15	0.74	0.79	0.65	0.77	0.92	1.02	0.98	1.03	0.93	0.84	0.87
- Limestone and dolomite use	0.037	0.061	0.062	0.081	0.080	0.076	0.082	0.089	0.082	0.082	0.079	0.079	0.082	0.083	0.065
- Formalin production	0.007	0.007	0.007	0.016	0.011	0.003	0.004	0.006	0.004	0.004	0.004	0.004	0.003	0.002	0.002
N_2O															
2.B 2 Nitric acid production	1.42	1.25	1.17	1.39	0.14	0.19	0.18	0.23	0.19	0.21	0.19	0.18	0.20	0.22	0.14
CH_4															
2.B 8b Ethylene	0.005	0.005	0.003	0.003	0.003	0.002	0.001	0.002	0.001	0.004	0.003	0.001	0.001	0.002	0.001
Total of subcategory	**1.70**	**1.52**	**1.44**	**1.69**	**1.01**	**1.10**	**0.95**	**1.14**	**1.23**	**1.35**	**1.29**	**1.33**	**1.26**	**1.18**	**1.12**

4.3.2 Ammonia production

4.3.2.1 Category description

Small amounts (12 to 30 kt per year) of ammonia have been produced only in 1990 to 1992, mainly peat and heavy oil as feedstock for the needed hydrogen (Finnish Chemical Industry, 1990). In Finland there was experimentation of use sod peat to produce synthesis gas for ammonia, hydrogen peroxide and formic acid production in 1988 to 1991. Experimentation was ended uneconomic and instead of peat gasification of oil products was continued (Bioenergy, 2015).

Time series of emissions from hydrogen peroxide and formic acid production are included in 2.B.10 Other; Hydrogen production, see Section 4.3.5.2.

4.3.2.2 Methodological issues

CO_2 emissions from ammonia production are calculated by multiplying the amount of produced ammonia with the emission factor. Activity data have been received directly from the company and the emission factor is the default factor from the 2006 IPCC Guidelines.

Emission factors

Emissions have been calculated with the highest default emission factor from the 2006 IPCC Guidelines (Table 3.1, Factor derived from European average values for specific energy consumption (a mix of modern and older plants, not natural gas)) since the plant was very old and it used solid or liquid raw material instead of natural gas to produce hydrogen for ammonia. The used emission factor was 3.273 tonnes CO_2/tonne ammonia produced).

Activity data

The amount of produced ammonia has been received from a company, which was producing it at the beginning of the time series. The amount of produced ammonia is shown in Table 4.3-5.

4.3.2.3 Uncertainty assessment and time series' consistency

Quantitative estimates of uncertainty are provided in Annex 2. The annex also documents assumptions made for the analysis. A description of the uncertainty analysis is included in Section 1.6.

The uncertainty of activity data in ammonia production was estimated to be 5% and emission factor 50% (Forsell, 2014).

4.3.2.4 Category-specific QA/QC and verification

The quality objectives and the QA/QC plan for the Finnish greenhouse gas inventory at the national inventory level are presented in Section 1.5. The QC procedures are performed according to the QA/QC plan in the Chemical industry sector in order to attain these quality objectives. A bilateral quality meeting or a quality desk review is held annually between the inventory unit and the sectoral expert.

4.3.2.5 Category-specific recalculations

There were no category-specific recalculations.

4.3.2.6 Category-specific planned improvements

No category-specific improvements are planned.

4.3.3 Nitric acid production

4.3.3.1 Category description

Nitric acid is nowadays produced in Finland in three single-stage medium pressure plants (3.8, 6.5 and 7.5 bar). Two of these plants are situated at the same site and the produced nitric acid is mainly used for the integrated fertiliser production. Since 2013, nitric acid production has been included in the EU ETS, however fertiliser production is not included in the EU ETS and therefore emissions of the inventory and the EU ETS differ in 2.B.2.

4.3.3.2 Methodological issues

In 2005, Statistics Finland cooperated with the nitric acid manufacturers to produce the annual emission estimates for 1990 to 2004. To calculate emissions of nitric acid production, the manufacturers provided the activity data and emission factors (Table 4.3-3), and Statistics Finland carried out the calculations using an agreed methodology that corresponds to the 2006 IPCC Guidelines' Equation 3.6. For emissions of fertiliser production, data received from the producer were used for 1990 to 2004 (Gåpå, 2005a).

Since no abatement or destruction took place at the Finnish plants before 2009 the Equation 3.6 simplifies to

$$N_2O\ emissions = specific\ emission\ factor \times production\ level$$

Since 2005 both emission and activity data of nitric acid and fertiliser production have been received from the YLVA system for each plant separately. The specific emission factors rather than emissions have been calculated by the inventory unit.

Emissions are calculated for each plant separately and then summed up to give the reported figure.

Emission data of fertiliser production are included in the total emissions of this subcategory; neither activity data nor emission factors of fertiliser production are reported in this inventory due to confidentiality reasons.

A project to cut down N_2O emissions of nitric acid plants was started in 2009. A N_2O abatement technology- a pelleted catalyst- was installed directly in the ammonia oxidation reactor underneath the ammonia oxidation catalyst (Pt-Rh) in all the three existing nitric acid plants. Due to catalyst, emissions have decreased by 86% in this subcategory in 2008 to 2017, which also reflects the emission factors used in the inventory. For more detailed information about the project, see the project reports (YARA, 2009 to 2012).

The work to decrease N_2O emissions from nitric acid production has continued. One of the plants continued to develop new kind of catalyst in 2018 and emissions were succeeded to be reduced (Yara, 2019). Emissions of that plant have decreased 52% since 2017. In the other plant the ammonia oxidation reactor was renewed in the summer 2022, the new reactor is larger and therefore more catalyst could be fitted in it. After the renewal N_2O emissions decreased by 95%. For the third plant it was also done some replacements of used parts of reactor and catalyst, it also led to decidedly lower emissions.

For 1990 to 2008, the Tier 2 method was used to calculate emission but after the project, plant level emission factors were obtained from direct measurements of emissions and the Tier 3 method has been used to calculate emissions from nitric acid and fertiliser production.

Emission factors

Before 2009, only one of the three plants was equipped with a continuous N_2O emission measurement unit. From 2005 onwards, the company also used a portable measurement device at the other two plants. A consultant made periodical measurements at the plants in 1999 to 2004. No measurements are available prior to 1999. Since 2009 all existing nitric acid plants have been equipped with automatic systems according to EU standards to continuously measure the concentration of N_2O in the tail gas and gas volume.

Based on the measurements, the emission factors presented in Table 4.3-3 are defined and used in the Finnish inventory for 1990 to 2022.

Table 4.3-3 N_2O emission factors for nitric acid production (mass of N_2O emitted per mass of nitric acid produced)

Plant	Emission factors			Plant in operation
	value (kg/t)	years	source	
A	7.6	1990-2005	Information from plant A	- 2005
B	9.5	1990-2004	Information from plant B	
	0.2-7.4[1]	2005-2022	Calculated based on YLVA data	
C	9.3	1990-2008	Information from plant C	
	0.2-4.3	2009-2022	Calculated based on YLVA data	
D	9.2[2]	1990-1992	(Pipatti, 2001)	- 1992
E	8.0-10.1[3]	2004-2008	Calculated based on YLVA data	2004 -
	0.5-6.6	2009-2022	Calculated based on YLVA data	

[1] plant B started to use a new kind of catalyst in May 2005.

[2] the process of a plant D was similar to plant B

[3] during the first years of operation the plant was not performing optimally and the emission factor was higher than expected

The average emission factor for all three plants in 2008 was 8.1 kg N_2O/t nitric acid (emissions from fertiliser plants are included). The use of the pelleted catalyst started during the inventory year 2009. The target of the project, which was tightened during the project, was that nitrous oxide emissions measured in those three plants will not exceed the level 1.85 kg N_2O/t nitric acid for the end of 2012 (Yara, 2009 to 2012). These projects have been very successful and the average emission factor for all those plants was 1.0 kg N_2O/t nitric acid in 2022 (emissions from fertiliser plants are included).

The 2006 IPCC Guidelines provide a default emission factor for processes similar to those used in Finland; for medium pressure plants it is 7 kg N_2O/t nitric acid -/+ 20%. The oldest, still operational, of our plants started commercial nitric acid production in 1973. Emission factors presented in Table 4.3-3 are in that range before the catalyst installation but well under the highest value.

Emission factors of two fertiliser plants are determined with FT-IR measurements. At the moment the measuring device is shared by those two plants, it first measures the N_2O content of the flow of plant 1, then the sample line will be flushed and after that the N_2O content of flow of plant 2 will be measured. N_2O emission factors for fertiliser production are not presented here due to confidentiality issues.

Activity data

As described before, the annual nitric acid and fertiliser production figures have been obtained from the production plants (Gåpå, 2005b) or from the YLVA system (see description in Annex 6). Production amounts of nitric acid are presented in Table 4.3-5. Production amounts of fertilisers are confidential and, therefore, not included in Table 4.3-5.

4.3.3.3 Uncertainty assessment and time series’ consistency

Quantitative estimates of uncertainty are provided in Annex 2. The annex also documents assumptions made for the analysis. A description of the uncertainty analysis is included in Section 1.6.

Statistics Finland performed a sensitivity study in 2010 to explore how the different parameters used in the calculation of the emissions for 2008 affect the uncertainty. The study showed that emission factors account for most of the uncertainty. Since 2009, an online measurement has been introduced to all plants, and this has further lowered the uncertainties of the emission factors.

According to the uncertainty assessment (see Section 1.6), the uncertainty of N_2O emissions from nitric acid production is +-15% (2021). Uncertainty for N_2O emissions in 90´s was determined by the company (Gåpå, 2005).

The continuous monitoring of measurement has been done according to QAL3 requirements and a third party reviews the measurements annually. Emission calculations and quality assurance mechanisms are verified by a third party every half year.

All activity and emission data have been received from the production plants or they are reported to the YLVA database and EU ETS (2013->) by the production plants. The time series are considered to be consistent.

4.3.3.4 Category-specific QA/QC and verification

The quality objectives and the QA/QC plan for the Finnish greenhouse gas inventory at the national inventory level are presented in Section 1.5. The QC procedures are performed according to the QA/QC plan in the Chemical industry sector in order to attain these quality objectives. A bilateral quality meeting or a quality desk review is held annually between the inventory unit and the sectoral expert. In the quality meeting in February 2024 the recalculations and improvement plan were discussed.

In the calculation of emissions from nitric acid production, several general inventory quality control procedures have been performed as mentioned in 2006 IPCC Guidelines, Table 6.1. Some of the checks are performed annually, like comparing with previous emissions by subcategory of the calculated emissions and ensuring that there are no transcription errors in calculations. Some of the checks have been performed when the calculation method has been developed.

In addition, category-specific quality control procedures have been carried out during calculation. Plant-based emission factors have been compared with IPCC defaults to verify that the plant-specific factors are reasonable.

It was noticed that plant-based emission factors for 2009 are higher than the default factors from the 2006 IPCC Guidelines. For other years (since 2009), plant-based factors are well lower than the default factor. Secondly, emission factors are based on accurate measurements of plants and, therefore, they represent the best possible knowledge of that production process and equipment.

Production data have been checked with YLVA data and industrial output statistics and only small differences (+/-1%) between figures have been noticed. All activity data are site-specific and reported to industrial output statistics or reported due to monitoring of the environmental or emissions permit of a company. According to the project reports, the monitoring of measurement has been done according to QAL3 requirements and a third party reviews the measurements annually. During the project and afterwards, emission calculations and quality assurance mechanisms are verified by a third party every half year. Emission data for 2013 to 2022 have been compared with EU ETS data and only a 0.0 to 0.6% difference between figures has been noticed. Quality assurance of emissions trading data is described in Appendix 3e.

In 2015, a Nordic greenhouse gas inventory experts meeting, which included participants from Finland, Sweden, Norway and Denmark, was held in Helsinki. In this meeting, issues concerning verification of decreasing N_2O emissions from nitric acid production due to improved abatement technologies were discussed. After the meeting, Norway, Sweden and Finland shared descriptions of their methodologies via email and Norway presented a graph of N_2O IEF for the Nordic countries. The graph had been updated since using information from the UNFCCC website. The three Nordic countries show similar N_2O IEF trends, and since 2011, derive roughly on the same IEF. See Figure 4.3-2.

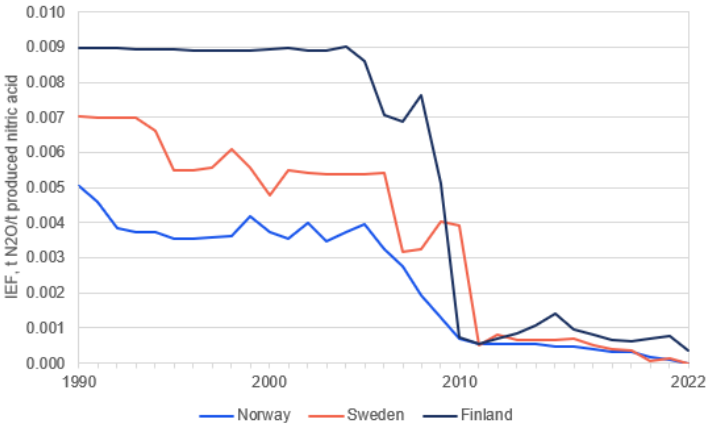


Figure 4.3-2 Verification of decrease of N_2O IEF with Nordic countries

4.3.3.5 Category-specific recalculations

No category-specific recalculations have been done.

4.3.3.6 Category-specific planned improvements

No category-specific improvements are planned.

4.3.4 Titanium dioxide production

4.3.4.1 Category description

Titanium dioxide has been produced using sulphate route process in Finland since the 1950s. Ilmenite and sulphuric acid are the main raw materials used. According to the 2006 IPCC Guidelines, the sulphate route process does not give rise to process greenhouse gas emissions that are of significance.

4.3.4.2 Methodological issues

According to EU ETS data, there are CO_2 emissions from titanium dioxide production as limestone or other carbonates are used for wastewater treatment and neutralisation of sludges. These emissions are, however, included in the Mineral industry, subcategory Other where all other limestone and dolomite (and other carbonate) uses for wastewater treatment are reported.

4.3.5 Ethylene production

4.3.5.1 Category description

Ethylene is produced in Finland, but only fugitive methane emissions are reported in CRF category 2.B as the methane produced in this production process is used as fuel in the ovens of cracking, in the benzene and cumene units at the petrochemical plants. The corresponding CO_2 emissions are reported in the energy sector. According to the experts in the petrochemical plants, some fugitive CH_4 emissions may occur from flanges, valves, and other process equipment during ethylene production. These emissions have not been measured (Leino, 2020), but they are calculated based on total VOC measurements.

4.3.5.2 Methodological issues

VOC emissions have been measured at the petrochemical plants since 1997. These emissions are total VOC emissions which include also CH_4. CH_4 emissions have not been measured separately from these fugitive emissions. Therefore, the estimation of the amount of CH_4 emissions is based on the amount of total VOC emissions. The share of methane in the total VOC emissions is based on information received from petrochemical plants (Anttila, 2019) and has been estimated to be the same for the total time series.

There are some years, when no measurements for total VOC were done, then the fugitive CH_4 emissions from flanges, valves and other process equipment have been calculated using the average of measured data from two previous years. The annual emissions in 1990-1996 have been calculated using the average of the four first measured years (1997-2000). The method is country-specific, but it corresponds to a Tier 2 method.

4.3.5.3 Uncertainty assessment and time series' consistency

Quantitative estimates of uncertainty are provided in Annex 2. The annex also documents assumptions made for the analysis. A description of the uncertainty analysis is included in Section 1.6.

According to experts at the production plants, the uncertainty of total VOC emissions has been ± 20-30%, therefore the uncertainty for methane emissions has been assessed to be higher than total VOCs. An expert estimation (Leino, 2020) was that the uncertainty of the CH_4 emissions is ±40%, and for those years for which average measured data has been used, the uncertainty is ±60%. The time series are considered to be consistent.

4.3.5.4 Category-specific QA/QC and verification

The quality objectives and the QA/QC plan for the Finnish greenhouse gas inventory at the national inventory level are presented in Section 1.5. The QC procedures are performed according to the QA/QC plan in the Chemical industry sector in order to attain these quality objectives. A bilateral quality meeting or a quality desk review is held annually between the inventory unit and the sectoral expert. In the quality meeting in February 2024 the recalculations and improvement plan were discussed. Category-specific recalculations

There were no category-specific recalculations done.

4.3.5.5 Category-specific planned improvements

No category-specific improvements are planned.

4.3.6 Other

4.3.6.1 Category description

In the category Other, Finland reports emissions from hydrogen, phosphoric acid and formalin production and limestone and dolomite use in the chemical industry.

4.3.6.2 Methodological issues

Hydrogen production

This description concerns only hydrogen production which causes greenhouse gas emissions. In Finland all these emissions are included in CRF 2.B.10; this category also includes emissions from the hydrogen production in the refineries.

Hydrogen is produced in Finland in two types of processes. Most used is continuous steam reforming process, where hydrocarbons dissociate on the metal surface. Also, partial oxidation with a controlled amount of oxygen and steam is used to produce hydrogen. There are several hydrogen production plants in Finland, the newest one started in 2016. The newest unit replaced an older production facility in the same site, increasing the refinery's capacity to produce hydrogen. The plant (steam reforming process) is providing one fifth of the needed hydrogen and uses natural gas as raw material (Linde, 2016).

Two of these hydrogen producing plants have a system to capture the formed carbon dioxide from hydrogen production process. A small part of CO_2 has been bottled and transported to PCC producing plants, bigger part has been used in other ways. Only the CO_2 which has been used for PCC production has been deducted from the total greenhouse gas emissions of Finland (see Section 3.4.1). The amount of CO_2 used in PCC production is being deducted from the CO_2 emissions of 1.A.2.d due to confidentiality reasons (see Section 3.4.1).

Pressure swing adsorption (PSA) is used in Finland for the recovery of pure hydrogen from different hydrogen-rich streams. In the PSA purification process, the impurities in the gas are adsorbed into the fixed adsorbent bed at high pressure. The offgases (also called purge gas) from the PSA unit may contain hydrogen and impurities as N_2, H_2O, CO, CO_2 and inert feedstock. Offgases are collected and used in reformer furnaces to heat the reformer. To avoid double-counting, the carbon in offgases is not included in the CO_2 emissions of combustion in Energy Sector (CO_2 EF for these offgases is set to be 0).

In partial oxidation, carbon from hydrocarbon reacts with steam to produce carbon monoxide and hydrogen. Hydrogen is used for hydrogen peroxide production and carbon monoxide for other processes. Part of the carbon from CO is bound in products and part is emitted to the atmosphere. Therefore, total emissions of these processes have been calculated using a mass balance (carbon in incoming hydrocarbon streams minus carbon in outgoing hydrocarbon streams).

Emissions from hydrogen production are calculated by multiplying activity data with emission factors.

Activity data are collected directly from individual companies. Data for the first half of the 1990s have been partly taken from industrial statistics and partly estimated on the basis of data from other years or output of a company.

For the mass balance calculation, all activity data for incoming hydrocarbon streams are collected from the company except for years 1990 and 1991 (uses of hydrocarbon for those years have been estimated using data of 1992). Most of the activity data of out coming hydrocarbons are received from the company, part of the earlier year´s activity data have been estimated using average of the ratios of incoming and outgoing hydrocarbons.

No default emission factor for hydrogen production is available in the 2006 IPCC Guidelines. The emission factor for calculating emissions from hydrogen production is based on the stoichiometric ratios of chemical reactions.

Reforming: $C_nH_m + nH_2O \rightarrow (n + m/2)H_2 + nCO$
CO inverting: $CO + H_2O \rightarrow CO_2 + H_2$

For example:
Natural gas as activity data: $CH_4 + 2\ H_2O \rightarrow CO_2 + 4\ H_2$

Emission factors of hydrogen production are reported by feedstock.

Table 4.3-4 Average of emission factors by feedstock, kt CO_2/ kt feedstock (note that emission factors from the mass balance calculation are not included in the table)

Feedstock	Emission factor
Natural gas	2.71
LNG	2.75
Naphtha	3.18
Propane	3.00
Membrane gas (refinery gas)	2.62

The consumption of hydrocarbons is used as activity data in calculating emissions from hydrogen production. The feedstocks used are natural gas (LNG as well), heavy fuel oil, naphtha, propane and membrane gas. Membrane gas is the same as refinery gas. The composition of membrane gas varies a lot but the composition is analysed eight times a month and the analysed data are used to calculate emissions (Neste Oyj, 2015).

The amount of used hydrocarbons is shown in Table 4.3-5.

Phosphoric acid production

Phosphoric acid is produced from phosphorus containing minerals, the most important mineral is phosphorite (=apatite $3Ca_3(PO_4)_2{*}CaF_2$). There are two different methods to produce phosphoric acid; thermal and wet process; in Finland, the wet process has been used. In the wet process, the raw phosphate is dissolved into sulphur acid and the released phosphoric acid is separated from calcium sulphate.

The most common impurity in phosphoric mineral is carbonate, and in Finland it is calcite. Sulphuric acid causes carbonate to degrade and carbon dioxide to be released. The amount of released CO_2 has been defined from a collected daily sample of apatite.

Calcite has also used in phosphoric acid plants as a neutraliser in waste water handling. The amount of released CO_2 has also been defined from a daily collected sample of calcite.

The total amount of CO_2 released from phosphoric acid plant has been calculated multiplying the use of apatite and calcite with CO_2 content of defined annually average of daily samples. Emission factors used amount of apatite and calcite and calculated CO_2 emissions were received from the phosphoric acid producing company.

Emission factors for apatite and calcite have been defined as an annually average of daily samples. Emission factors are received directly from the phosphoric acid producing company and are confidential.

The activity data are the used amount of apatite and calcite. The amounts of them are received from the company and are also confidential.

Formalin production

According to EU ETS data, there are CO_2 emissions from formalin production. Formaldehyde is produced by oxidation of methanol using metal oxide catalyst in a steam phase oxidation reactor as a continuous process. The formaldehyde gas is directed to the bottom part of absorber tower, it will be absorbed to process water and the formed formalin will be removed from the tower. The concentrated formalin will be used for resin production.

For CO_2 emission calculation from formalin production is the mass balance calculation used, activity data (methanol and formalin) are collected from the YLVA/Vahti system for years since 1997 (formalin) and since 2003 (methanol). Activity data of formalin for earlier years have been calculated using average of data for 1997-2000. Activity data of used methanol for the earlier years (1990-2002) have been calculated using an average ratio of produced formalin and used methanol (2003 to 2022) and amount of produced formalin. Activity data in the CRF reporter are reported as “C” for confidentiality reasons (2.B.10 Other Chemicals production).

Used emission factor for methanol is 1.37 t CO_2/t (CO_2 source) and formalin 1.47 t CO_2/t (CO_2 sink).

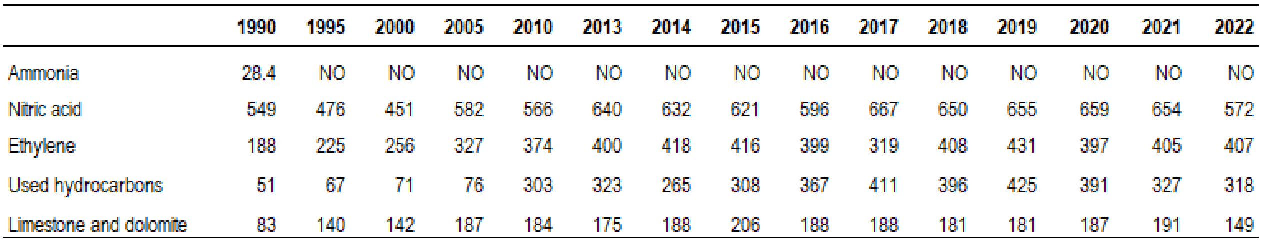
Limestone and dolomite use in the chemical industry

Emissions from limestone and dolomite use in production of chemicals are included in this subcategory.

Emissions from limestone and dolomite use are calculated using the Tier 3 method by multiplying emission factors with activity data. Activity data are collected mainly directly from the industry but industrial statistics have also been used to calculate emissions at the beginning of the time series.

The emission factors are default emission factors. The correction factor from Equation 2.16 (2006 IPCC Guidelines) is 1.0., except for a plant which reported that the average of the $CaCO_3$ content of limestone is 96%.

Table 4.3-5 Production amount of different chemicals (kt)



	1990	1995	2000	2005	2010	2013	2014	2015	2016	2017	2018	2019	2020	2021	2022
Ammonia	28.4	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO
Nitric acid	549	476	451	582	566	640	632	621	596	667	650	655	659	654	572
Ethylene	188	225	256	327	374	400	418	416	399	319	408	431	397	405	407
Used hydrocarbons	51	67	71	76	303	323	265	308	367	411	396	425	391	327	318
Limestone and dolomite	83	140	142	187	184	175	188	206	188	188	181	181	187	191	149

4.3.6.3 Uncertainty assessment and time series’ consistency

Quantitative estimates of uncertainty are provided in Annex 2. The annex also documents assumptions made for the analysis. A description of the uncertainty analysis is included in Section 1.6.

The uncertainty of activity data in hydrogen production was estimated at ±5% and the uncertainty in emission factors ±3%. The lack of knowledge concerning the exact number of reagents that actually react in the various processes have an effect on uncertainty. Activity data have improved in recent years, mainly due to increased availability of measured data. Therefore, uncertainties in recent years are smaller than at the beginning of the 1990s.

The uncertainty in emissions in phosphoric acid production was ±7%.

The uncertainty of activity data in formalin production was estimated at ±5% and the uncertainty of emission factors ±3%. For the activity data of the earlier years, the uncertainty is ±10%.

The uncertainty of activity data in limestone and dolomite use in the chemical industry was estimated to be ±5% and the uncertainty for emission factor is ±3%.

Due to lack of knowledge concerning some earlier years, the time series are calculated using partly estimated data (that is: all data are not as accurate as the data for 2000 to 2021). For years prior to 2000, all activity data have not been gained directly from companies, but industrial statistics or estimations based on data from other years have been used. Time series are considered to be consistent.

4.3.6.4 Category-specific QA/QC and verification

The quality objectives and the QA/QC plan for the Finnish greenhouse gas inventory at the national inventory level are presented in Section 1.5. The QC procedures are performed according to the QA/QC plan in the Chemical Industry sector in order to attain these quality objectives. A bilateral quality meeting or a quality desk review is held annually between the inventory unit and the sectoral expert. In the quality meeting in February 2024 the recalculations and improvement of the consistency of fuel data used in Energy and IPPU sector were discussed..

Hydrogen production

In the calculation of emissions from hydrogen production, several general inventory quality control procedures have been performed as mentioned in the 2006 IPCC Guidelines, Table 6.1. The checks are performed annually, for example comparing with previous emissions of the subcategory of the calculated emissions and ensuring that there are no transcription errors in the calculations.

A few category-specific quality control procedures have been carried out during calculation. The stoichiometric emission factors are considered to be adequate. Activity data have been checked using as many independent sources as possible and only small differences between figures have been noticed. All activity data are site-specific and reported to industrial output statistics or reported due to monitoring of the environmental or emission permit of a company.

The calculated emission data of four plants (out of nine) have been verified with ETS data and emissions have been found to be almost equal. Two of these plants are the biggest emitters in this category, the amount of their emissions represents almost 90% of category’s emissions. Quality assurance of emissions trading data is described in Appendix 3e.

Phosphoric acid production

In the calculation of emissions from phosphoric acid production, several general inventory quality control procedures have been planned to perform as mentioned in 2006 IPCC Guidelines, Table 6.1. Some of the checks are performed annually, like comparing with previous emissions of the subcategory of the calculated emissions and ensuring that there are no transcription errors in the calculations, and some when the calculation method was developed or changed. For this inventory, submission emission estimates have been compared with emissions reported to the YLVA system, emissions have observed to be equal.

Formalin production

In the calculation of emissions from hydrogen production, several general inventory quality control procedures have been performed as mentioned in the 2006 IPCC Guidelines, Table 6.1.

Limestone and dolomite use in the chemical industry

In the calculation of emissions from limestone and dolomite use, several general inventory quality control procedures have been performed as mentioned in the 2006 IPCC Guidelines, Table 6.1. Some of the checks are performed annually, like comparing with previous emissions of the subcategory of the calculated emissions and ensuring that there are no transcription errors in the calculations. Some of the checks have been performed when the calculation method was developed.

In addition, category-specific quality control procedures have been carried out during calculation. In use of limestone and dolomite, the default emission factor multiplied with the correction factor has been defined to be adequate for Finnish circumstances and processes, because default emission factors are stoichiometric; based on chemical equations and the content of carbonate in limestone and dolomite used in Finland is very high. The fluctuations in emission factors of limestone use have been checked and the reason for it originates from different calcium carbonate content in used limestone

Activity data have been checked using as many independent sources as possible and only small differences between figures have been noticed, the results of the comparisons are included in the calculation sheets. This activity data are site-specific and reported to industrial output statistics or reported due to monitoring of the environmental or emissions trading permit of a company.

4.3.6.5 Category-specific recalculations

CO_2 emissions from formalin production were included to the inventory for the whole time series, annual emissions have fluctuated 2 kt to 16 kt. Some small corrections were done for the 2021 data of hydrogen production, emissions decreased 14 kt.

4.3.6.6 Category-specific planned improvements

No category-specific improvements are planned.

4.4 Metal Industry (CRF 2.C)

4.4.1 Introduction

This category in the Finnish inventory includes CO_2 emissions from coke and heavy bottom oil used in blast furnaces and from zinc, copper and nickel production and CH_4 emissions from coke production (reported in CRF tables under Iron and steel production). Also, emissions from limestone used in steel industry are included in this category. SF_6 emissions from magnesium die-casting are included in the inventory until 2012 and reported under the CRF category 2.H Other due to confidentiality issues.

CO_2 emissions from ferroalloys production in Finland are reported in Iron and steel production, because ferrochromium production is part of an integrated stainless steel plant (Table 4.4-1). Emissions from lime production in a steel plant are included in the CRF category 2.A.2. Lime Production.

There is no primary aluminium production in Finland.

Indirect CO_2 emissions from NMVOC and CH_4 emissions in the metal industry are described in Section 9.1.2.

Iron and steel production (CO_2 emissions) is a key category in the Finnish inventory.

Table 4.4-1 Reported emissions, calculation methods and type of emission factors for the subcategory Metal Production in the Finnish inventory

CRF	Source	Emissions reported	Methods	Emission factors
2.C.1	Iron and Steel Production			
	Steel	CO_2	Tier 3, CS	CS
	Limestone use	CO_2	Tier 3	CS
	Pig iron	IE (Steel)	Tier 3, CS	CS
	Sinter	IE (Steel)	Tier 3, CS	CS
	Other: Coke	CH_4	Tier 1	D
2.C.2	Ferroalloys Production	IE (2.C.1)	Tier 3, CS	CS
2.C.4	Magnesium production	CO_2	NA	NA
		SF_6 IE (2.H.3)	Tier 2	NA
2.C.6	Zinc Production	IE (2.C.7)	Tier 2	CS
2.C 7	Other - Zinc, Copper and Nickel Production	CO_2	Tier 2	CS

Process emissions of metal production were 2.0 Mt CO_2 eq. in 2022 and this was about 40% of the sector's and about 4.3% of Finland's total greenhouse gas emissions. The emissions in 2022 were at the same level than in 1990 and 6% lower than in 2021. Iron and steel production contributes over 99% of emissions of metal production.

Table 4.4-2 Emissions by gas and subcategory (Mt CO_2 eq.)

	1990	1995	2000	2005	2010	2013	2014	2015	2016	2017	2018	2019	2020	2021	2022
CO_2															
2.C 1 Production of steel	1.97	2.07	2.38	2.39	2.42	2.07	2.05	2.13	2.18	1.91	2.07	1.85	1.73	2.08	1.96
2.C.7 Other metal industry	0.009	0.008	0.013	0.013	0.017	0.022	0.020	0.020	0.017	0.020	0.022	0.023	0.025	0.019	0.017
CH_4															
2.C 1 Coke production	1.4E-06	2.6E-06	2.5E-06	2.5E-06	2.3E-06	2.5E-06	2.5E-06	2.5E-06	2.1E-06	2.1E-06	2.2E-06	2.3E-06	2.1E-06	2.3E-06	2.3E-06
Total of subcategory	**1.98**	**2.08**	**2.39**	**2.40**	**2.44**	**2.09**	**2.07**	**2.15**	**2.20**	**1.93**	**2.10**	**1.87**	**1.76**	**2.09**	**1.97**

There was a sudden growth in the production of steel in the beginning of the 2000s because one steel plant increased production and improved its energy efficiency. From 2007 to 2009, the production of steel was lower due to the market situation (Figure 4.4-1). The trend turned upward in 2010 and the amount of produced steel increased by 32% in a year. Until the economic downturn in 2007 to 2009, the amount of produced steel had increased by 54% since 1990, while total emissions of the iron and steel industry increased only by 36% at the same time. The economic downturn caused higher CO_2 IEF, because the energy efficiency of the processes becomes lower when full capacity cannot be used (Hemminki, 2008). In 2012, fuel combustion emissions in iron and steel production declined due to closing of one sintering plant. This can be clearly seen in Figure 4.4-1 and Figure 4.4-2. In 2019 the production of one steel plant was clearly lower, partly due to maintenance breakdown of blast furnaces. Later the other blast furnace was temporary closed due to bad market situation. The emissions from iron and steel production are split to fuel-based (combustion, reported under categories 1.A.1a and 1.A.2a) emissions and process emissions; Figure 4.4-1 and Figure 4.4-2 include both types of emissions.

CO_2 emissions from zinc, copper and nickel production have more than doubled since 1990 due to increased productions. The proportion of these emissions were only 0.3% of the emissions of the Industrial Processes and Product Use Sector.

Methane emissions from coke production almost doubled in 1993 due to the opening of a second coke oven in a steel factory but emissions are negligible compared to CO_2 emissions from this sub-category (Table 4.4-4).

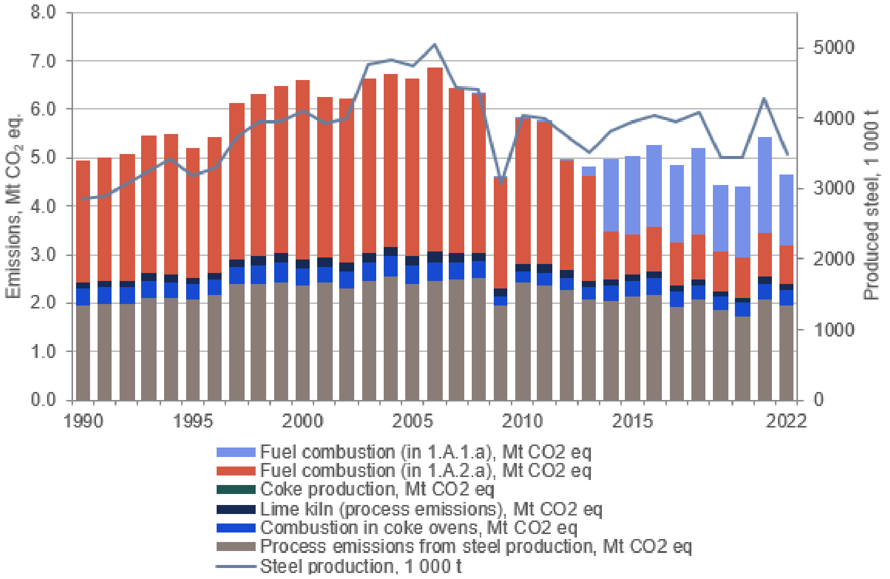


Figure 4.4-1 Total emissions from steel production and amount of produced steel

4.4.2 Iron and steel and metallurgical coke production

4.4.2.1 Category description

The plants included in this sector are:

- One iron and steel plant including coke oven, blast furnace, lime production plant and steel converter
- One iron and steel plant including blast furnace and steel converter (closed down in 2012)
- One integrated ferrochromium and stainless steel plant
- One steel plant with electric-arc furnace, using scrap iron only

In addition there are approximately 20 iron and steel foundries; the emissions from these plants are not included in this section, since all greenhouse gas emissions are allocated as combustion emissions to CRF 1.A.2a.

4.4.2.2 Methodological issues

The calculation method of CO_2 emissions from the iron and steel industry is a country-specific bottom-up methodology. Both fuel-based emissions and process emissions are calculated in connection with the ILMARI calculation system (see Section 3.1) using plant/process level data. The methodology is plant-specific, because all plants differ from each other. Inclusion of plant-level carbon balances in the NID is not possible, due to confidentiality restrictions (see Section 1.5.7 in the NID).

The main common feature for all plants is that fuel-based emissions for each installation are calculated in the ILMARI system from the use of fuels, excluding coke, PCI-coal and heavy bottom oil used in blast furnaces, and subtracted from total CO_2 emissions (described below). Fuel-based emissions are allocated to CRF 1.A.2a, CRF 1.A.1a and CRF 1.A.1c (coke ovens). The rest of the emissions are allocated to process emissions in CRF 2.C.1 (and CRF 2.A.2 in the case of lime kilns).

According to the 2006 IPCC Guidelines (Volume 3, p. 4.11) carbon used in blast furnaces should be considered process-related IPPU emissions. Finland aims to maintain comparability of the inventory and energy statistics data (both IEA and national statistics) and continues to report part of these emissions under the energy sector. As described in Section 3.1.4, the bottom-up data collection system follows this principle. Thus, energy and emissions from combustion of blast furnace gases are collected and reported under the actual process/unit (e.g., power plant, sintering plant, coking plant). With this allocation principle Finland has maintained times series consistency and avoided massive emission shifts between main categories IPPU and Energy as the industry has outsourced its BFG-fired power plants to Energy companies.

Total CO_2 emissions for each installation (coke oven, sintering plant, blast furnace, lime kiln, steel converter, rolling mills and power plants/boilers) in each plant are taken from the YLVA (formerly VAHTI) system until 2004 (see also Section 1.3 and Annex 6). These emissions are basically calculated by the plant operators using carbon inputs (fuel inputs and reducing materials) and they are reported by installations separately. From 2005 on, all four iron and steel plants in Finland report to the EU ETS, however in 2012 one plant was closed down. Starting from the 2007 submission (2005 data), the total CO_2 emissions for the GHG inventory have been taken from the ETS data, although the split between process and fuel-based emissions has been done in the same way as in the previous years' calculations.

The time series of CO_2 emission data are not fully complete in the original data taken from YLVA system. Emissions for 1990 to 1995 have not been reported to YLVA. Therefore, total CO_2 emissions for these years are calculated from the input of fuels, reducing agents and carbonates in each installation (excluding blast furnace gases to avoid double counting). The time series data of fuels and reducing agents are sufficiently consistent, although some corrections had to be made to the original fuel data taken from the YLVA system. The corrections were based on several data sources (updated time series directly from the plants, energy statistics and energy consumption survey of manufacturing industries). This fuel and carbonate-based calculation was also done for later years to compare the methodology and results for 1996 to 2006 (cross-check calculation). The reported total emissions (by installation) are fairly close to the calculated emissions, and the method has been judged reliable to be used for years prior to 1995.

In this methodology used for 1990 to 2004, some streams of carbon inputs and outputs (for example, C input in scrap iron and C output in steel) are not taken into account. According to the EU ETS (Emissions Trading System, Section 1.3) monitoring plans of the largest iron and steel producers in Finland, these streams are part of very small streams with an overall cumulative effect on the emissions of less than 1% of the plants' total CO_2 emissions. These small streams of carbon are included in the EU ETS data, which are used in the inventory from 2005 on.

Emissions are reported in the CRF categories using the allocations as mentioned in Table 4.4-3.

Table 4.4-3 Allocation of emissions from iron and steel production in Finland

CRF category	Emission source
CRF 1.A.1a	Power plants from 2014
CRF 1.A.1c	Emissions from fuels used in coking plants (coke oven gas and BF gases)
CRF 1.A.2a	Emissions from fuels used in iron and steel plants' processes and power plants: (LPG, LNG, residual fuel oil, gasoil, coke oven gas and BF gas, excluding BF gas used for blast furnaces' air pre-heaters)
CRF 2.A.2	Process emissions from lime production in iron and steel plant
CRF 2.C.1	Process emissions from iron and steel production (includes ferroalloys production in integrated stainless steel plants and limestone used in iron and steel production)

Personal communications (Perander 2005 and 2006) with iron and steel plant staff showed that the present method used in the GHG inventory gives the best results, taking into account the availability of the data for the whole time series. The mass balance approach was in principle seen as a more accurate methodology, but the complete data are not available for earlier years. In addition, stock changes were not reported in the early 1990s accurately enough to allow for a full mass balance approach calculation.

Emissions from limestone use are calculated using the Tier 3 method by multiplying emission factors with activity data. Activity data are collected directly from the industry until 2004 and from EU ETS since then.

The calculation method for CH_4 emissions from coke production is from 2006 IPCC Guidelines.

CH_4 emissions from pig iron and sinter production are calculated as energy-based emissions and included in the CRF category 1.A.2a.

Emission factors

The CO_2 emission factors used in the calculation are presented in Table 3.2-4. Plant-specific CO_2 emission factors have been used as far as possible. Implied emission factors for CO_2 emissions in iron and steel industry can be seen in Figure 4.4-2.

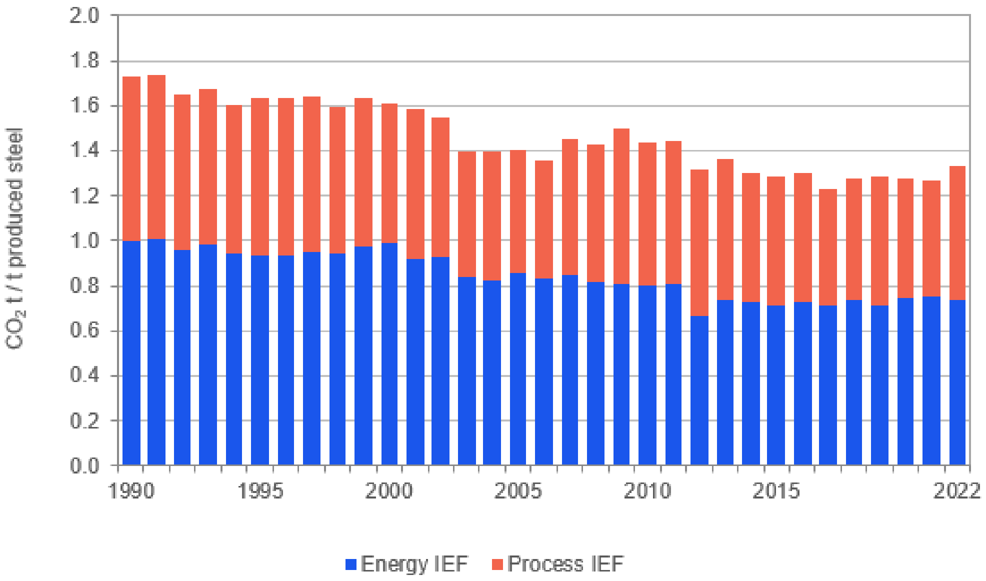


Figure 4.4-2 Implied emission factors for CO_2 in energy production and Industrial Processes and Product Use in the steel industry

The emission factor for limestone use is a default emission factor and correction factor is 1.

The emission factor 0.1 g/t produced coke is used in the calculation of CH_4 emissions from coke production is the 2006 IPCC Guidelines' default value.

Activity data

Activity data for the calculation and comparison of CO_2 emissions are taken from the YLVA system, energy statistics (Energy Statistics), manufacturing industry statistics and special surveys by Statistics Finland. The production of steel can be found in Table 4.4-4.

Fuel data and reducing agent data are available for all years and all plants, but this has required combining of several data sources. CO_2 emission data are available starting from 1996. ETS data are available from 2005 on.

There are also supplementary data for some plants and some years:

- mass balance data for 1990 and 2004 (the biggest plant)
- mass balance data and CO_2 emissions for all years before ETS (1990 to 2004) (the second biggest plant)

The quality of the data varies over time. Below is a qualitative assessment of the data for the three biggest plants. These data have been used for the calculations for 1990 to 2004 (before using ETS data). In addition, actions needed to complete calculations have been briefly described.

Plant 1	**Time series, data quality**
Data from operator (mass balance)	1979 to 2004; data set is very consistent and reliable
YLVA data (fuels and emissions by installations)	1990 to 1995; only partial data, poor quality, one-third of CO_2 missing 1996 to 2004, fairly good

Actions: hardly any estimates needed, because data from the operator could be used to complete YLVA time series.

Plant 2	**Time series, data quality**
Data from operator (mass balance)	1990 and 2004; data set is very consistent and reliable
YLVA data (fuels and emissions by installations)	1990 to 1995; only partial fuel data, poor quality, CO_2 data missing 1996 to 2004, fairly good

Actions: Fuels and reducing agents for 1990 to 1994 have been complemented from many sources. The allocation for each process/installation has been partly estimated. Total CO_2 emissions for these years have been calculated using fuel data, reducing agents and $CaCO_3$ input data. Process emissions have been partly estimated using data from later years and supplementary information (mass balance data) for 1990.

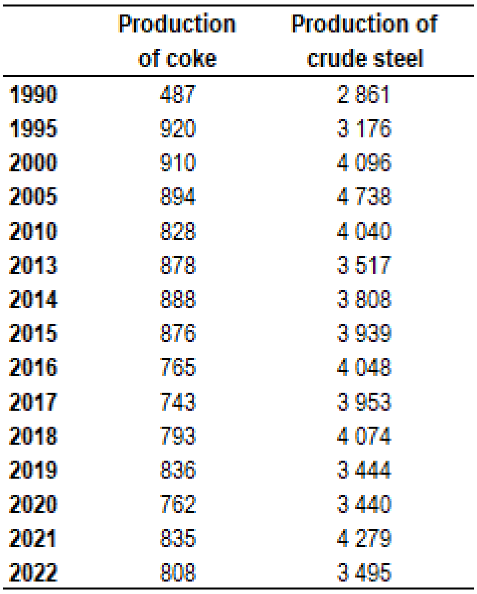
Plant 3	**Time series, data quality**
Data from operator (mass balance)	no separate operator data set available
YLVA data (fuels and emissions by installations)	1990 to 1995; only partial data, poor quality, CO_2 data missing 1996 to 2004, fairly good; (process emissions are included since 2003)

Actions: Fuels and reducing agents for 1990 to 1994 have been complemented from many sources. The allocation for each process/installation has been partly estimated. Total CO_2 emissions for these years have been calculated using fuel data, reducing agents and $CaCO_3$ input data. Process emissions have been partly estimated using data from later years.

Activity data for the calculation of CH_4 emissions from coke production are obtained from Energy Statistics. Coke production data are presented in Table 4.4-4. Coke production almost doubled in 1993 due to the opening of a second coke oven; increased production substituted imported coke.

Activity data for limestone use in the iron and steel industry have been received directly from the producers, but due to confidentiality reasons the data are not reported.

Table 4.4-4 Production of coke and crude steel, kt



	Production of coke	Production of crude steel
1990	487	2 861
1995	920	3 176
2000	910	4 096
2005	894	4 738
2010	828	4 040
2013	878	3 517
2014	888	3 808
2015	876	3 939
2016	765	4 048
2017	743	3 953
2018	793	4 074
2019	836	3 444
2020	762	3 440
2021	835	4 279
2022	808	3 495

4.4.2.3 Uncertainty assessment and time series' consistency

As described in the previous sections, there are three different periods of calculation methodologies:

1990 to 1995: 'coke and carbonates' method (includes fuels, reducing agents and carbonates, excludes BFG)
1996 to 2004: emissions taken mostly from the YLVA system, cross checked using 'coke and carbonates' method
since 2005: emissions taken from EU ETS data: crosschecked with YLVA data and 'coke and carbonates' method

The results of these periods are crosschecked using several comparisons. After these cross-checkings, the time series can be judged consistent (read: as consistent as possible), taking into account, that there are remarkable changes in the data availability.

The most important change from the methodological point of view is, that in the pre-ETS era, certain small streams of carbon are not accounted, as described in Section 4.4.2.2. We have studied the amounts of these small streams based on ETS data. 'Small streams' here include tens of streams of carbon, for example scrap iron, steel products, other by-products, graphite electrodes, slag, dust, etc., basically everything except the main reducing agents, fuels and calcium carbonates. The sum of these small streams seems to lie within +- 1% of the total emissions of these plants; it varies according to plant and year. This variation is far less, than the estimated pre-ETS uncertainty level, which is mostly affected by the uncertainties in activity data of coke and heavy bottom oil inputs.

The changes in the methodologies are reflected in the uncertainty calculations as described below.

Quantitative estimates of uncertainty are provided in Annex 2. The annex also documents assumptions made for the analysis. A description of the uncertainty analysis is included in Section 1.6.

The uncertainty calculation was revised for the 2013 submission. The EU ETS data, which is used as the primary source for the total CO_2 emission of the iron and steel industry from 2005 on, has clearly lower uncertainty than the data for 1990 to 2004. The uncertainty estimates for 1990 have remained the same as in previous submissions. For the latest inventory year, the total uncertainty for categories 2.C.1+1.A.2a is deducted from the ETS information. This uncertainty is split between 2.C.1 and 1.A.2a in a way that the effect on total uncertainty does not change.

In 1990 the uncertainty of 2.C.1 was estimated at ±10% (Grönfors, 2007). For 2022, the overall uncertainty of 2.C.1+1.A.2a was ±2%, based on ETS data. A summary of the uncertainty analysis has been described in Section 1.6.

The uncertainty for activity data in coke production was estimated to be around ±3% and for emission factors around ±20% (Slioor, 2004).

As described in Section 4.4.2.2, the time series are considered to be consistent.

4.4.2.4 Category-specific QA/QC and verification

The quality objectives and the QA/QC plan for the Finnish greenhouse gas inventory at the national inventory level are presented in Section 1.5. The QC procedures are performed according to the QA/QC plan in the Metal Production sector in order to attain these quality objectives. A bilateral quality meeting or a quality desk review is held annually between the inventory unit and the sectoral expert.

As a part of sector-specific QA/QC, energy and GHG experts from Statistics Finland made a plant visit to an iron and steel plant in January 2013. During the visit, the monitoring methods, definitions and system boundaries of the complex integrated plant were discussed. The main object was to harmonise the reporting practises and data on energy use, production, feedstocks and emissions, so that comparable results can be achieved both in Energy Statistics and GHG inventory and also in EU ETS monitoring. Quality assurance of emissions trading data is described in Appendix 3e.

The main annual quality checks are:

- Comparison of different methodologies (reported and calculated emissions)
- Comparison to the mass/balance approach for certain years
- Checking of activity data from several independent sources.

All calculations are performed in a single sheet (by each plant), and emissions calculated by each subcategory/process are compared to total reported emissions in the ETS data. In the plant level calculation sheets differences between reported total and aggregated sums of each process can be seen immediately. The data have been produced and allocated in a such way, that double-counting of emissions between the energy and IPPU sectors is not possible.

In the metallurgical coke production, the calculated emissions have been compared with previous emissions of the subcategory and all activity data are site-specific and reported to industrial output statistics or due to monitoring of environmental permit of a company. Activity data have been checked using as many independent sources as possible.

4.4.2.5 Category-specific recalculations

No category-specific recalculations have been done since the previous submission.

4.4.2.6 Category-specific planned improvements

There are no category-specific planned improvements.

4.4.3 Magnesium production

4.4.3.1 Category description

The use of SF_6 in magnesium die-casting (2.C.4) occurred in Finland from 1994 to 2009 and in 2012 but has ceased since then. According to the EU F gas regulation (517/2014), the use of SF_6 in all magnesium die-casting has been prohibited from 1 January 2018. The emission estimation method is presented in this Section.

However, due to confidentiality issues, emissions are reported aggregated with other confidential SF_6 emissions in the category Other (2.H.3).

Point sources, which make a considerable contribution to SF_6 emissions globally, but are absent from Finland, include the primary aluminium and magnesium industry.

4.4.3.2 Methodological issues

SF_6 emission from magnesium die casting are estimated with the Tier 2 method of the 2006 IPCC Guidelines (Volume 3, Equation 4.31). The emissions equal the SF_6 sold annually to the aforementioned application. The activity data for the calculation of emissions are obtained from annual surveys of importers of special gases.

4.4.3.3 Uncertainty assessment and time series' consistency

The time series of SF_6 emissions from 2.C.4 has been calculated with the same methodology for the whole time series 1994 to 2009 and in 2012 and is, therefore, considered consistent.

4.4.3.4 Category-specific QA/QC and verification

The use of SF_6 in magnesium die-casting has ceased since 2012. The general QC procedures were performed according to the QA/QC and verification plan, and the resulting findings, corrections and planned improvements were recorded in the annual QA/QC form. The emission trends were graphed and explained in category 2.C.4. The quality of activity data for each year was checked by comparing the data with the corresponding data of the three previous years. If unrealistic changes were noted, the correctness of the data was checked with the survey respondent.

4.4.3.5 Category-specific recalculations

No category-specific recalculations have been done since the previous submission.

4.4.3.6 Category-specific planned improvements

No planned improvements in this category.

4.4.4 Zinc production

4.4.4.1 Category description

Special high-grade zinc is produced in Finland by an electrolytic process in a smelter. The electrolytic process includes four main stages: 1) Roasting of zinc concentrate in a temperature of more than 900°C (ZnO as product), 2) Leaching stage, where the zinc oxide is separated from the other calcines 3) Impurities elimination 4) Electrolysis. According to 2006 IPCC Guidelines this process does not result in non-energy CO_2 emissions, but in Finland the zinc concentrate contains small amount of carbon which will be released in forthcoming processes. Due the confidentiality reasons (only one plant in Finland) emissions from zinc production are reported together with emissions of copper and nickel production in CRF 2.C.7.

4.4.4.2 Methodological issues

As mentioned above in Finland the zinc concentrate contains a small amount of carbon (zinc ore naturally contains a small amount of carbonate), which will be released in roasting and elimination processes as CO_2 emission.

Emission factors

There are no default emission factors for the electro-thermic process in 2006 IPCC Guidelines, because no non-energy CO_2 is believed to be released. However, in Finland, emissions for 1990 to 2012 (prior to second emissions trading period) have been calculated using the carbon content of concentrate. This emission factor is an average of measured (2005 to 2012) carbon contents. Since 2013 emissions are the reported emissions for the EU ETS. The plant has to measure the carbon content of every new batch of concentrate for the reporting of CO_2 emissions of zinc production. The emission factor of certain year is the annual average of these measurements.

Activity data

The amount of zinc concentrate was used as activity data to calculate emissions of zinc production. Activity data were received directly from the production plant.

4.4.4.3 Uncertainty assessment and time series’ consistency

Quantitative estimates of uncertainty are provided in Annex 2. The annex also documents assumptions made for the analysis. A description of the uncertainty analysis is included in Section 1.6.

The uncertainty in activity data in zinc concentrate was estimated at ±2% and for emission factor ±5%.

All activity data have been received directly from the company producing zinc and, therefore, the time series are consistent.

4.4.4.4 Category-specific QA/QC and verification

The quality objectives and the QA/QC plan for the Finnish greenhouse gas inventory at the national inventory level are presented in Section 1.5. The QC procedures are performed according to the QA/QC plan in the estimation of the emissions from the Metal Industry sector in order to attain these quality objectives. A bilateral quality meeting or a quality desk review is held annually between the inventory unit and the sectoral expert. In the quality meeting in February 2024 the recalculations and improvement plan were discussed.

In the calculation of emissions from zinc production, several general inventory quality control procedures have been performed as mentioned in the 2006 IPCC Guidelines, Table 1.6. The amount of emissions were compared with the company’s emission calculation which was received (for years 1990 to 2012). These emissions were equal. Emission factors, calculated from emissions of 2013 to 2017, have compared with the average emission factor (1990 to 2012) and measured emission factors of 2005 to 2012 and they are found to be of same size. Altogether the annual emission factors (carbon content) do not fluctuate substantially.

A few category-specific quality control procedures have been carried out during the calculation. Activity data have been checked using the YLVA system. All activity data are site-specific and reported as part of the monitoring of the environmental permit of a company.

4.4.4.5 Category-specific recalculations

No category-specific recalculations have been done.

4.4.4.6 Category-specific planned improvements

No category-specific improvements are planned.

4.4.5 Other

4.4.5.1 Category description

In the Other category of Metal Industry, Finland reports emissions from copper and nickel smelting process. Due the confidentiality reasons emissions from copper and nickel concentrate production are reported together with emissions of zinc production in CRF 2.C.7.

4.4.5.2 Methodological issues

In Finland, the copper and nickel concentrates contain a small amount of carbon (natural carbonate in ore), which is released in the smelting processes as CO_2 emission. The plant also uses secondary raw materials in the metal production process, a small amount of electronic scrap is also refined in the smelter. Carbon in that scrap is released also as CO_2 emission.

Copper and nickel are produced in the flash smelting process. The flash smelting process is based on utilisation of the feed material’s internal energy for smelting. Finely ground sulfidic copper concentrate is mixed with oxygen-enriched air to form a rapidly reacting suspension in the reaction shaft of the flash smelting furnace. Sulphide compounds of the feed ignite, oxidise and release heat, acting as a fuel for the process and no external energy is needed for smelting.

After the flash smelting, the copper stone are led to the converter to oxidise iron and sulphur. The blister copper produced in the converting furnace contains some sulphur. The final sulphur is removed in an anode furnace by air oxidisation.

After the flash smelting, the nickel stones are upgraded using leaching and extraction in a different plant.

Emission factors

There are no default emission factors for copper or nickel smelting processes in 2006 IPCC Guidelines. In Finland emissions have been calculated using the carbon and moisture content of concentrates and electronic scarp. Emission factors are averages of annual average of measured (2009 to 2012) data (confidential). These emission factors have been used to calculate emissions from 1990 to 2014. Since 2015 the plants have had to collect samples of concentrates and analyse their carbon and moisture contents quarterly for the EU ETS. This change has given better information on the carbon content of copper and nickel concentrate. Therefore, the emissions from EU ETS have been used since 2015. Emission factors for electronic scrap are the same as for 1990 to 2014.

Activity data

The amount of copper and nickel concentrate and used electronic scrap were used as activity data to calculate emissions of copper and nickel production. Activity data were received directly from the production plant.

4.4.5.3 Uncertainty assessment and time series’ consistency

Quantitative estimates of uncertainty are provided in Annex 2. The annex also documents assumptions made for the analysis. A description of the uncertainty analysis is included in Section 1.6.

The uncertainty in activity data in copper and nickel concentrate and electronic scrap were estimated at ±2% and for emission factor ±5%.

All activity data have been received directly from the company producing copper and nickel and, therefore, the time series are consistent.

4.4.5.4 Category-specific QA/QC and verification

The quality objectives and the QA/QC plan for the Finnish greenhouse gas inventory at the national inventory level are presented in Section 1.5. The QC procedures are performed according to the QA/QC plan in the estimation of the emissions from the in the Metal Industry sector in order to attain these quality objectives. A bilateral quality meeting or a quality desk review will be held annually between the inventory unit and the sectoral expert. In the quality meeting in February 2024 the recalculations and improvement plan were discussed.

In the calculation of emissions from copper and nickel smelting processes several general inventory quality control procedures have been performed as mentioned in the 2006 IPCC Guidelines, Table 1.6.

A few category-specific quality control procedures have been carried out during calculation. Activity data have been checked using the YLVA system. All activity data are site-specific and reported as part of the monitoring of the environmental permit of a company.

4.4.5.5 Category-specific recalculations

No category-specific recalculations have been done.

4.4.5.6 Category-specific planned improvements

No category-specific improvements are planned.

4.5 Non-energy products from fuels and solvent use (CRF 2.D)

4.5.1 Introduction

Under non-energy products from fuels and solvent use, Finland reports greenhouse gas emissions from use of lubricants, paraffin waxes, urea-based catalysts, also CO_2 emissions from use of urea in NOx control is now included to the greenhouse gas inventory for the first time. Information of calculation of NMVOC emissions and their indirect CO_2 emissions can be found in Section 9.1.2.

Table 4.5-1 Reported emissions, calculation methods and type of emission factors for the subcategory Non-energy products form fuels and solvent use in the Finnish inventory

CRF	Source	Emissions reported	Methods	Emission factors
2.D.1	Lubricant use	CO_2 CH_4, N_2O	Tier 1	D CS
2.D.2	Paraffin wax use	CO_2	Tier 1	D
2.D.3	Other			
	Other; Use of urea-based catalysts	CO_2	Tier 1	D
	Other; Use of urea in NOx control	CO_2	Tier 3	PS

Emissions from non-energy products from fuels and solvent use were 0.1 Mt CO_2 eq. in 2022 and they decreased by 13% in a year. These emissions were 3.0% of the emissions of Industrial processes and product use and 0.3% of the total emissions. Emissions have decreased by 40% since 1990 due to reduced use of lubricants. At the same time emissions from the use of paraffin wax have doubled due to increased import of paraffin candles. Since 2006 more than 70% of these (paraffin wax use) emissions are from the use of imported paraffin candles.

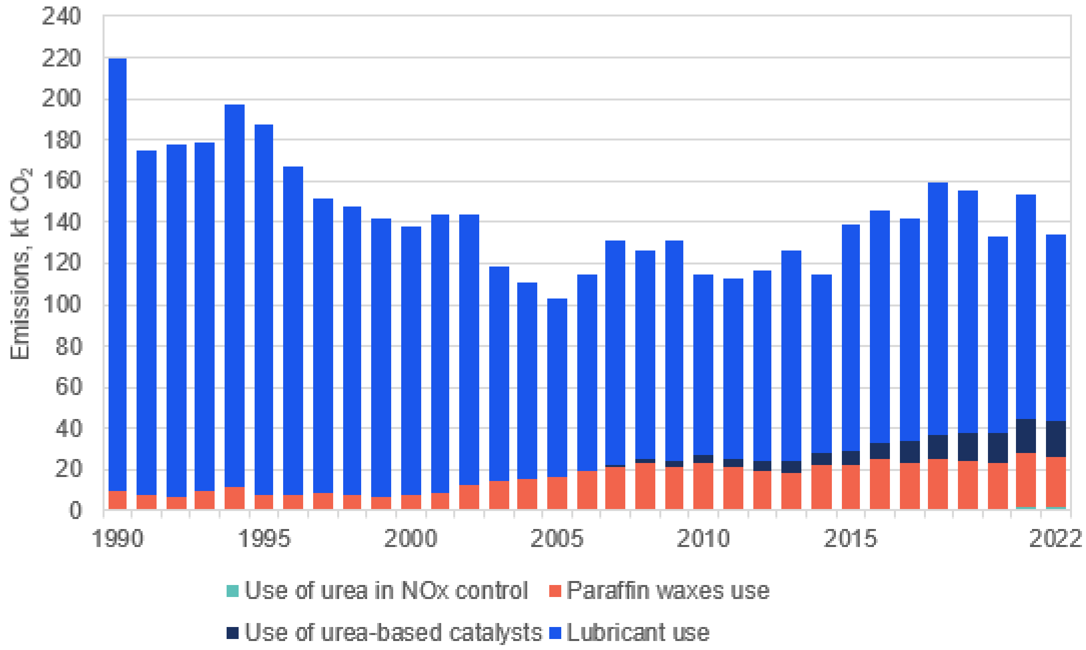
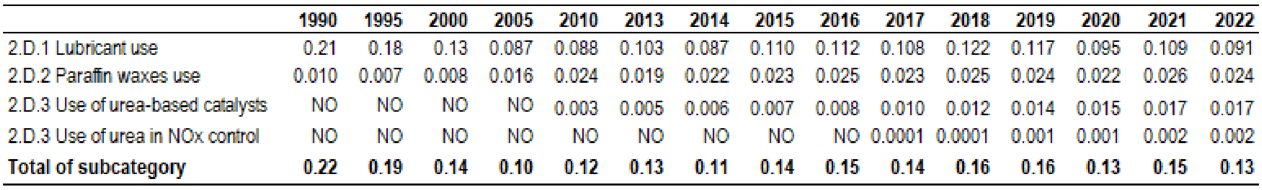


Figure 4.5-1 Emissions of non-energy products from fuels and solvent use

Table 4.5-2 Emissions from non-energy products from fuels and solvent use, Mt CO_2 eq.



	1990	1995	2000	2005	2010	2013	2014	2015	2016	2017	2018	2019	2020	2021	2022
2.D.1 Lubricant use	0.21	0.18	0.13	0.087	0.088	0.103	0.087	0.110	0.112	0.108	0.122	0.117	0.095	0.109	0.091
2.D.2 Paraffin waxes use	0.010	0.007	0.008	0.016	0.024	0.019	0.022	0.023	0.025	0.023	0.025	0.024	0.022	0.026	0.024
2.D.3 Use of urea-based catalysts	NO	NO	NO	NO	0.003	0.005	0.006	0.007	0.008	0.010	0.012	0.014	0.015	0.017	0.017
2.D.3 Use of urea in NOx control	NO	NO	NO	NO	NO	NO	NO	NO	NO	0.0001	0.0001	0.001	0.001	0.002	0.002
Total of subcategory	**0.22**	**0.19**	**0.14**	**0.10**	**0.12**	**0.13**	**0.11**	**0.14**	**0.15**	**0.14**	**0.16**	**0.16**	**0.13**	**0.15**	**0.13**

4.5.2 Lubricant use

4.5.2.1 Category description

The use of lubricants in engines is primarily for their lubricating properties and associated emissions are considered as non-combustion emissions. In the Finnish inventory, emissions from lubricants include emissions from burning of two-stroke and four-stroke oil in engines as well as illegal burning of waste oil.

4.5.2.2 Methodological issues

Information on the used total amount of lubricants is received from energy statistics. The CO_2 emission factor used for calculation is an IPCC default value and based on the carbon content of lubricants (20 t C/TJ). The ILMARI system includes point source (bottom-up) data on waste oil combustion in different branches of industry, and these emissions are reported in corresponding subcategories of 1.A.2. For the rest of lubricants, 33% of carbon is estimated to be stored in products (recycled lubricants) and 67% of carbon released as CO_2 either in burning of lubricants in motors or illegal combustion of waste oil in small boilers. These non-specified emissions from burning of feedstocks (which are not included in 1.A.2) are included in this category even thought this partly deviates from the 2006 IPCC Guidelines.

Splitting and reallocating 2-stroke oil emissions from 2.D.1 to energy subsectors (1.A.3b, 1.A.3d, 1.A.4aii, 1.A.4bii and 1.A.4cii) would not change the total amount of emissions. However, this would result in higher uncertainties since full time series of gasoline consumption in 2-stroke engines to estimate the emissions from 2-stroke oil in each subcategory is not available. Previously, the approximate level of emissions was estimated for 2013 emissions. Results showed that CO_2 emissions from 2-stroke oil would be around 7 kt CO_2 which is approximately 0.01% from the total 2013 emissions.

4.5.2.3 Uncertainty assessment and time series' consistency

Quantitative estimates of uncertainty are provided in Annex 2. The annex also documents assumptions made for the analysis. A description of the uncertainty analysis is included in Section 1.6.

4.5.2.4 Category-specific QA/QC and verification

The QA/QC procedures used are described in Section 3.2.4.4.

4.5.2.5 Category-specific recalculations

No category-specific recalculations have been done.

4.5.2.6 Category-specific planned improvements

No category-specific improvements are planned.

4.5.3 Paraffin waxes use

4.5.3.1 Category description

Paraffin waxes use is included in the Finnish inventory. Paraffin waxes are used in Finland for instance to produce candles, adhesives or detergents and to corrugate boxes and to coat papers. Emissions from imported paraffin candles are also included in the inventory.

4.5.3.2 Methodological issues

Emissions from paraffin waxes use are calculated using the Tier 1 method of 2006 IPCC Guidelines, Equation 5.4.

$$CO_2\ emissions = PW * CC_{Wax} * ODU_{Wax} * 44/12$$

Where: CO_2 emissions = CO_2 emissions from waxes tonne CO_2
PW = total wax consumption, TJ
CC_{Wax} = carbon content of paraffin wax (default, 20 t C/TJ), tonne C/TJ (=kg C/GJ)
ODU_{Wax} = ODU factor for paraffin wax, fraction
44/12 = mass ratio of CO_2/C

To calculate emissions with aggregated default data it has been assumed that 20% of paraffin waxes are used in a manner leading to emissions, mainly through the burning of candles. The default calorific value of paraffin waxes, 40.2 TJ/kt from Table 1.2 Volume 2, Chapter 1 is used to convert physical units into energy.

In Finland also imported (and exported) paraffin containing candles are included in the inventory calculations. Emissions are calculated using same default values as for paraffin waxes except the percentage mentioned earlier.

Emission factors

Emissions from paraffin waxes and paraffin candles are calculated using default emission factors from the 2006 IPCC Guidelines.

To calculate emissions from candles, one-third of imported candles are estimated (Grönfors, 2014) to be made from stearin and, therefore, no emissions are calculated for them. Candles are expected to burn completely. The share of used paraffin waxes and candles change in the time series leading fluctuating IEF.

Activity data

All data on import and export of paraffin waxes and candles are collected from the Customs data for the whole time series.

4.5.3.3 Uncertainty assessment and time series’ consistency

Quantitative estimates of uncertainty are provided in Annex 2. The annex also documents assumptions made for the analysis. A description of the uncertainty analysis is included in Section 1.6.

The uncertainty in activity data in paraffin waxes use were estimated at ±5% and for emission factor ±100%.

All activity data have been collected from the Customs data and the used calculation methodology is the same for the whole time series, therefore, the time series are considered consistent.

4.5.3.4 Category-specific QA/QC and verification

The quality objectives and the QA/QC plan for the Finnish greenhouse gas inventory at the national inventory level are presented in Section 1.5. The QC procedures are performed according to the QA/QC plan in the calculation of the emissions from paraffin waxes use in order to attain these quality objectives. A bilateral quality meeting or a quality desk review is held annually between the inventory unit and the sectoral expert. In the quality meeting in February 2024 the recalculations and improvement plan were discussed.

In the calculation of emissions from paraffin waxes use several general inventory quality control procedures have been performed as mentioned in the 2006 IPCC Guidelines, Table 1.6. The calculation method has been checked to follow the default calculation from the 2006 IPCC Guidelines and it does not include any transcription and transfer errors.

4.5.3.5 Category-specific recalculations

No category-specific recalculations have been done.

4.5.3.6 Category-specific planned improvements

No category-specific improvements are planned.

4.5.4 Other

4.5.4.1 Category description

Under the Other category, Finland reports CO_2 emissions from the use of urea-based catalysts and urea used in the NOx control in the energy industry. Emissions are reported in the Industrial processes and product use sector, (CRF category 2.D.3) as the emissions are non-combustive and the activity data are tons of urea whereas all emissions reported in the Energy sector have been calculated using TJs as activity data.

4.5.4.2 Methodological issues

Use of urea-based additives in catalytic converters

Estimation of CO_2 emissions from use of urea-based additives (AdBlue) in catalytic converters is based on Equation 3.2.2 (Vol 2) from 2006 IPCC Guidelines.

$$Emissions = Activity * 12/60 * Purity * 44/12$$

where:
Emissions = CO_2 emissions from urea-based additive in catalytic converters (kt CO_2)
Activity = amount of urea-based additive consumed for use in catalytic converters (kt)
Purity = the mass fraction (=percentage divided by 100) of urea in the urea-based additive

Emissions have been calculated since 2006, when the use of urea-based additive started.

The default purity, 32.5%, has been used to calculate emissions.

Activity data to calculate emissions have been received from the LIPASTO system (see Section 3.2.5.2) and they include AdBlue used in road transportation and off-road vehicles and other machinery. In the LIPASTO system calculation of the total amount of AdBlue (activity in kg) is based on the share of diesel fuel consumed by SCR technology vehicles and the share of urea solution relative to the consumed diesel in those vehicles. The same method is also valid for working machine calculations. Internationally the amount of urea is known to be overestimated because part of the drivers is not using urea even if they should. However, the extent of this kind of cheating is not known, and thus cannot be included.

Use of urea in the NOx control in the energy industry

CO_2 emissions from the urea use in the NOx control in the energy industry are estimated using a same equation as mentioned above. Emissions are calculated using plant-specific activity data received from the EU-ETS and YLVA registry. Emission factors have depended on a purity of urea used and activity data have been informed as pure urea, or urea in 32.5% or 40% aqueous solution.

Urea has been used in NOx control since 2017, in some plants it has replaced ammonia in the NOx control because it is easier to handle and safer to use.

4.5.4.3 Uncertainty assessment and time series' consistency

Quantitative estimates of uncertainty are provided in Annex 2. The annex also documents assumptions made for the analysis. A description of uncertainty analysis is included in Section 1.6.

The uncertainty of activity data is 20% and of emission factor 2%. Time series are checked to be consistent.

4.5.4.4 Category-specific QA/QC and verification

The quality objectives and the QA/QC plan for the Finnish greenhouse gas inventory at the national inventory level are presented in Section 1.5. The QC procedures are performed according to the QA/QC plan in the calculation of CO_2 emissions from the use of urea-based catalysts in order to attain these quality objectives. A bilateral quality meeting or a quality desk review is held annually between the inventory unit and the sectoral expert. In the quality meeting in February 2024 the recalculations and improvement plan were discussed.

In the calculation of emissions from the use of urea-based additive, several general inventory quality control procedures have been performed as mentioned in the 2006 IPCC Guidelines, Table 1.6. The calculation method has been checked to follow default calculation from the 2006 IPCC Guidelines and it does not include any transcription and transfer errors.

The activity data, amount of urea-based additive consumed, calculated in the LIPASTO-model are compared to annual sales of AdBlue. The amounts have been found to be nearly equal.

4.5.4.5 Category-specific recalculations

The activity data of urea used in NOx control were corrected for 2021, emissions increased 0.09 kt CO_2.

4.5.4.6 Category-specific planned improvements

No category-specific improvements are planned.

4.6 Electronics industry (CRF 2.E)

4.6.1 Introduction

HFC, PFC and SF_6 emissions from integrated circuit or semiconductor (2.E.1) occur in Finland, and the emission estimation method is presented in this section. However, due to confidentiality issues, emissions are reported aggregated with other confidential HFC, PFC and SF_6 emissions in the category Other (2.H.3).

Emissions from TFT flat panel displays (2.E.2), photovoltaics (2.E.3) and heat transfer fluids (2.E.4) do not occur in Finland.

Table 4.6-1 Reported emissions, calculation methods and type of emission factors for the subcategory Electronics industry in the Finnish inventory

CRF	Source	Emissions reported	Methods	Emission factors
2.E.1	Integrated circuit or semiconductor	HFC-23, CF_4, C_2F_6, c-C_4F_8, C_3F_8 (1990-2006, 2014, 2016-2022) and SF_6 IE (2.H.3)	OTH, Tier 2a	CS, D

4.6.2 Integrated circuit or semiconductor

4.6.2.1 Category description

Emissions from semiconductor manufacturing cannot be reported separately due to confidentiality. Emissions are reported aggregated with other confidential F gas emission sources in category CRF 2.H.3 Grouped confidential data of halocarbons and SF_6. CRF 2.H.3 Grouped confidential HFC, PFC and SF_6 emissions altogether contribute around 1% to the total F gas emissions and only 0.02% to the total greenhouse gas emissions in 2022. In addition, N_2O is used for semiconductor manufacturing. Emissions from this process use are calculated and reported in 2.G.3 according to the 2006 IPCC Guidelines (see Section 4.8.3).

Total emissions from 2.E.1 were 2% lower in 2022 compared to 2021 due to a slight decrease in the consumption of F gases in semiconductor manufacturing. The fraction of F gas volumes used in processes with emission control technologies was the same in 2022 compared to 2021. Emissions have increased compared to 1990. In 2022, the emissions were 10-fold compared to 1990. There is some fluctuation in the emission level in the mid-2000s due to changes in the semiconductor market. After that, the emissions grew strongly until 2014 due to increased amounts of F gases used in semiconductor manufacturing. In 2015, the emissions dropped significantly since the major Finnish semiconductor manufacturer in terms of F gas usage installed emission control technologies to the processes using F gases. However, since then the overall trend in the amount of F gases used in semiconductor manufacturing has been increasing with some interannual variation.

A small amount of NF_3 was used in semiconductor manufacturing by one company in 2003. Use of NF_3 was tested by that company in 2003 but results of the tests did not lead to any further use of NF_3. The amount of NF_3 used was very small and the resulted emissions are considered insignificant. Therefore, the emissions of NF_3 are reported as not estimated in Finland (see Section 1.7.5, Description of insignificant categories). The potential use of NF_3 in Finland has been investigated and no other use, in addition to the reported use in 2003, has been found.

4.6.2.2 Methodological issues

Methods

The F gas emissions from semiconductor manufacturing are reported with the IPCC Tier 2a method (Equations 6.3-6.6 in the 2006 IPCC Guidelines, See Annex 4a). The activity data to support the calculation of emissions with the 2006 IPCC Guidelines' methods are available from 2002 onwards. The emission estimates for 1990 to 2001 are calculated with a simplified method as described in Chapter 3.10 in Oinonen (2003):

$$E_n = E_{2003}(1 + 0.15)^{-(2003-n)}$$

The method assumes an annual growth of emissions of 15% for the period 1990 to 2001. The use of 15% reflects the general growth of production within the industry at that time (Oinonen and Soimakallio, 2001). This estimation method of missing data is consistent with the extrapolation method presented in the 2006 IPCC Guidelines (Volume 1). 2003 is used as a reference year in the model since activity data are available from all semiconductor manufacturers from that year.

Emission factors

The emission factors to calculate emissions from semiconductor manufacturing are from Table 6.3 of the 2006 IPCC Guidelines (p. 6.17) and presented in Table 4.6-2. All the Finnish semiconductor manufacturers have emission control technologies. Two manufacturers have delivered plant-specific data required by the Tier 2a method of the 2006 IPCC Guidelines (fraction of gas volume used in processes with emission control technologies and fraction of gases destroyed by the emission control technology). One company is not able to deliver the parameters, and therefore the emission control technologies are not applied to that company in the emission estimation. However, the amount of F gases used in their processes is very small. In addition, one company does not process F gases with the technology due to small amount of F gases used. The plant-specific emission control data is confidential and is therefore not presented in the NID.

Table 4.6-2 Emission factors for the semiconductor manufacturing (2006 IPCC Guidelines)

	CF_4	C_2F_6	CHF_3	C_3F_8	c-C_4F_8	SF_6
Use rate of gas (fraction destroyed or transformed in process)	0.1	0.4	0.6	0.6	0.9	0.8
Fraction of gas remaining in shipping container after use	0.1	0.1	0.1	0.1	0.1	0.1
kg CF_4 created per kg of gas i	NA	0.2	0.07	0.1	0.1	NA
kg C_2F_6 created per kg of gas i	NA	NA	NA	NA	0.1	NA

Activity data

The activity data for the calculation of emissions from semiconductor manufacturing are obtained from annual surveys to companies, research institutes and importers of special gases. All the companies responded to the survey of the 2022 data.

4.6.2.3 Uncertainty assessment and time series' consistency

Emissions from this category are estimated with the Tier 2a method given in the 2006 IPCC Guidelines for years 2002 to 2021. Emissions from previous years are estimated with the surrogate method presented in the 2006 IPCC Guidelines (Volume 1, Equation 5.2) and, therefore, the time series can be considered as consistent. Since due to confidentiality the emissions are reported in category 2.H.3, the uncertainties of activity data and emission factors of this category are also included in the uncertainty estimation of category 2.H.3.

4.6.2.4 Category-specific QA/QC and verification

QA/QC procedures described in Section 1.5 are implemented in the category 2.E.1. The QC procedures are performed according to the QA/QC and verification plan, and the resulting findings, corrections and planned improvements are recorded in the annual QA/QC form. Bilateral quality meeting was held between the inventory unit and the sectoral expert in January 2024. The documentation and archiving of the 2.E.1 category are detailed in Section 1.2.3.

In the calculation of emissions from category 2.E, several general inventory quality control procedures have been performed as mentioned in 2006 IPCC Guidelines, Table 6.1. The correctness of the calculations is checked each year by reproducing a representative sample of the emission calculations manually and the use of appropriate units and conversion factors throughout the calculations is crosschecked simultaneously.

The category-specific QC procedures for category 2.E.1 include emission and activity data comparisons, as well as uncertainty estimates as part of the uncertainty of category 2.H.3. The results are compared with those obtained using a simpler model, i.e. actual emissions are compared with potential emissions. The results of the comparison between the potential and actual emissions indicated that the actual emission estimates are at a reasonable level. The emission trends are graphed and explained. The quality of activity data for each year is checked by comparing the data with the corresponding data of the three previous years. If unrealistic changes are noted, the correctness of the data is checked with the survey respondent.

4.6.2.5 Category-specific recalculations

No category-specific recalculations have been done since the previous submission.

4.6.2.6 Category-specific planned improvements

There are no planned improvements in this category.

4.7 Product uses as substitutes for ozone depleting substances (CRF 2.F)

4.7.1 Introduction

In 2022, greenhouse gas emissions under the category CRF 2.F Emissions of Product uses as substitutes for ozone depleting substances amounted to 0.8 Mt CO_2 eq., which is 1.7% of the total greenhouse gas emissions in Finland. Emissions decreased by 9% compared to the previous year (Table 4.7-2). Emissions from different subcategories reported under this sector are listed in Table 4.7-1. In all, 97% of the emissions in 2022 originated from refrigeration and air conditioning equipment (Figure 4.7-1). Emissions from category 2.F.3 Fire protection cannot be reported separately due to confidentiality. HFC emissions from fire protection are reported aggregated with other confidential F gas data in category CRF 2.H.3 Grouped confidential data of halocarbons and SF_6. Emissions from Solvents (2.F.5) and other applications (2.F.6) do not occur in Finland.

Based on the Approach 1 and Approach 2 level and trend assessment, HFC emissions from category 2.F.1 refrigeration and air conditioning equipment, is a key category by level and trend in 2022.

Table 4.7-1 Reported emission source categories under the category Product uses as substitutes for ozone depleting substances in the Finnish inventory

CRF	Source	Emissions reported	Methods	Emission factors
2.F.1	Refrigeration and air conditioning equipment	HFC, PFC	Tier 2	D, CS
2.F.2	Foam blowing and use of foam products	HFC	Tier 2	D
2.F.3	Fire protection	IE (2.H.3)	OTH	D, NA
2.F.4	Technical aerosols, one-component polyurethane foam, tear gas and metered dose inhalers	HFC	Tier 2	D

The subcategory Technical Aerosols includes one-component polyurethane foam cans (OCF), an aerosol-like product. This practice for reporting originates from the 1996 IPCC Guidelines. In the Good Practice Guidance 2000 and the 2006 IPCC Guidelines, OCF is discussed together with other foam types, and the methodology is slightly different from that applied to aerosols. Finland has continued the practice of including OCF in the aerosols subcategory because the AD available does not allow for the use of the 2006 IPCC Guidelines' method for the whole time series.

The total emissions of F gases from 2.F have increased significantly since 1990. In 1990, HFC containing refrigerants were used in small quantities in stationary air conditioning. From the mid-1990s, emissions have increased strongly. A key driver behind the growing emission trend has been the substitution of ozone depleting substances (ODS) by F gases, especially with HFCs, in many applications. Restrictions of ODS in the mid-1990s have led to rapid growth of the use of HFCs as refrigerant agents and, simultaneously, to an increase of the emissions towards the end of the decade. The peak level of HFC emissions occurred in 2009 after which the emissions turned into a slow decrease. The decrease of emissions has accelerated in the recent years. In 2022 the emissions were 9% lower than in 2021. The decrease in emissions resulted mainly from decreased emissions in commercial refrigeration.

The share of PFC emissions from the total emissions of the sector is only 0.1% in 2022. The peak level of PFC emissions in Finland occurred in the early and mid-2000s mostly due to use of refrigerant R-413A in supermarket refrigeration and R-403B in transport refrigeration. PFC emissions from supermarket and transport refrigeration have ceased today. During the most recent years, the emissions have followed the steady trend in industrial refrigeration applications. Today the emissions are at a significantly lower level compared to the peak level of emissions in the early and mid-2000s.

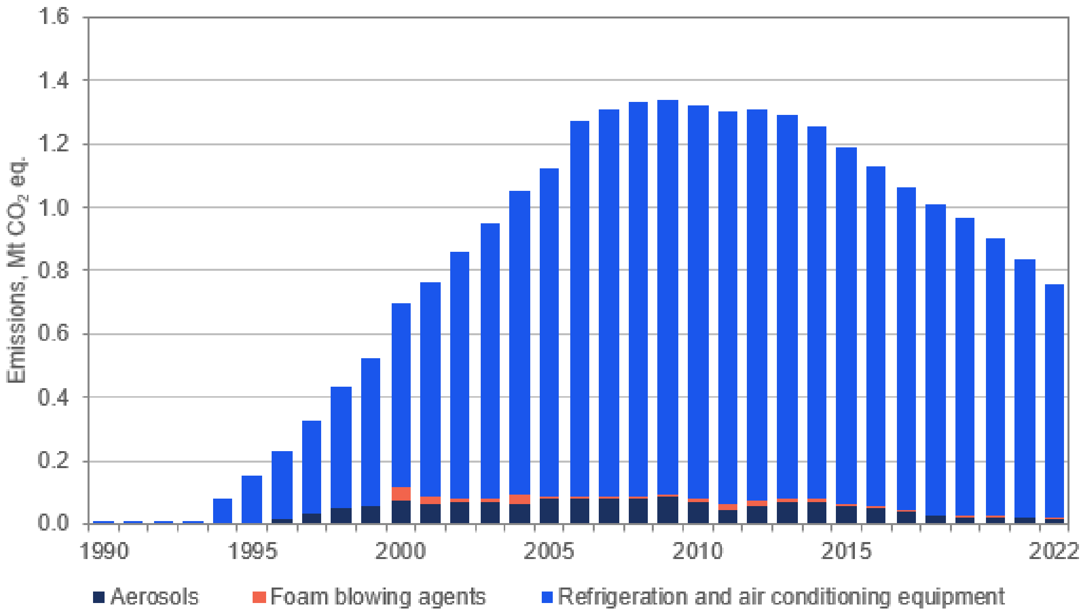


Figure 4.7-1 Greenhouse gas emissions from Product uses as substitutes for ozone depleting substances, Mt CO_2 eq.

Table 4.7-2 Emissions by gas and subcategory (Mt CO_2 eq.)

	1990	1995	2000	2005	2010	2013	2014	2015	2016	2017	2018	2019	2020	2021	2022
HFC															
2.F 1 Refrigeration and air conditioning equipment	1.2E-05	0.15	0.58	1.04	1.23	1.21	1.18	1.13	1.08	1.01	0.98	0.94	0.88	0.81	0.74
2.F 2 Foam blowing agents	NO	0.000	0.039	0.005	0.012	0.010	0.0087	0.0052	0.0052	0.0049	0.0049	0.0045	0.0039	0.0043	0.0043
2.F 3 Aerosols	NO	0.002	0.077	0.081	0.070	0.070	0.069	0.055	0.048	0.040	0.024	0.021	0.020	0.018	0.017
PFC															
2.F 1 Refrigeration and air conditioning equipment	NO	NO	0.002	2.5E-03	NO	0.002	0.0013	0.0010	0.0008	0.0008	0.0007	0.0007	0.0007	0.0007	0.0006
Total of subcategory	**1.2E-05**	**0.15**	**0.70**	**1.13**	**1.32**	**1.29**	**1.26**	**1.19**	**1.13**	**1.06**	**1.01**	**0.97**	**0.90**	**0.83**	**0.76**

4.7.2 Refrigeration and air conditioning

4.7.2.1 Category description

The category covers HFCs, PFC-218 and PFC-116 emissions from refrigeration and air conditioning equipment. Emissions are reported in six subcategories in accordance with the 2006 IPCC Guidelines. Included are commercial refrigeration, domestic refrigeration, industrial refrigeration, transport refrigeration, mobile air conditioning and stationary air conditioning. A majority of the HFC emissions originate from commercial refrigeration. Other significant emission sources are mobile and stationary air conditioning. PFC emissions originate from commercial, industrial and transport refrigeration with the vast majority from industrial refrigeration.

In 2022, HFC emissions totalled 0.7 Mt CO_2 eq. and PFC emissions 0.0006 Mt CO_2 eq. Compared to the previous year, the HFC emissions decreased by 9% mainly due to decreased emissions from commercial refrigeration. During the recent years, the replacement of higher-GWP HFC-refrigerants with mostly CO_2 in commercial refrigeration applications has strengthened and this has turned the HFC emissions into decrease. Compared to 2021, the PFC emissions decreased by 4% in 2022 due to decreased emissions from industrial refrigeration (Figure 4.7-2 and Figure 4.7-3).

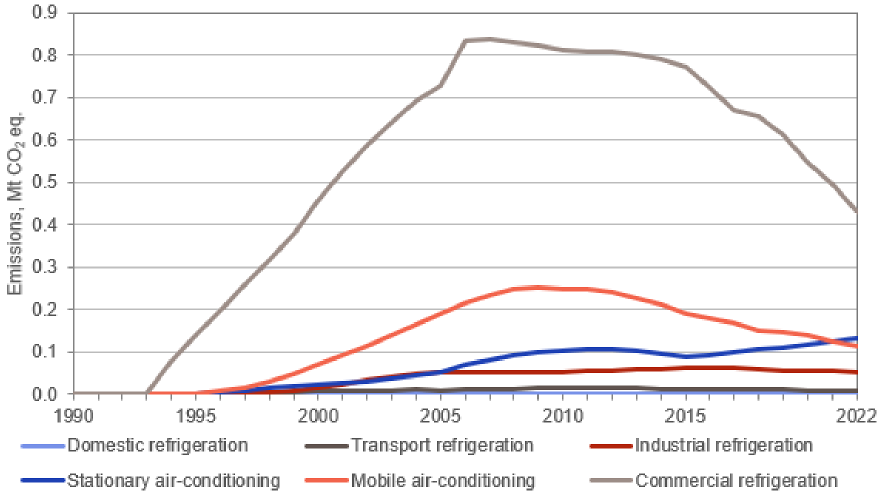


Figure 4.7-2 Greenhouse gas emission from six subcategories of the Refrigeration and air conditioning equipment (Mt CO$_2$ eq.)

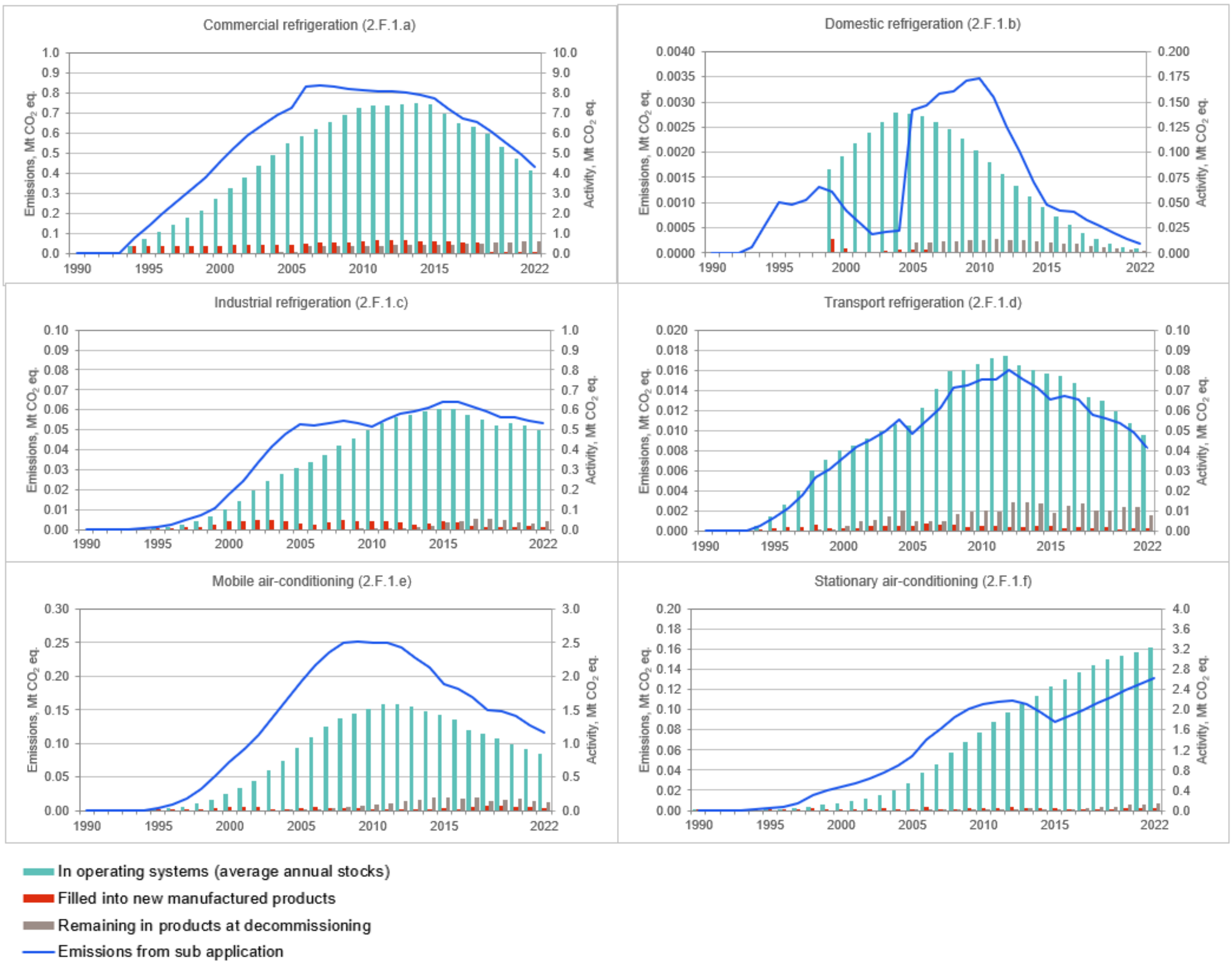


Figure 4.7-3 Total greenhouse gas emission and amounts of gas in operating systems, filled into new manufactured products and remaining in products at decommissioning of six subcategories of the Refrigeration and air conditioning equipment (Mt CO$_2$ eq.)

In the largest emission source, category 2.F.1a Commercial refrigeration, the emissions increased strongly since the introduction of F gases in the mid-1990s as a substitution for ozone depleting substances (ODS). The increase of emissions started to flatten out at the end of 2000s mostly due to introduction of CO_2 as a refrigerant in these applications. In addition, as a result of the introduction of the F gas regulation in the mid-2000s, the leakage rates from existing equipment started to decrease during the 2000s. The first centralized commercial refrigeration systems with HFCs reached their end-of-life in 2006 and were disposed of. The beginning of emissions from end-of-life operations caused the slight increase in emission level between 2005 and 2006. The emissions from end-of-life have decreased during the 2010s due to improved recovery of refrigerants from systems at disposal. In 2022, the emissions continued to decrease mostly due to the strengthening introduction of natural refrigerants (CO_2 and propane) in centralized refrigeration systems.

There is a fluctuating trend in the emissions of category 2.F.1b Domestic refrigeration. The emissions increased throughout the 1990s but decreased at the turn of the decade. The share of HFC’s in new equipment started to decrease as the non-HFC alternatives (namely refrigerant R-600A, isobutane) increased their share strongly. The emissions increased again strongly in the mid-2000s when the HFC equipment started to reach the end of their service life and were disposed of. Since then, most of the emissions have been emissions from end-of-life. The emissions from end-of-life have decreased during the 2010s due to improved recovery of refrigerants from systems at disposal. The emission trend today is decreasing.

The emissions from category 2.F.1c Industrial refrigeration increased steadily throughout the time period from the mid-1990s to the mid-2000s. The increase of emissions freezed after the mid-2000s mostly due to decreasing effect of the F gas regulation on the leakage rates from existing equipment. The disposal of equipment containing F gases begun in the early 2010s and affected the increasing trend of emissions after that. The recovery of refrigerants from equipment at disposal has improved during the last decade. The emissions have turned into slow decrease in the most recent years mostly due to increased amount of HFC alternatives in these applications.

In the category 2.F.1d Transport refrigeration, the emissions increased since the introduction of F gases in this sector in the mid-1990s. There was a little peak in new equipment introduced to the market at the end of 2000s. The emissions turned into decrease during the 2010s mostly since the equipment taken into use during the peak time reached the end of their service life and were disposed of resulting in the decrease of the existing F gas stock. The recovery of refrigerants from equipment at disposal has also improved during the last decade. In addition, the high GWP refrigerant R-404A has almost completely been replaced by lower GWP alternatives in new equipment during the recent years.

Emissions from category 2.F.1e Mobile air-conditioning, increased strongly from the mid-1990s when HFC’s were introduced to the market. The increase of emissions freezed at the end of 2000s due to decreasing effect of EU legislation on the leakage rates and the decrease of refrigerant charge levels. The introduction of HFC alternatives in passenger cars during the 2010s together with the decreasing leakage rates have resulted in a decreasing emissions trend.

In the category 2.F.1f Stationary air-conditioning, the emissions increased steadily from the mid-1990s, when HFC equipment were introduced to the market, and during the first decade of the 2000s. The emissions turned into slow decrease in the early 2010s, mostly due to decreasing effect of EU legislation on the leakage rates. The increased disposal of HFC equipment and the increasing popularity and sales of heat pumps have contributed the increasing emissions trend in the most recent years. In 2022 the total emissions increased by 5% compared to 2021.

4.7.2.2 Methodological issues (2.F.1)

An overview of the methods used to quantify emissions of F gases from category CRF 2.F.1 is presented in Table 4.7-3.

Table 4.7-3 Summary of the methods used in category CRF 2.F.1 in 2022.

Source category	Methods used	Gases reported	Notes
Commercial Refrigeration (CRF 2.F.1a)	Tier 2a	HFC-32, HFC-125, HFC-134a, HFC-143a	-
Domestic Refrigeration (CRF 2.F.1b)	Tier 2a	HFC-134a	Emissions from manufacturing are included in the emissions from stocks from 1993 to 1998 due to confidentiality
Industrial Refrigeration (CRF 2.F.1c)	Tier 2a	HFC-23, HFC-32, HFC-125, HFC-134a, HFC-143a, PFC-116, PFC-218	
Transport Refrigeration (CRF 2.F.1d)	Tier 2a	HFC-32, HFC-125, HFC-134a, HFC-143a	
Mobile Air-Conditioning (CRF 2.F.1e)	Tier 2a	HFC-32, HFC-125, HFC-134a	-
Stationary Air-Conditioning (CRF 2.F.1f)	Tier 2a	HFC-32, HFC-125, HFC-134a, HFC-143a	

Emissions are calculated by the IPCC Tier 2a emission factor approach of the 2006 IPCC Guidelines. The system under consideration is the geographic area of Finland. Emissions are calculated with the same methodology for all subcategories 2.F.1a-f. Emissions are given by (Vol. 3, Chapter 7, Equation 7.10, p. 7.49)

$$\text{Emissions}_{\text{total}} = \text{Emissions}_{\text{containers}} + \text{Emissions}_{\text{charge}} + \text{Emissions}_{\text{lifetime}} + \text{Emissions}_{\text{end-of-life}}$$

The emissions related to refrigerant container management as presented in the 2006 IPCC Guidelines are considered negligible in Finland. According to the RAC industry, no transfer of refrigerants from bulk containers to containers with smaller capacities have taken place in Finland since the late 1980s. All the refrigerants are imported to Finland in smaller containers (Hannula, 2014).

Charge emissions relate to the domestic charging of refrigerants into new equipment and they are estimated as:

$$\text{Emissions}_{\text{charge}} = \text{Refrigerant charge into new equipment} * \text{EF}_{\text{charge}}$$

Lifetime emissions are related to the annual leakage from the refrigerant banks in existing equipment and they are estimated via the following equation:

$$\text{Emissions}_{\text{lifetime}} = \text{Refrigerants banked in existing equipment} * \text{EF}_{\text{lifetime}}$$

End-of-life emissions refer to emissions from equipment at disposal and they are estimated as:

$$\text{Emissions}_{\text{end-of-life}} = \text{Initial refrigerant charge into new equipment in year n-x} * \text{EF}_{\text{end-of-life}}$$

Year x denotes the equipment lifetime. The emission factor for end-of-life emissions comprises of two parameters:

$$\text{EF}_{\text{end-of-life}} = p * \eta_{\text{rec, d}}$$

where p = residual charge of refrigerants in equipment at disposal expressed in percentage of full charge

$\eta_{\text{rec, d}}$ = recovery efficiency at disposal (ratio of recovered refrigerant referred to the refrigerant contained in the equipment)

National emission factors have been used when they have been available. In most cases, default emission factors from the IPCC Guidelines have been used. In general, default EF's for 1990s have been taken from the 1996 IPCC Guidelines and default EF's for later years have been taken from the 2006 IPCC Guidelines. Details of the emission factors are presented below in the category specific chapters.

The recovery in the CRF tables is treated as recovery itself and not emissions from recovery. Recovery is calculated with the simplified way of subtracting disposal emissions from the amount of HFC's/PFC's in products at decommissioning. The methodology to estimate recovery has been applied to all categories under 2.F.1.

Commercial refrigeration (2.F.1a)

Methods and activity data

Commercial refrigeration is the largest application area in terms of HFC use and emissions in the category refrigeration and air conditioning equipment. This sub-category includes four different sub-applications – commercial centralized refrigeration systems, centralized systems in professional kitchens, commercial stand-alone units and stand-alone units in professional kitchens. The so-called condensing units are included in the centralized systems' sub-applications. Centralized systems are typically customised direct or secondary indirect vapour compression systems. Secondary systems have lower refrigerant charge levels compared to the direct systems. A considerable amount of direct systems are still used in Finland. R-404A is still the most commonly used refrigerant in centralized systems in operation. The use of HFC refrigerants began in Finland in 1994. In addition to R-404A, R-134A was used already in the mid 1990s in smaller quantities. A PFC containing refrigerant R-413A was also used in small quantities from the beginning of 2000s. The first systems with natural refrigerant CO_2 were introduced in Finland in 2007. In 2022 42% of the installed systems used natural refrigerants CO_2 or propane. The first systems with propane have been introduced during the most recent years. Other currently used refrigerants are R-134A, R-407A, R-407F, R-422D, R-448A, R-449A and R-452A. The vast majority of the new systems annually taken into use today use CO_2.

A specific calculation model is used to estimate HFC and PFC emissions from commercial centralized refrigeration systems. The starting point of the emission estimation is the number of different types of food retail stores operating annually in Finland. The number of stores is statistically recorded and the information is available from the Finnish Grocery Trade Association (Finnish Grocery Trade Association, 2023). The statistical data is available for the years 2004 to 2022. The number of stores for the years 1990 to 2003 are derived mathematically based on the data for the years 2004 to 2016 using MS Excel's exponentially smoothed trend function. Exponential smoothing compensates the over- and underestimation of a purely linear model. According to the statistics, the number of stores does not follow a purely linear trend. The second parameter needed in the calculation is the refrigerant charge in a typical centralized system of a typical food retail store. The different types of food retail stores and their refrigerant charges are presented in Table 4.7-4. The charges are expert estimations made at Syke based on data received from companies in the refrigeration and food retail industries (Forsberg, 2017a). All the charges are within the value range for medium and large commercial refrigeration given by the 2006 IPCC Guidelines in Vol. 3, Table 7.9, 50 to 2000 kg.

Table 4.7-4 Refrigerant charges of different types of food retail stores

Store type	Refrigerant charge, kg
Hypermarkets	1000
Department stores	600
Supermarkets (big)	700
Supermarkets (small)	500
Convenience stores (big)	350
Convenience stores (small)	250
Small shops	250
Specialized shops	100
Others	100

The annual refrigerant stocks are calculated with the help of these coefficients and the percentage shares of individual refrigerants used. The percentage shares of refrigerants are determined at Syke based on expert estimations from the refrigerant industry and international literature (Forsberg, 2023a). The refrigerant shares are presented in Appendix_4c. The additions of refrigerants into new systems are estimated by dividing the refrigerant stocks by the systems’ average lifetime. The average lifetime for centralized systems is 12 years and it is an expert estimate received from Finnish Refrigeration Enterprises Association FREA (Hannula, 2014). The lifetime is within the value range given by the 2006 IPCC Guidelines in Vol. 3, Table 7.9, 7 to 15 years. The amount of refrigerants at disposal are estimated with the help of average lifetime. Activity data for the disposal emissions is the initial charge into new systems from the year of installation of the systems.

HFC emissions from centralized systems in professional kitchens are calculated with the same methodology as the other commercial centralized refrigeration systems. The activity data, the number of professional kitchens annually operating in Finland, was available for the inventory for the years 1997, 2003, 2006 to 2007, 2009, 2011, 2013, 2015, 2017, 2019 and 2020. The information was available from the Finnish Grocery Trade Association or from market research company Taloustutkimus. The activity data for 2021 was based on Statistics Finland’s regional statistics on entrepreneurial activity. Data for the years 1990 to 1996 was estimated mathematically using MS Excel’s exponentially smoothed trend function. Data for the missing years between 1997 and 2017 was estimated using interpolation. In addition, the data for 2017 was used for 2018 and data for 2021 was used for 2022 as statistical data for these years were not available. The different types of professional kitchens and their refrigerant charges are presented in Table 4.7-5. The charges are expert estimations made at Syke based on data received from companies in the refrigeration industry (Forsberg, 2017b).

Table 4.7-5 Refrigerant charges in different types of professional kitchens

Professional kitchen type	Refrigerant charge, kg
Restaurants, cafes, bars and hotels	7
Staff diners	75
Hospitals, schools, day-care centers and nursing homes	60

It was estimated that every third restaurant/café/bar/hotel in Finland has a centralized refrigeration system. In the case of all the other types of professional kitchens, it was estimated that 100% of them have a centralized system in use (Forsberg, 2017b). The percentage shares of refrigerants used were determined at Syke based on expert estimations from the refrigerant industry and international literature (Forsberg, 2023b). HFC refrigerants R-404A and R-134A have been used since 1994 with R-404A being the dominant one. Since 2011 refrigerants R-407A and R-422D have been used in small quantities. Since 2016 also refrigerants R-448A and R-449A and R-452A and propane since 2021 have been used in small quantities. CO_2 systems have started to replace the HFC systems in the recent years. In 2022, it was estimated that around 16% of the systems in use had CO_2 as refrigerant. Detailed refrigerant shares are presented in Appendix_4c. The average lifetime of 12 years was used as for other centralized systems.

HFC emissions from commercial stand-alone units and stand-alone units in professional kitchens are calculated based on the same basic activity data as for centralized systems, namely the number of different types of stores or kitchens in operation annually in Finland. Other parameters needed to determine the refrigerant stocks are the number of stand-alone units in a typical food retail store or professional kitchen and the refrigerant charge of a typical stand-alone equipment. The refrigerant charge of a typical stand-alone equipment used in the calculation was estimated at 400 g. It is an expert estimation made at Syke based on data received from companies in the refrigeration and food retail industries (Forsberg, 2017c). It is within the value range for stand-alone commercial applications given by the 2006 IPCC Guidelines in Vol. 3, Table 7.9, 200 to 6000 g. The number of stand-alone equipment in a typical food retail store or professional kitchen are presented in Table 4.7-6 and Table 4.7-7, respectively. The figures are also expert estimation made at Syke based on data received from companies in the refrigeration and food retail industries (Forsberg, 2017d and Forsberg, 2017e). Majority of the stand-alone units in commercial refrigeration are imported in Finland. Some domestic manufacturing of stand-alone units also exists in Finland. The share of domestically manufactured units from the total amount of stand-alone units used in Finland in food retail stores and professional kitchens is 15%. It is an expert estimate from the industry and it applies to the whole time series (Kari, 2018). The 15% estimate was also supported by another expert from the industry (Kahrola, 2018). The additions of refrigerants into new units are estimated by dividing the refrigerant stocks by the systems’ average lifetime and taking into account the share of domestically manufactured units from the total amount of units in use.

Table 4.7-6 Number of stand-alone equipment in different types of food retail stores

Store type	Number of stand-alone equipment, pieces
Hypermarkets	28
Department stores	10
Supermarkets (big)	23
Supermarkets (small)	15
Convenience stores (big)	10
Convenience stores (small)	6
Small shops	6
Specialized shops	8
Others	25

Table 4.7-7 Number of stand-alone equipment in different types of professional kitchens

Professional kitchen type	Number of stand-alone equipment, pieces
Restaurants, cafes, bars and hotels	4
Staff diners	6
Hospitals, schools, day-care centers and nursing homes	4

The average lifetime for stand-alone units is 10 years and it is an expert estimate received from Finnish Refrigeration Enterprises Association FREA (Hannula, 2014). The lifetime is within the value range given by the 2006 IPCC Guidelines in Vol. 3, Table 7.9, 10 to 15 years. Detailed percentage shares of individual refrigerants used in stand-alone units in food retail stores and professional kitchens are presented in Appendix_4c. The percentage shares of refrigerants used were determined at Syke based on expert estimations from the refrigerant industry and international literature (Forsberg, 2020a).

Emission factors

Emission factors used in the calculation of emissions from commercial refrigeration sub-applications are presented in Table 4.7-8, Table 4.7-9 and Table 4.7-10. Mainly the default emission factors presented in the 1996 and 2006 IPCC Guidelines have been used. Emission factors from the 1996 IPCC Guidelines have been used for the 1990s emission estimation since they are assumed to be more suitable to be used for estimating the emissions for the 1990s than the emission factors presented in the later versions of the IPCC guidelines. According to the RAC industry (Hannula, 2014) the emission factors of the 2006 IPCC Guidelines would underestimate the emissions in the 1990s since the follow-up and prevention of leakages have improved significantly in the 2000s. Recovery efficiencies in 2015 and 2020 are national estimates (Forsberg, 2021e) and based on expert estimates from the RAC industry (Kahrola, 2020 and Keitaanranta, 2021) and the best available techniques (BAT) reference document for waste treatment (Pinasseau et al., 2018). They exceed the upper limit of 70% provided in the 2006 IPCC Guidelines for Medium & Large Commercial Refrigeration and Stand-alone applications. The experts have also referred to the waste treatment BAT where the 90% recovery efficiency is a minimum with optimized removal of refrigerants. In addition, it is assumed that the increasing scarcity of HFCs on the EU market and related price increase due to the phase down mechanism of the EU F-gas Regulation affects to the thoroughness of the recovery measures today. In the case of charge and lifetime emissions, a linear decrease is assumed in the emission factors from the 1999 level to 2010 level presented in Table 4.7-8 and Table 4.7-9. The present level of leakage rate from centralised systems during their lifetime, 10%, has been verified by Swedish measurements of leakage rates from different kinds of units. As mentioned above, a considerable amount of direct systems are still used in Finland. The Swedish measurements suggest 10% leakage rate for such installations (Landé, 2017). In the case of recovery efficiency, a linear increase is also assumed between 2010 to 2015 and 2015 to 2020.

Table 4.7-8 Charge emission factors for commercial refrigeration categories

Sector	Time range	Charge EF, %	Source
Centralised supermarket refrigeration systems	1994-1999	5	IPCC 1996 GL
	from 2010	0.5	IPCC 2006 GL
Professional kitchens (centralised systems)	1994-1999	5	IPCC 1996 GL
	from 2010	0.5	IPCC 2006 GL
Commercial stand-alone refrigeration units	1994-1999	5	IPCC 1996 GL
	from 2010	0.5	IPCC 2006 GL
Stand-alone units of professional kitchens	1994-1999	5	IPCC 1996 GL
	from 2010	0.5	IPCC 2006 GL

A linear decrease is assumed in the emission factors between the time ranges presented in the table.

Table 4.7-9 Lifetime emission factors for commercial refrigeration categories

Sector	Time range	Lifetime EF, %	Source
Centralised supermarket refrigeration systems	1994-1999	17	IPCC 1996 GL
	from 2010	10	IPCC 2006 GL
Professional kitchens (centralised systems)	1994-1999	17	IPCC 1996 GL
	from 2010	10	IPCC 2006 GL
Commercial stand-alone refrigeration units	1994-1999	17	IPCC 1996 GL
	from 2010	1	IPCC 2006 GL
Stand-alone units of professional kitchens	1994-1999	17	IPCC 1996 GL
	from 2010	1	IPCC 2006 GL

A linear decrease is assumed in the emission factors between the time ranges presented in the table.

Table 4.7-10 End-of-life emission factors for commercial refrigeration categories

Sector	Time range	End-of-life Initial charge remaining, %	 Recovery efficiency, %	Source
Centralised supermarket refrigeration systems/ Professional kitchens (centralised systems)	2006-2010	90	70	IPCC 2006 GL
	2015	90	90	IPCC 2006 GL, CS
	from 2020	90	95	IPCC 2006 GL, CS
Commercial stand-alone refrigeration units/ Stand-alone units of professional kitchens	2004-2010	80	70	IPCC 2006 GL
	2015	80	90	IPCC 2006 GL, CS
	from 2020	80	95	IPCC 2006 GL, CS

The end-of-life emissions begin according to the average lifetime of equipment in each sector. A linear increase is assumed in the recovery efficiencies between the time ranges presented in the table.

Domestic refrigeration (2.F.1b)

Methods and activity data

Domestic refrigeration category includes household stand-alone refrigerators, freezers and coolers and their combinations. The only HFC refrigerant used in this application area is R-134A. The import and production of R-134A equipment in Finland began in 1993. The dominant refrigerant in this application area is isobutane (R-600A). The estimation of HFC stock is based on annual sales figures of domestic refrigeration equipment received from the Finnish Association of Electronics Wholesalers (Luukkainen, 2023). The proportion of R-134A equipment from the total amount of sold equipment was 40% for the time period 1993 to 1999 (Oinonen and Soimakallio, 2001). The further transition to R-600A is expected to have started from 2000. The R-134A share decreased to 5% in 2010 (Alaja, 2009). Under the EU F-gas regulation (517/2014), use of refrigerants with GWPs of 150 or higher in new household refrigerators and freezers is prohibited as of 2015. A linear decrease is assumed in the R-134A share from 1999 to 2010 and further to 0% in 2015.

The average charge of 100 g of R-134A per unit sold has been used in the calculations which is within the value range given by the 2006 IPCC Guidelines in Vol. 3, Table 7.9, 50 to 500 g. The average lifetime for domestic refrigeration equipment is 12 years and it is an expert estimate received from Finnish Refrigeration Enterprises Association FREA (Hannula, 2014). The lifetime is within the value range given by the 2006 IPCC Guidelines in Vol. 3, Table 7.9, 12 to 20 years. The amount of R-134A consumed in domestic manufacturing of equipment for the years 1993 to 1998 is taken from Oinonen (2000). For the years 2000 to 2014, the data was available from the annual survey that was used to collect the category 2.F.1 activity data for the Tier 2b mass balance approach of the 2006 IPCC Guidelines that was used in this category prior to 2018 submission. The data for 1999 was estimated as an average of the 1998 and 2000 data. The amount of refrigerants at disposal are estimated with the help of average lifetime. Activity data for the disposal emissions is the annual sales of equipment from the year n-12.

Emission factors

Emission factors used in the calculation of emissions from domestic refrigeration sub-applications are presented in Table 4.7-11, Table 4.7-12 and Table 4.7-13. In the case of charge emissions in time period 1993 to 1999, a national emission factor has been used. In the mid-1990s there were three Finnish manufacturers of domestic refrigeration equipment. The emission factor is based on identical data reported by two manufacturers. The emission rate has been estimated as the difference between the total annual R-134A consumption in manufacturing reported by the plants and the calculated total refrigerant fill in manufactured equipment (based on number of manufactured equipment and refrigerant fill in one equipment). As in Oinonen (2000), the same emission factor has been assumed to be applicable also to the third manufacturer. The emission factor for the years 2005 to 2014 is taken from the 2006 IPCC Guidelines. In the case of lifetime emissions, the default emission factor from the 1996 IPCC Guidelines has been used for the time period 1993 to 1999. According to the RAC industry (Hannula, 2014) the emission factors of the 2006 IPCC Guidelines would underestimate the emissions in the 1990s since the follow-up and prevention of leakages have improved significantly in the 2000s. In the case of charge and lifetime emissions, a linear decrease is assumed in the emission factors from the 1999 level to 2005 level and to 2002 level, respectively. The end-of-life emission factors for 2005 to 2010 are default emission factors from the 2006 IPCC Guidelines. In the case of recovery efficiency, a country specific estimate (Forsberg, 2021e) based on expert estimate from the RAC and waste management industries (Partanen, 2020) and the best available techniques (BAT) reference document for waste treatment (Pinasseau et al., 2018) is applied from 2015 and it exceeds the upper limit of 70% provided in the 2006 IPCC Guidelines for Domestic refrigeration applications.

Table 4.7-11 Charge emission factors for domestic refrigeration

Sector	Time range	Charge EF, %	Source
Domestic refrigeration	1993-1999	2.7	Country-specific
	2005-2014	0.6	IPCC 2006 GL

A linear decrease is assumed in the emission factors between the time ranges presented in the table. Emissions are not occurring after 2014.

Table 4.7-12 Lifetime emission factors for domestic refrigeration

Sector	Time range	Lifetime EF, %	Source
Domestic refrigeration	1993-1999	1	IPCC 1996 GL
	from 2002	0.3	IPCC 2006 GL

A linear decrease is assumed in the emission factors between the time ranges presented in the table.

Table 4.7-13 End-of-life emission factors for domestic refrigeration

Sector	Time range	End-of-life		Source
		Initial charge remaining, %	Recovery efficiency, %	
Domestic refrigeration	2005-2010	80	70	IPCC 2006 GL
	from 2015	80	90	IPCC 2006 GL, CS

The end-of-life emissions begin according to the average lifetime of equipment. A linear increase is assumed in the recovery efficiencies between the time ranges presented in the table.

Industrial refrigeration (2.F.1c)

Methods and activity data

Industrial refrigeration consists of a wide variety of applications for refrigeration and freezing mainly in the production of products. Applications vary from the major food and drink industry and cold storage to smaller capacity equipment e.g. specialised environmental simulation chambers. Applications can also be classified to larger scale customised on-site build systems and factory build equipment from series production. Natural refrigerants, mainly ammonia, have widely been used in this sector in larger scale systems.

In the calculation model, this category is divided into two sub-applications, industrial refrigeration and ice rinks. Ice rinks are separated from other applications since specific activity data was available from the Finnish Ice Hockey Association.

For industrial refrigeration sub-application, a wide variety of refrigerants are used, the dominant ones being R-404A, R-134A, R-407C and R-422D. Use of HFC refrigerants began in this sector in 1994 and refrigerants containing PFCs in 2000. In the recent years, a number of new refrigerants have been introduced to the market in these applications as medium-term alternatives to the high GWP refrigerant R-404A. These refrigerants include R-448A, R-449A, R-452A and R-513A. The activity data for the years 1994 to 1998, annual new additions of refrigerants into new systems, was taken from Oinonen (2000). The data for the years 2000 to 2021 was available from the annual survey that was used to collect the category 2.F.1 activity data for the Tier 2b mass balance approach of the 2006 IPCC Guidelines that was used in this category prior to 2018 submission. The data consists of annual amount of refrigerants imported and exported in equipment, amount of refrigerants used for factory charged equipment and amount of refrigerants used for on-site installation of new systems. The data for 1999 was estimated as an average of the 1998 and 2000 data. The annual refrigerant stocks are calculated with the help of these data and the percentage shares of individual refrigerants used. The percentage shares of refrigerants are determined at Syke based on expert estimations from the refrigerant industry and international literature (Forsberg, 2023c). Detailed percentage shares of individual refrigerants used are presented in Appendix_4c. The average lifetime for industrial refrigeration is 15 years and it is an expert estimate received from Finnish Refrigeration Enterprises Association FREA (Hannula, 2014). The lifetime is within the value range given by the 2006 IPCC Guidelines in Vol. 3, Table 7.9, 15 to 30 years. The amount of refrigerants at disposal are estimated with the help of average lifetime. Activity data for the disposal emissions is the initial charge into new systems from the year of installation of the systems.

The starting point for the calculation of HFC emissions from ice rinks is the number of new ice rinks taken into use and renovation of existing ice rinks annually. During the renovation of ice rinks, the refrigeration systems are usually rebuilt too. The data was available from the Finnish Ice Hockey Association for the whole time series (Finnish Ice Hockey Association, 2023). From the beginning of 1990s, all the new ice rinks in Finland have been indirect systems with considerably lower refrigerant charge levels compared to direct ones. R-404A has been the only HFC refrigerant used in this sector. According to Alaja (2009), in 1999 70% of the annual refrigerant charge of constructed and renovated ice rinks was R-404A and the remaining 30% ammonia. This proportion is estimated to have changed to 80% ammonia and 20% R-404A by 2010. In the calculation model, the R-404A share was linearly increased from 0% in 1993 to 70% in 1999 and decreased from 70% in 1999 to 20% in 2010. Since 2020 no new refrigeration systems with R-404A have been taken into use. All the new systems today use either ammonia or CO_2. The refrigerant charge is taken from Alaja (2009). For the years 1994 to 1999 it is estimated at 140 kg. The charge is estimated to have decreased into 50 kg in 2007 (linear decrease) and to stay constant thereafter. The annual HFC stock and additions into new systems is calculated with the help of these data and assumptions. The average lifetime for ice rinks is 20 years and it is taken from Alaja (2009). The amount of refrigerants at disposal are estimated with the help of average lifetime.

Emission factors

Emission factors used in the calculation of emissions from industrial refrigeration sub-applications are presented in Table 4.7-14, Table 4.7-15 and Table 4.7-16. The default emission factors presented in the 2006 IPCC Guidelines have been used since specific national emission factors are not available. In the case of charge and lifetime emissions, a linear decrease is assumed in the emission factors from the higher level to the lower level presented in Table 4.7-14 and Table 4.7-15. In the case recovery efficiency at end-of-life, a linear increase is assumed between the time ranges presented in Table 4.7-16.

Table 4.7-14 Charge emission factors for industrial refrigeration categories

Sector	Time range	Charge EF, %	Source
Industrial refrigeration	1994-2002	2	IPCC 2006 GL
	from 2010	1	IPCC 2006 GL
Ice rinks	1994-2003	2	IPCC 2006 GL
	from 2012	1	IPCC 2006 GL

A linear decrease is assumed in the emission factors between the time ranges presented in the table.

Table 4.7-15 Lifetime emission factors for industrial refrigeration categories

Sector	Time range	Lifetime EF, %	Source
Industrial refrigeration	1994-2005	17	IPCC 2006 GL
	from 2015	10	IPCC 2006 GL
Ice rinks	1994-2005	15	IPCC 2006 GL
	from 2015	9	IPCC 2006 GL

A linear decrease is assumed in the emission factors between the time ranges presented in the table.

Table 4.7-16 End-of-life emission factors for industrial refrigeration categories

Sector	Time range	End-of-life		Source
		Initial charge remaining, %	Recovery efficiency, %	
Industrial refrigeration	2009-2010	90	80	IPCC 2006 GL
	from 2015	90	90	IPCC 2006 GL
Ice rinks	2010	90	80	IPCC 2006 GL
	from 2015	90	90	IPCC 2006 GL

The end-of-life emissions begin according to the average lifetime of equipment in each sector. A linear increase is assumed in the recovery efficiencies between the time ranges presented in the table.

Transport refrigeration (2.F.1d)

Methods and activity data

Transport refrigeration mainly comprised of refrigerated trucks and trailers or containers, which can be transported by road, sea or rail. Refrigerated rail transport is however uncommon in Finland. The state-owned railway company VR does not have refrigerated railcars. Domestic distribution services especially in cities are often carried out with refrigerated vans or light trucks (Alaja, 2009).

The HFC and PFC emission calculation from this category is based on annual quantities of new transport refrigeration equipment taken into use. The international transportation and transportation equipment of perishable foodstuffs is regulated by the ATP-agreement (Agreement concerning the International Carriage of Perishable Foodstuffs and on the Special Equipment to be Used for such Carriage). The ATP-agreement is enforced by Finnish Food Authority in Finland. The ATP approved transportation equipment is certified by Natural Resources Institute Finland which keeps a register of these equipment.

The annual HFC and PFC stocks are calculated based on activity data, the annual amount of refrigerants taken into use in new transport refrigeration equipment by refrigerant type, received from Natural Resources Institute Finland (Rantti, 2023). Use of PFC refrigerants began in this sector in Finland in 1992 and use of HFC refrigerants in 1994. The dominant refrigerants have been R-404A and R-410A. A new HFC/HFO blend refrigerant R-452A was introduced to market in 2015 and has almost completely replaced R-404A in new equipment. Use of R-410A in new equipment has already ceased. Majority of the transport refrigeration equipment are imported to Finland. Some domestic production and charge of new equipment also exist. According to the industry the share of domestic charge is estimated to have been slightly higher in the 1990s than what it is today (Leppänen, 2018). The share of domestic charge from the annual amount of refrigerants taken into use in new transport refrigeration equipment was estimated to be 30% during 1992 to 2000 and 20% from 2010 onwards. A linear decrease was assumed in the share between the years 2000 and 2010. The shares are expert estimations made at Syke based on data received from companies in the transport refrigeration industry (Forsberg, 2018c). The average lifetime for transport refrigeration is 6 years and it is an expert estimate received from Finnish Refrigeration Enterprises Association FREA (Hannula, 2014). The lifetime is within the value range given by the 2006 IPCC Guidelines in Vol. 3, Table 7.9, 6 to 9 years. The amount of refrigerants at disposal are estimated with the help of average lifetime.

Emission factors

Emission factors used in the calculation of emissions from transport refrigeration are presented in Table 4.7-17, Table 4.7-18 and Table 4.7-19. The default emission factors presented in the 1996 and 2006 IPCC Guidelines have been used since specific national emission factors are not available. Emission factors from the 1996 IPCC Guidelines have been used for the 1990s emission estimation of charge emissions since according to the RAC industry (Hannula, 2014), the emission factors of the 2006 IPCC Guidelines would underestimate the emissions in the 1990s since the follow-up and prevention of leakages have improved significantly in the 2000s. In the case of charge and lifetime emissions, a linear decrease is assumed in the emission factors from the higher level to the lower level presented in Table 4.7-17 and Table 4.7-18. In the case recovery efficiency at end-of-life, a linear increase is assumed between the time ranges presented in Table 4.7-19.

Table 4.7-17 Charge emission factors for transport refrigeration

Sector	Time range	Charge EF, %	Source
Transport refrigeration	1994-1999	5	IPCC 1996 GL
	2010	0.6	IPCC 2006 GL
	from 2015	0.3	IPCC 2006 GL

A linear decrease is assumed in the emission factors between the time ranges presented in the table.

Table 4.7-18 Lifetime emission factors for transport refrigeration

Sector	Time range	Lifetime EF, %	Source
Transport refrigeration	1992-1999	17	IPCC 2006 GL
	from 2010	15	IPCC 2006 GL

A linear decrease is assumed in the emission factors between the time ranges presented in the table.

Table 4.7-19 End-of-life emission factors for transport refrigeration

Sector	Time range	End-of-life Initial charge remaining, %	End-of-life Recovery efficiency, %	Source
Transport refrigeration	1998-2010	50	50	IPCC 2006 GL
	from 2015	50	70	IPCC 2006 GL

The end-of-life emissions begin according to the average lifetime of equipment. A linear increase is assumed in the recovery efficiencies between the time ranges presented in the table.

Mobile air-conditioning (2.F.1e)

Methods and activity data

Mobile air-conditioning (MAC) category is divided into four different sub-applications – road vehicles (passenger cars, light duty vehicles, busses and trucks), off-road machinery, railway cars and trams/underground railway cars. Since the phase out CFC's in the 1990s, HFC refrigerants have been used in mobile air-conditioning in Finland since 1995. R-134A has been the most commonly used refrigerant. R-407C has been used in some tram railcars since 2006 and in some underground railway cars since 2015.

The starting point of the estimation of the annual HFC stock in road vehicle sub-application are the statistics of annual new registrations of vehicles available from Finnish Transport and Communications Agency Traficom (Finnish Transport and Communications Agency, 2023a). The number of new registrations of vehicles are available by vehicle type – passenger cars, light duty vehicles, buses and trucks. Other parameters needed in the calculation are the share of vehicles equipped with MAC devices, refrigerant charge in one MAC device and the share of refrigerants used. The share of vehicles equipped with MACs for the years 1995 to 1999 was taken from Oinonen and Soimakallio (2001). The share for the years 2002 to 2014 was taken from the annual survey (MAC survey) that was used to collect the category 2.F.1e activity data for the Tier 2b mass balance approach of the 2006 IPCC Guidelines that was used in this category prior to 2018 submission. The share of vehicles equipped with MACs has been assumed to be 100% since 2015. The refrigerant charges used in the calculation are presented in Table 4.7-20. In the case of passenger cars and light duty vehicles, the charge for the years 1995 to 1998 are taken from Oinonen (2000). The same charges are assumed for the years 1999 to 2005. The charge for the year 2012 is taken from the survey conducted in 2013 to vehicle importers. A linear decrease is assumed from the 2005 level to 2012 level. The charges are within the value range given by the 2006 IPCC Guidelines in Vol. 3, Table 7.9, 0.5 to 1.5 kg. In the case of trucks and busses, the charges are taken from Oinonen (2000) and the same charges are assumed for the whole time series.

Table 4.7-20 Refrigerant charges of air-conditioning equipment of different types of road vehicles

Vehicle type	Time range	Refrigerant charge, kg
Passenger cars	1995-2005	0.8
	from 2012	0.63
Light duty vehicles	1995-2005	0.8
	from 2012	0.63
Trucks	from1995	1.7
Busses	from1995	10

A linear decrease is assumed in the refrigerant charges of passenger cars and light duty vehicles between the time ranges presented in the table.

Refrigerant R-134A has been the most widely used refrigerant in road vehicles. In the case of trucks and busses, R-134A has been the only refrigerant used in the time period 1995 to 2020. First passenger cars equipped with HFO low-GWP refrigerant R-1234yf were imported and registered in Finland in 2012. The annual share of passenger cars equipped with R-1234yf for the years 2012 to 2017 is taken from the MAC survey mentioned above. The shares are 5% in 2012, 10% in 2013, 15% in 2014, 20% in 2015, 50% in 2016 and 96% in 2017. Since 2018, all new imported and registered passenger cars have been equipped with R-1234yf. According to the MAC survey, the first light duty vehicles equipped with R-1234yf were imported and registered in Finland in 2016. The share of R-1234yf in light duty vehicles in 2016 was 5%, in 2017 42%, in 2018 20%, 35% in 2019, 39% in 2020, 60% in 2021 and 44% in 2022. The EU MAC Directive prohibits the use of F gases with GWP >150 in all new passenger cars and small light duty vehicles produced from 2017. However, according to Traficom (Kuikka, 2018), during the transition period (1.1.2017-31.12.2017) the end-of-series clauses of Framework Directive 2007/46/EC were applied in Finland. This means that during 2017 some car importers were allowed to put into market new passenger cars and small vans with R-134A. They had to apply the permission from Traficom. This explains the share of R-134A in new passenger cars and small vans that were still registered in Finland in 2017. Registration of used passenger cars and small light duty vehicles with R-134A is still possible. It was assumed that in 2018 90% of the imported and registered used passenger cars were using refrigerant R-134A and 10% R-1234yf. In 2019, the figures were 85% and 15%, in 2020 and 2021 80% and 20%, and in 2022 51% and 49, respectively. The shares are expert estimates made at Syke (Niemelä, 2023). The first trucks equipped with R-1234yf were imported and registered in Finland in 2021 and first busses equipped with R-1234yf were imported and registered in 2022.

Domestic manufacturing of passenger cars takes place in one plant in Finland. The activity data, the number of vehicles manufactured annually by vehicle brand and model, was received from the plant and from the YLVA (formerly VAHTI) system (see Annex 6). In addition, the parameters needed in the emission estimation, namely the share of manufactured vehicles equipped with air-conditioning and refrigerant charge were received from the plant. The refrigerant charges vary between 0.85 to 0.63 kg depending on the vehicle brand and model. Between 1995 and 2011, only R-134A was used as a refrigerant. Since 2012, also R-1234yf has been used in certain models that are sold to the European market (Pietilä, 2017). The data from the plant has been used to estimate the annual new additions of HFC's into new equipment in the category road vehicles. The vast majority of the production from the plant has been exported annually. The average lifetime for air conditioning equipment in road vehicles is 9 years and it is an expert estimate received from Finnish Refrigeration Enterprises Association FREA (Hannula, 2014). The lifetime is within the value range given by the 2006 IPCC Guidelines in Vol. 3, Table 7.9, 9 to 16 years. The amount of refrigerants at disposal are estimated with the help of average lifetime.

As in the case of road vehicles, the starting point of the estimation of annual HFC stock in off-road machinery sub-application are the statistics of annual new registrations of vehicles available from Finnish Transport and Communications Agency Traficom (Finnish Transport and Communications Agency, 2023a). Off-road machinery is divided into two types of machinery in the statistics, tractors and motorised working machines. The latter category includes several types of machinery, e.g. other agricultural machinery than tractors, excavators or road graders. According to the information from the industry (Hakulinen and Toivonen, 2016), the use HFC refrigerants began at the same time as in road vehicles and the refrigerant charge of a typical working machine usually varies between 1 and 2 kg and R-134A has been used as refrigerant. In the beginning of 2000s around 50% of the machinery registered annually were equipped with air-conditioning. Based on this information, it was assumed in the calculation that R-134A use began in 1995 and 1.5 kg was chosen as a refrigerant charge. R-134A was assumed as the only refrigerant used in the time period 1995 to 2022. Also the same refrigerant charge was assumed for the same time period. The share of machinery registered annually and equipped with air-conditioning was assumed to be 100% beginning from 2015. A linear increase was assumed from 0% in 1994 to 50% in 2000 and further to 100% in 2015 (Forsberg, 2017g).

The annual new additions of HFC's into new equipment in the category off-road machinery are estimated from domestic manufacturing of tractors. The activity data, the number of tractors manufactured annually was available from the YLVA system. The assumption for refrigerant use, charge level and share of equipment equipped with MACs were used as in the case of annual new registrations. The average lifetime was assumed to 12 years, which is an expert estimate made at Syke (Forsberg, 2017). The amount of refrigerants at disposal are estimated with the help of average lifetime.

The starting point of the estimation of the annual HFC stock in different railway vehicles is the number of units equipped with air-conditioning taken into use annually. A number of information sources have been used to gather this data. In the case of railway cars the following information sources have been used: Finnish Railway Statistics published by Finnish Transport and Communications Agency (Finnish Transport and Communications Agency, 2023b, Finnish Transport and Communications Agency, 2019 and Idman, 2019), state-owned railway company VR (VR, 2017, VR, 2018 and VR, 2019), Pääkaupunkiseudun Junakalusto Oy (Vesanen, 2016) and Lumikko Oy (Lumikko Oy, 2017 and Laitamäki, 2016). In the calculation, the railway car fleet is divided into the following types of units: trains, locomotives, passenger cars and restaurant cars. HFC refrigerants have been used in railway cars in Finland since 1995. R-134A is the only HFC refrigerant that has been used. The refrigerant charges of different types of units are presented in Table 4.7-21. The charges are based on data received from the companies producing air-conditioning solutions for railway fleet and companies that own the fleet.

Table 4.7-21 Refrigerant charges of air-conditioning equipment of different types of railway vehicles

Vehicle type	Time range	Refrigerant charge, kg
Trains	from 1995	19.4
Locomotives	from 1997	1.3
Passenger cars	from 1999	17
Restaurant cars	from 2002	3.5

The average lifetime of railway cars was assumed to 20 years, which is an expert estimate made at Syke (Forsberg, 2017h). The amount of refrigerants at disposal are estimated with the help of average lifetime.

In the case of trams and underground railway cars, the information sources for the annual fleet equipped with air-conditioning taken into use were Helsinki City Transport HKL (Niippa, 2016) and Lumikko Oy (Lumikko Oy, 2017 and Laitamäki, 2016). Helsinki is the only city in Finland where trams and metro operate. HFC refrigerants have been used in trams since 1998. Three types of trams operate in Helsinki that are air-conditioned. Two of these tram types have been equipped with air-conditioning from the beginning when they were built. The first type, called Variotram, was taken into use 1998 and the second one, called Artic, in 2013. R-134A is used as refrigerant in these tram types. The refrigerant charges, 16.5 kg and 12.4 kg have been received from HKL (Niippa, 2016). In addition to these two tram types, air-conditioning equipment have been post-installed into one type of trams since 2006. These trams use R-407C as refrigerant with a refrigerant charge of 10.5 kg. The refrigerant type and charge were received from Helsinki City Transport HKL (Niippa, 2016). R-407C is also used as refrigerant in the new metro trains that started operation in Helsinki in 2015. According to HKL, the refrigerant charge in one metro train is 28 kg (Niippa, 2016). The average lifetime of trams and underground railway cars was assumed to 20 years, which is an expert estimate made at Syke (Forsberg, 2017h). The amount of refrigerants at disposal are estimated with the help of average lifetime. All the Variotram type trams were removed from traffic for good during 2018. This was also taken into account in the emission calculation.

Emission factors

Emission factors used in the calculation of emissions from commercial refrigeration sub-applications are presented in Table 4.7-22, Table 4.7-23 and Table 4.7-24. The default emission factors presented in the 1996 and 2006 IPCC Guidelines have been used since specific national emission factors are not available. Emission factors from the 1996 IPCC Guidelines have been used for the 1990s emission estimation since they are assumed to be more suitable to be used for estimating the emissions for the 1990s than the emission factors presented in the later versions of the IPCC guidelines. According to the RAC industry (Hannula, 2014) the emission factors of the 2006 IPCC Guidelines would underestimate the emissions in the 1990s since the follow-up and prevention of leakages have improved significantly in the 2000s. A linear decrease is assumed in charge and lifetime emissions between the time ranges presented in Table 4.7-22 and Table 4.7-23.

Table 4.7-22 Charge emission factors for mobile air-conditioning categories

Sector	Time range	Charge EF, %	Source
Road vehicles	1995-1999	5	IPCC 1996 GL
	from 2015	0.2	IPCC 2006 GL
Railway cars	1995-1999	5	IPCC 1996 GL
	from 2015	0.2	IPCC 2006 GL
Underground railway cars and trams	1998-1999	5	IPCC 1996 GL
	from 2015	0.2	IPCC 2006 GL
Off-road machinery	1995-1999	5	IPCC 1996 GL
	from 2015	0.2	IPCC 2006 GL

A linear decrease is assumed in the emission factors between the time ranges presented in the table.

Table 4.7-23 Lifetime emission factors for mobile air-conditioning categories

Sector	Time range	Lifetime EF, %	Source
Road vehicles	1995-1999	30	IPCC 1996 GL
	2005	20	IPCC 2006 GL
	from 2015	10	IPCC 2006 GL
Railway cars	1995-1999	30	IPCC 1996 GL
	2005	20	IPCC 2006 GL
	from 2015	10	IPCC 2006 GL
Underground railway cars and trams	1998-1999	30	IPCC 1996 GL
	2005	20	IPCC 2006 GL
	from 2015	10	IPCC 2006 GL
Off-road machinery	1995-1999	30	IPCC 1996 GL
	2005	20	IPCC 2006 GL
	from 2015	10	IPCC 2006 GL

A linear decrease is assumed in the emission factors between the time ranges presented in the table.

Table 4.7-24 End-of-life emission factors for mobile air-conditioning categories

Sector	Time range	End-of-life		Source
		Initial charge remaining, %	Recovery efficiency, %	
Road vehicles	from 2004	50	50	IPCC 2006 GL
Railway cars	from 2015	50	50	IPCC 2006 GL
Underground railway cars and trams	NO	50	50	IPCC 2006 GL
Off-road machinery	from 2007	50	50	IPCC 2006 GL

The end-of-life emissions begin according to the average lifetime of equipment in each sector. End-of-life emissions from underground railway cars and trams have not started yet.

Stationary air-conditioning (2.F.1f)

Methods and activity data

The category stationary air-conditioning includes different types of heat pumps and other stationary equipment used for building air conditioning like water chillers and room air conditioners. In the calculation model, this category is divided into three different sub-applications. They are heat pumps, large heat pumps and other stationary air-conditioning equipment.

Heat pumps are equipment that utilise heat from the air, ground or water for heating or cooling buildings or heating of water. In the calculation model, heat pumps are grouped by the source of heat and its distribution method. Heat pumps are divided into five different categories: ground source heat pumps, exhaust air heat pumps, air-to-water heat pumps, air-to-air heat pumps and heat pump tumble dryers.

The estimation of the HFC stock from different types of heat pumps is based on annual sales figures of heat pumps received from the Finnish Heat Pump Association SULPU (Finnish Heat Pump Association, 2023). The annual sales figures of heat pump tumble dryers were received from the Finnish Association of Electronics Wholesalers (Luukkainen, 2023). HFC refrigerants R-134A, R-407C and R-410A have been used in heat pumps in Finland since 1995. In addition, R-32 has been used since 2011. R-134A and R-407C were the most common refrigerants between 1995 and 1999. Since then R-410A has become the most commonly used refrigerant. However, in the case of air-to-air heat pumps, R-32 replaced R-410A in new equipment almost completely during 2019. According to the industry, 90% of the sold new air-to-air heat pumps were equipped with R-32 in 2019 and 95% in 2020 (Kapanen, 2020). In 2018, the share of R-32 air-to-air heat pumps was estimated to have been less than 10%. Since 2021, the share has been 100%. Heat pump tumble dryers were introduced to the Finnish market in 2013. R-134A and R-407C have been used as refrigerants. 70% of annually sold heat pump tumble dryers use R-134A as refrigerant and the rest use R-407C. The shares of refrigerants in heat pumps are expert estimations made at Syke and are based on data from the industry (Forsberg, 2023e). Detailed percentage shares of individual refrigerants used are presented in Appendix_4c. Refrigerant charges and equipment lifetimes used in the calculation are presented in Table 4.7-25. Charges and lifetimes of other heat pumps than air-to-air heat pumps and tumble dryers are expert estimations from SULPU and they are within the value ranges given by the 2006 IPCC Guidelines in Vol. 3, Table 7.9. The lifetime of air-to-air heat pumps is an expert estimate made at Statistics Finland (Rouhiainen, 2022). The charge of tumble dryers is an expert estimate made at Syke based data from the industry. In the case lifetime of tumble dryers, it was estimated to be the same as for domestic refrigeration equipment (Forsberg, 2017i). In the case of air-to-air heat pumps, the refrigerant charge is 1 kg from 2010 onwards. Between 1995 and 2000 the charge is 2 kg and a linear decrease in the charge is assumed between the years 2000 and 2010. The 1 kg charge is an expert estimate made at Syke (Forsberg, 2018e) and the 2 kg charge is expert estimate from SULPU and presented in Alaja (2009).

Table 4.7-25 Refrigerant charges and equipment lifetimes of different types of heat pumps

Heat pump type	Charge, kg	Lifetime, years
Ground source HP	2	20
Exhaust air HP	2	15
Air-to-water HP	2	15
Air-to-air HP	1[1]	15
HP clothes dryers	0.23	12

[1] A charge of 1 kg from 2010 onwards. Between 1995 and 2000 the charge is 2 kg and a linear decrease in the charge is assumed between the years 2000 and 2010.

Only ground source heat pumps are manufactured in Finland. All the other heat pump types are imported equipment. According to SULPU, 30% of the annually sold ground source heat pumps are domestically manufactured. The same share applies to the whole time series (Hirvonen, 2017). The additions of refrigerants into new equipment were calculated with the help of these data and assumptions. The amount of refrigerants at disposal are estimated with the help of average lifetime.

The sub-application large heat pumps consist of larger scale heat pumps in the size range usually from 0.1 MW up to around 20 MW. Examples of application areas include district heating/cooling plants and various industrial heat pumps systems. These heat pumps are not covered by SULPU’s sale statistics. The 2019 to 2022 activity data of large heat pumps was taken from the annual survey that was used to collect the category

2.F.1 activity data for the Tier 2b mass balance approach of the 2006 IPCC Guidelines that was used in this category prior to 2018 submission. The annual installation data on these systems for earlier years was acquired by Statistics Finland with the help of SULPU and Finnish Refrigeration Enterprises Association FREA. The first heat pumps were installed in 2001. The installation data was available for the years 2001 to 2016. The data was not acquired for 2017 and 2018. Therefore, the data for 2017 was derived mathematically based on the data for the years 2001 to 2016 using MS Excel's exponentially smoothed trend function. The same figure was also used for 2018. It was estimated based on information from the industry that R-134A is the only refrigerant used in these systems until 2018 (Forsberg, 2020e). The 2020 data revealed that some new refrigerants were introduced to the market for large heat pumps. In addition to R-134A, refrigerants R-1234ze, R-450A, R-513A and ammonia are used in some heat pumps in this category. R-1234ze is a pure HFO refrigerant and R-450A/R-513A are blends of HFO's and HFC-134a. In addition, large heat pumps with refrigerant R-410A were reported for the first time in the 2020 data. Detailed percentage shares of individual refrigerants used are presented in Appendix_4c. The annual heating capacity taken into use by these heat pumps was used as the starting point of the estimation of annual HFC stock. Based on data from the industry, it was estimated that the refrigerant charge per MW heating capacity was 472 kg. The average lifetime was assumed to be 20 years, which is an expert estimate made at Syke (Forsberg, 2017j). These systems are usually on-site build installations, but also domestic factory production and export of domestically manufactured equipment exists. A small part of large heat pumps is also imported pre-charged with refrigerants. The amount of refrigerants at disposal are estimated with the help of average lifetime.

For other stationary air-conditioning sub-application, a wide variety of refrigerants are used, the dominant ones being R-134A, R-407C, R-410A and R-422D. HFC substance HFC-152a was used already in 1990 as component of refrigerant R-500. The use of refrigerants R-134A and R-407C began in 1994 and 1995, respectively. The activity data for the years 1990 to 1998, annual new additions of HFC refrigerants into new systems, was taken from Oinonen (2000). The data for the years 2000 to 2022 was available from the annual survey that was used to collect the category 2.F.1 activity data for the Tier 2b mass balance approach of the 2006 IPCC Guidelines that was used in this category prior to 2018 submission. The data consists of annual amount of refrigerants imported and exported in equipment, amount of refrigerants used for factory charged equipment and amount of refrigerants used for on-site installation of new systems. The data for 1999 was estimated as an average of the 1998 and 2000 data. The annual refrigerant stocks are calculated with the help of these data and the percentage shares of individual refrigerants used. The percentage shares of refrigerants are determined at Syke based on expert estimations from the refrigerant industry and international literature (Forsberg, 2023e). Detailed percentage shares of individual refrigerants used are presented in Appendix_4c. The average lifetime for industrial refrigeration is 15 years and it is an expert estimate received from Finnish Refrigeration Enterprises Association FREA (Hannula, 2014). The lifetime is within the value range given by the 2006 IPCC Guidelines in Vol. 3, Table 7.9, 9 to 16 years. The amount of refrigerants at disposal are estimated with the help of average lifetime.

Emission factors

Emission factors used in the calculation of emissions from stationary air-conditioning sub-applications are presented in Table 4.7-26, Table 4.7-27 and Table 4.7-28. The default emission factors presented in the 1996 and 2006 IPCC Guidelines have been used together with national emission factors. National emission factor is available for the calculation of lifetime emissions for 2015 onwards. The national emission factor was developed in 2019 together with Syke and Helsinki University Properties Ltd. A more detailed description of the development is presented in Section 4.7.2.4. Emission factors from the 1996 IPCC Guidelines have been used for the1990s emission estimation since they are assumed to be more suitable to be used for estimating the emissions for the 1990s than the emission factors presented in the later versions of the IPCC guidelines. According to the RAC industry (Hannula, 2014) the emission factors of the 2006 IPCC Guidelines would underestimate the emissions in the 1990s since the follow-up and prevention of leakages have improved significantly in the 2000s. A linear decrease is assumed in charge and lifetime emissions between the time ranges presented in Table 4.7-26 and Table 4.7-27. In the case recovery efficiency at end-of-life of other stationary air-conditioning equipment, a linear increase is assumed between the time ranges presented in Table 4.7-28.

Table 4.7-26 Charge emission factors for stationary air-conditioning categories

Sector	Time range	Charge EF, %	Source
Heat pumps (all types)	1995-1999	5	IPCC 1996 GL
	from 2010	0.2	IPCC 2006 GL
Other stationary air-conditioning equipment	1990-1999	5	IPCC 1996 GL
	from 2010	0.2	IPCC 2006 GL

A linear decrease is assumed in the emission factors between the time ranges presented in the table.

Table 4.7-27 Lifetime emission factors for stationary air-conditioning categories

Sector	Time range	Lifetime EF, %	Source
Heat pumps (all types)	1995-1999	17	IPCC 1996 GL
	2005	10	IPCC 2006 GL
	from 2015	3.5	Country-specific
Other stationary air-conditioning equipment	1990-1999	17	IPCC 1996 GL
	2005	10	IPCC 2006 GL
	from 2015	3.5	Country-specific

A linear decrease is assumed in the emission factors between the time ranges presented in the table.

Table 4.7-28 End-of-life emission factors for stationary air-conditioning categories

Sector	Time range	End-of-life Initial charge remaining, %	 Recovery efficiency, %	Source
Heat pumps (all types)	from 2005	80	80	IPCC 2006 GL
Other stationary air-conditioning equipment	2010	80	80	IPCC 2006 GL
	2015	80	90	IPCC 2006 GL
	from 2020	80	95	IPCC 2006 GL
Large heat pumps	from 2021	80	95	IPCC 2006 GL

The end-of-life emissions begin according to the average lifetime of equipment in each sector. A linear increase is assumed in the recovery efficiencies between the time ranges presented in the table.

4.7.2.3 Uncertainty assessment and time series consistency

Quantitative estimates of uncertainty are provided in Annex 2. The annex also documents assumptions made for the analysis. A description of the uncertainty analysis is included in Section 1.6.

Emission estimates of HFC and PFC emissions from categories 2.F.1a-f has been calculated with the same methodology given in the 2006 IPCC Guidelines for the whole time series in every category. Therefore, every time series is considered consistent. In the case of emission factors, default emission factors for 1990s have generally been taken from the 1996 IPCC Guidelines since they are assumed to be more suitable to be used for estimating the emissions for the 1990s than the emission factors presented in the later versions of the IPCC guidelines. According to the RAC industry (Hannula, 2014) the emission factors of the 2006 IPCC Guidelines would underestimate the emissions in the 1990s since the follow-up and prevention of leakages have improved significantly in the 2000s due to the EU legislation concerning f gases introduced during that time. Emission factors for 2000s and onwards have been taken from the 2006 IPCC Guidelines. A linear decrease in the emission factors from the 1990s levels to the levels of 2006 IPCC Guidelines has been assumed to reflect the effect of the legislation on reducing emission rates.

2006 IPCC Guidelines do not provide uncertainty estimates for activity data nor for emission factors. Therefore, the 2021 uncertainties for activity data and emission factors for categories 2.F.1a-f were set as an expert judgement at Syke (Forsberg, 2021d). Uncertainty for emission factors for categories 2.F.1a/b/f were set at ±40% and for category 2.F.1c/d/e at ±50%. The slightly lower uncertainty for categories 2.F.1a/b/f is due to use of national emission factor for the estimation of lifetime emissions in category 2.F.1.f and due to use of national estimate for the recovery efficiency in end-of-life emission estimation in categories 2.F.1.a/b. In the case of activity data uncertainty, the uncertainty in categories 2.F.1a, 2.F.1b, 2.F.1d and 2.F.1f was set at ±20%. In the case of category 2.F.1c the uncertainty was set at ±25% and in the case of category 2.F.1e at ±15%.

4.7.2.4 Category-specific QA/QC and verification

QA/QC procedures described in Section 1.5 are implemented in category 2.F.1. QC procedures are performed according to the QA/QC plan and the resulting findings, corrections and planned improvements are recorded in the annual QA/QC form. Bilateral quality meeting was held between the inventory unit and the sectoral expert in January 2024. The documentation and archiving of the 2.F.1 category are detailed in Section 1.2.3.

In the calculation of emissions from category 2.F.1, several general inventory quality control procedures have been performed as mentioned in 2006 IPCC Guidelines, Table 6.1. The correctness of the calculations is checked each year by reproducing a representative sample of the emission calculations manually and the use of appropriate units and conversion factors throughout the calculations is crosschecked simultaneously.

The quality of activity data for each year is checked by comparing the data with the corresponding data of the three previous years. If unrealistic changes are noted, the correctness of the data is checked with the survey respondent.

The 2022 activity data of category 2.F were compared with the data reported to the Finnish Safety and Chemicals Agency's KemiDigi chemical register. Enterprises or their representatives responsible for placing a chemical on the market or in use in Finland must submit a chemical notification. The information required in the notification is primarily the same as that provided in the safety data sheet. A chemical notification must be submitted about chemicals that are classified as dangerous to health or the environment or as causing a fire or explosion hazard. A notification must also be submitted about unclassified chemicals if they contain one or more substances that poses a risk to health or the environment or a substance which has a European Community workplace exposure limit. In addition to the chemical notification, the imported and manufactured amounts of chemicals must be reported to the KemiDigi chemical register.

A survey to the largest grocery retailers in Finland was conducted in 2020 and 2022 to verify the assumptions used in the emission estimation regarding the shares of used refrigerants in refrigeration applications in different types of food retail stores in operation in Finland. The survey comprised the largest grocery retailers with aggregated market share of 96 % in 2021 (Finnish Grocery Trade Association, 2022). The refrigerant shares used in calculation of F gas emissions from centralized refrigeration systems and stand-alone units in food retail stores are presented in Appendix_4c and are based on Forsberg, 2023a and Forsberg, 2020a. A detailed refrigerant composition data in centralized refrigeration and stand-alone units in all types of food retail stores operated by each retailer group was acquired in the surveys. As a result of the surveys, the refrigerant shares of centralized refrigeration systems for the years 2019 and 2020 was updated in submission 2023. According to the survey results, the shares of natural refrigerants were higher compared to the previous assumptions. No updates were needed in submission 2023 for the current assumptions on refrigerant shares of stand-alone equipment. The refrigerant survey for the grocery retailers is a biennial survey and the next one will be conducted in 2024.

The purpose of use for the chemical is also reported to the chemical register. The imported amounts of HFC's and PFC's from the chemical register data identified as refrigerants, foam blowing agents and aerosol products were compared to the imported amounts reported in the inventory activity data surveys. For some chemicals, the comparisons had to be made aggregated across all F gas use categories since the chemical register data cannot be allocated into specific categories. In addition, some chemical data reported to the register have been concealed due to confidentiality reasons. In category 2.F.1, import of all F gases identified as refrigerants in the chemical register data (HFC-32 and HFC-125) were also reported in the inventory survey. The imported amounts in the register were lower than in the inventory survey, which indicates that the data of some companies are missing from the chemical register. In the case HFC-134a in the chemical register, it was not possible to break down the imported amount into different categories. However, the total imported amount reported to the register was considerably lower compared to the total amount in the different inventory surveys. No data of HFC-143a were reported in the chemical register for 2022.

A project called 'Nordic policy cluster for F gases' started in 2017 (project reports: http://norden.diva-portal.org/smash/record.jsf?pid=diva2%3A1344817&dswid=-2943 and https://norden.diva-portal.org/smash/record.jsf?pid=diva2%3A1691867&dswid=5007). The project includes all the Nordic countries (Finland, Denmark, Iceland, Norway and Sweden) and has been funded by the Nordic council of ministers. The aim of the project has been to compare the Nordic F gas emission inventories. Variations and similarities in the total emissions and consumption figures, data sources, emission estimation methodologies, emission factors and other parameters have been identified.. In category 2.F.1a the most important finding in the project was the verification of the leakage rate level used for the largest single emission source of F gases in Finland, lifetime emissions of centralized commercial systems, as explained in more detail in Section 4.7.2.2. In category 2.F.1f stationary air-conditioning, the estimate of refrigerant charge level of air-to-air heat pumps turned out to be an overestimation in the Finnish F gas inventory in the 2018 submission. It was revealed in the project work during 2018. The estimate was revised to the 2019 submission following the project work and according to other Nordic countries and domestic technical literature and expert estimation. As a result, the HFC emissions from heat pumps in category 2.F.1f were recalculated for 2001 to 2016 in submission 2019. The emission factor for lifetime emissions in this category in submissions 2018 and 2019 was clearly higher in Finland compared to other Nordic countries. Therefore, leakage rates in these applications were investigated during 2019. As a result of this work, a national emission factor was developed for the lifetime emissions in category 2.F.1f. The emission factor is based on equipment stock data from Helsinki University Properties Ltd. The stock data comprised all of their stationary air-conditioning equipment with a total number of individual equipment of around 90. Most of the equipment were water chillers with varying capacities and age and split-units (air-to-air heat pumps). The refrigerant stock of these equipment was analysed, and together with an assessment of annual servicing to compensate the refrigerant leakage, it was possible to calculate the estimate for annual leakage rate. It was estimated that Helsinki University Properties Ltd. presented a best possible example of how the equipment maintenance and refrigerant management can be executed. Therefore, when estimating the leakage rate for the equipment stock of the whole country, the leakage rate calculated based on Helsinki University Properties Ltd. data was increased. The new emission factor is applied to all sub-categories in category 2.F.1f. It is well in line with emission factors used by other Nordic countries and within the value ranges given by the 2006 IPCC Guidelines in Vol. 3, for the equipment of this category. Following the update of the emission factor, the lifetime emissions from category 2.F.1f were recalculated for 2006 to 2017 in submission 2020. Other important findings in the project included the national characteristics explaining the differences of emission levels in this category, e.g. a large amount of direct centralised systems still used in Finland in food retail stores and professional kitchens. The Nordic co-operation related to the F gas inventories also initiated the update of recovery efficiencies in the estimation of end-of-life emissions in categories 2.F.1a/b/c/d/f in submission 2022. The recovery rate estimates for the latest years are based on several data sources. These include expert estimates from the Finnish RAC and waste treatment industry, Best Available Techniques (BAT) Reference Document for Waste Treatment, IPCC 2006 Guidelines and recovery rates applied in the F Gas emission inventories in other Nordic countries. The end-of-life emission factors are presented in more detail in Section 4.7.2.2.

In June 2018, a quality meeting with the Finnish Refrigeration Enterprises Association FREA was organised to check the quality of data and assumptions in the new calculation model taken in use in this category in submission 2018. The meeting focused on categories 2.F.1a commercial refrigeration, 2.F.1e mobile air-conditioning and 2.F.1f stationary air-conditioning. As a result of the meeting in category 2.F.1a, the shares of refrigerants in use in commercial centralized refrigeration systems in food retail stores and professional kitchens were updated. In submission 2018, the share of carbon dioxide was slightly overestimated for the years after 2015. Therefore its share was slightly decreased according to the latest information from the industry. In addition, the refrigerants R-448A and R-449A were added to the calculation for the years after 2015. They are both medium-term drop-in alternatives to the high GWP refrigerant R-404A that is still in use in large number of systems. In category 2.F.1f, the shares of refrigerants in annually sold heat pumps were updated to correspond to the latest information from the industry. The share of refrigerant R-32 was slightly decreased for the years after 2010. In addition, FREA also supported the revision of the refrigerant charge of air-to-air heat pumps in 2019.

The emission estimates calculated with the present 2006 IPCC Guidelines Tier 2a emission factor approach is compared to the Tier 2b mass balance approach used prior to the 2018 submission. The emission estimates calculated with the mass balance approach are available from 2000 onwards. Compared to the emission factor approach, the mass balance approach gives lower emissions for 2000s and higher emissions for 2010s even though there is interannual fluctuation in the mass balance emissions. The emissions peak in 2014 in the mass balance approach whereas the peak level of emissions in the emission factor approach occur a year earlier in 2008 (but stay at a fairly constant level in the next few years). Both approaches show a decreasing emission trend at the moment. In 2018 and 2019, the mass balance approach gave slightly lower emissions compared to the emission factor approach, whereas in 2020 and 2021 the mass balance gave slightly higher emissions. The F-gases imported in bulk in 2018 and 2019 decreased compared to 2017 due to the new phase-down step under the EU F-gas regulation (63% in 2018-2020 vs. 93% 2016-2017). There was an increase in the bulk import figures for 2020 most likely due to a new phase-down step in 2021-2023 (45%). Mostly the changes in the bulk import level fluctuate the emissions level in the mass balance approach.

4.7.2.5 Category-specific recalculations

In category 2.F.1.a, HFC emissions were recalculated for 2021 due to update of the number of professional kitchens in operation in Finland. The correction resulted only in minor increase of emissions (below 1 kt CO_2-eq.).

HFC emissions from category 2.F.1.f were recalculated for 2020 to 2021 due to update of activity data of large heat pumps for these years. The correction resulted only in minor decrease of emissions for both years (below 1 kt CO_2-eq.).

4.7.2.6 Category-specific planned improvements

No planned improvements in this category.

4.7.3 Foam blowing agents

4.7.3.1 Category description

The category covers HFC emissions from foam blowing and from the use of HFC-containing foam products. In 2022, emissions totalled 0.004 Mt CO_2 eq. In 2022, the emissions increased by 1% compared to 2021 mostly due to increased consumption of HFC-227ea in the manufacturing of integral skin foams. Emissions from integral skin foams mainly occur in the production phase. In 2022 the confidential emissions data of HFC-152a was reported aggregated with other confidential F gas emission sources in category CRF 2.H.3 Grouped confidential data of halocarbons and SF_6. Emissions were not occurring in 1990 since the use of HFC blowing agents in Finland began in 1994. The peak level of emissions occurred in the early 2000s right after HCFCs were prohibited as blowing agents and replaced mainly by HFC-134a. In overall, the use of HFC blowing agents has decreased in the recent years.

Blowing agent HFC emissions in Finland result from the manufacturing and use of extruded polystyrene (XPS), polyurethane (PU) integral skin foam, PU appliance foam, injected PU foam, PU flexible moulded foam and PU panels. Most of the production has been based on hydrocarbons since the phasing out of CFCs and HCFCs. Some smaller producers decided to use HCFCs as long as possible and switched to HFCs when HCFCs were prohibited by an EC regulation in 2000.

Since the majority of the producers have changed to the use of hydrocarbons or CO_2 as blowing agents, the HFCs emissions from this sub-category are mainly emissions from products. It is estimated that in the beginning of the 2000s, over 80% of the emissions originated from manufacturing processes, whereas, in 2021 8% were due to manufacturing and other first year losses and the rest from the gas banked in foam products. The releases from foam products in use are expected to remain quite steady during the product lifetime, which can be up to several decades. In Finland, retiring foam products are usually re-used as frost insulation or land filled without gas recovery (Alaja, 2009). Therefore, the emissions are assumed to continue at the same rate as in the original use-phase until all of the blowing agent has been emitted.

Between 2010 and 2013, HFC-152a was used as a blowing agent in one extruded polystyrene plant. A small proportion of HFC-365mfc has been used in the production of open-celled PU flexible moulded foam since 2000. The blowing agent used in open-cell foam blowing is released immediately. The emissions from open-celled foams cannot be reported separately due to confidentially. These emissions are reported together with the HFC-365mfc emissions from category 2.F.2a Closed cells.

4.7.3.2 Methodological issues

Methods

Emissions from this category are calculated with the Tier 2 method described in the 2006 IPCC Guidelines (Equation 7.7 in page 7.33). A more detailed description of the method is presented in Appendix_4a.

Table 4.7-29 A summary of the methods used in category CRF 2.F.2

Source category	Methods used	Gases reported	Notes
Closed Cells (CRF 2.F.2a)	Tier 2	HFC-134a, HFC-152a, HFC-227ea, HFC-245fa and HFC-365mfc	HFC-365mfc emissions from CFR 2.F.2b Open Cells are included here in 2000 to 2019 and 2021 to 2022 due to confidentiality. HFC-152a emissions in 2015 to 2022 are reported in 2.H.3 Grouped confidential data of halocarbons and SF_6 due to confidentiality.
Open Cells (CRF 2.F.2b)	Tier 2	HFC-365mfc (IE 2.F.2a)	Emissions from this source are not reported separately due to confidentiality.

The activity data for the calculation of HFC emissions with the Tier 2 method are available from 1998 on. The calculation of emissions for 1994 to 1997 is based on the method presented in the IPCC 1996 Guidelines (p. 2.53).

Emission factors and other parameters

The calculation model is dependent on the use of emission factors for each foam type. Since such national factors are not available, IPCC default factors are used (2006 IPCC Guidelines p. 7.37). The emission factors used are shown in Table 4.7-30.

Table 4.7-30 Emission factors for foam blowing (2006 IPCC Guidelines)

i	Foam type	HFC-134a		HFC-152a		HFC-245fa/HFC-365mfc/HFC-227ea	
		First year loss %	Annual loss %	First year loss %	Annual loss %	First year loss %	Annual loss %
1	XPS	25	0.75	50	25		
2	PU integral skin	95	2.5			95	2.5
3	PU injected	12.5	0.5			10	0.5
4	PU appliance	7	0.5			4	0.25
5	PU discontinuous panel	12.5	0.5			12	0.5
6	PU flexible moulded foam					100	0

If foam blowing was a key category in the Finnish inventory, more reliable emission factors could be developed, placing emphasis on the most important sectors of production. Given the low level of emissions and transition of Finnish manufacturers mostly into the use of hydrocarbons or CO_2 as a blowing agent, a detailed study has not been seen as necessary.

The methodology for the calculation of 1994 to 1997 emissions also require emission factors. The selected emission factors for initial and lifetime emissions are 7.5% and 0.5% respectively. Emission factors came from Oinonen, 2000 and are based on 1996 IPCC Guidelines.

Activity data

The activity data for calculating emissions from foam blowing are obtained from an annual survey of the Finnish companies’ manufacturing, importing and exporting relevant foam products and raw materials used in foam blowing. In the 2022 survey, response activity was 58%. All the foam product manufacturers replied to the survey. Note that the calculation model (see Appendix_4) also requires data from the previous inventories.

In 2004, the quantity of blowing agents used in manufacturing of products was nearly double in comparison with the previous years due to the establishment of a new production plant by the biggest manufacturer in Finland. In 2005, the same manufacturer replaced the HFC-134a blowing agent with CO_2 in its processes, which led to a notable decline in chemical imports, emissions from manufacture and product exports in this sector. In 2007, HFC-134a emissions from manufacturing declined even more because one large manufacturer has not used HFC-containing products in their insulations since 2006. Since the rapid changes in the market in the beginning of the 2000s, the overall quantities of HFC compounds used in foam blowing have stayed quite constant. The quantity dropped clearly in 2014 due to the closure of the XPS plant in 2013 that used HFC-152a as a blowing agent. The emissions from product use increased until 2005 but have declined since then due to decreased amounts of new HFC-134a containing products taken into use.

4.7.3.3 Uncertainty assessment and time series consistency

Quantitative estimates of uncertainty are provided in Annex 2. The annex also documents assumptions made for the analysis. A description of the uncertainty analysis is included in Section 1.6.

2022 uncertainties for activity data and emission factors for category 2.F.2 were set as an expert judgement at Syke(Forsberg, 2021d). Uncertainty for emission factors were set at ±50% and for activity data at ±20%.

Two different methods in the calculation of emissions are used in the time series, the IPCC 1996 Guidelines methodology for 1994 to 1997 and the Tier 2 method of the 2006 IPCC Guidelines for the emissions from 1998 onwards. Although the methodology is slightly different, the current emission estimates give a reliable representation of the development of emissions in the 1990s. The emission estimates between 1994 and 1999 represent the steady increase of the use of HFC-134a as a blowing agent in the manufacturing of foam products. The sharp rise in emissions from 1999 to 2000 is due to prohibition of HCFC’s as blowing agents from 1 January 2000. HCFC were substituted mainly by HFC-134a.

4.7.3.4 Category-specific QA/QC and verification

QA/QC procedures described in Section 1.5 are implemented in category 2.F.2. The QC procedures are performed according to the QA/QC and verification plan and the resulting findings, corrections and planned improvements are recorded in the annual QA/QC form. Bilateral quality meeting was held between the inventory unit and the sectoral expert in January 2024. The documentation and archiving of the 2.F.2 category are detailed in Section 1.2.3.

In the calculation of emissions from category 2.F.2, several general inventory quality control procedures have been performed as mentioned in 2006 IPCC Guidelines, Table 6.1. The correctness of the calculations is checked each year by reproducing a representative sample of the emission calculations manually and the use of appropriate units and conversion factors throughout the calculations is crosschecked simultaneously.

The category-specific QC procedures for category 2.F.2 include emission and activity data comparisons as well as uncertainty estimates. The results are compared with those obtained using a simpler model, i.e. actual emissions are compared with potential emissions. The results of the comparison between the potential and actual emissions indicated that the actual emission estimates are at a reasonable level. The emission trends are graphed and explained. The quality of the activity data for each year is checked by comparing the data with the corresponding data of the three previous years. If unrealistic changes are noted, the correctness of the data is checked with the survey respondent.

The 2022 activity data of category 2.F including category 2.F.2 were compared with the data reported to the Finnish Safety and Chemicals Agency’s KemiDigi chemical register (see also Section 4.7.2.4). HFC-365mfc was the only gas identified as a blowing agent in the 2022 chemical register data. However, the HFC-365mfc data reported to the register was concealed due to confidentiality reasons.

Uncertainty estimates are quantified for all of the source categories and the underlying assumptions documented in the F gas inventory archives explained in more detailed in Section 1.2.3. Importance analysis is used to elucidate the factors that have significant bearing on the uncertainty of each category. The results are described in Section 4.7.2.3 above.

4.7.3.5 Category-specific recalculations

No category-specific recalculations have been done since the previous submission.

4.7.3.6 Category-specific planned improvements

No planned improvements in this category.

4.7.4 Fire protection

4.7.4.1 Category description

Emissions from Fire protection (2.F.3) occur in Finland and the emission estimation method is presented in this section. However, emissions from fire protection cannot be reported separately due to confidentiality. Emissions are reported aggregated with other confidential F gas emission sources in category CRF 2.H.3 Grouped confidential data of halocarbons and SF_6.

Halons were phased-out in fixed fire suppression systems in the mid-1990s and substituted with an extinguishant that is a mixture of HFC-125, HFC-134a and CO_2. First, this led to the growth of HFC usage in this category. When the halons had been mostly replaced in the existing systems, the installing activity and imported quantities of HFCs for this purpose decreased. Since 2015, also an extinguishant which contains HFC-227ea, has been used. The emissions from fire suppression systems occur when the system is discharged in case of fire or accidentally and there is an element of chance affecting the annual emission level as well.

4.7.4.2 Methodological issues

HFC-125, HFC-134a and HFC-227ea emissions from fixed firefighting systems are reported with the “direct” method, i.e. the companies that sell, install and service the systems keep statistics on the quantities released in fires and the quantities released due to system malfunction.

The activity data for the calculation of emissions from fixed firefighting systems are obtained from annual surveys of companies. 43% of the companies responded to the 2022 inventory survey. However, all the companies who have previously reported data on the HFC extinguishants responded to the survey.

4.7.4.3 Uncertainty assessment and time series’ consistency

Quantitative estimates of uncertainty are provided in Annex 2. The annex also documents assumptions made for the analysis. A description of the uncertainty analysis is included in Section 1.6.

The time series of HFC emissions from 2.F.3 has been calculated with the same methodology for the whole time series and is, therefore, considered consistent. Since due to confidentiality the emissions are reported in category 2.H.3, the uncertainties of activity data and emission factors of this category are also included in the uncertainty estimation of category 2.H.3.

4.7.4.4 Category-specific QA/QC and verification

QC procedures are performed according to the QA/QC and verification plan and the resulting findings, corrections and planned improvements are recorded in the annual QA/QC form. Bilateral quality meeting was held between the inventory unit and the sectoral expert in January 2024.

In the calculation of emissions from category 2.F.3, several general inventory quality control procedures have been performed as mentioned in 2006 IPCC Guidelines, Table 6.1. The correctness of the calculations is checked each year by reproducing a representative sample of the emission calculations manually and the use of appropriate units and conversion factors throughout the calculations is crosschecked simultaneously.

The emission trends are graphed and explained. The quality of the activity data for each year is checked by comparing the data with the corresponding data of the three previous years. If unrealistic changes are noted, the correctness of the data is checked with the survey respondent.

4.7.4.5 Category-specific recalculations

No category-specific recalculations have been done since the previous submission.

4.7.4.6 Category-specific planned improvements

No planned improvements in this category.

4.7.5 Aerosols

4.7.5.1 Category description

The category covers HFC-134a, HFC-152a, HFC-227ea, HFC-245fa and HFC-43-10mee emissions from technical and novelty aerosols, one-component polyurethane foam, tear gas and metered dose inhalers (MDIs). The confidential emissions data of HFC-227ea (MDIs), HFC-245fa (technical aerosols) and HFC-43-10mee (technical aerosols) are reported aggregated with other confidential F gas emission sources in category CRF 2.H.3 Grouped confidential data of halocarbons and SF_6. In addition, HFC-134a emissions from metered dose inhalers cannot be reported separately due to confidentiality. For 2022, total emissions from aerosols and MDIs totalled 0.02 Mt CO_2 eq. The 2022 emissions were 4% lower compared to the year 2020 due to decreased amount of HFCs imported in products. One large company phased out their production during 2010, which caused a temporary drop of emissions in 2011. The EU F gas regulation and its measures to control emissions of F gases has been the most significant reason for the phase out of HFCs by two large domestic manufacturers during 2016 and 2017. The amount of HFCs consumed by the remaining domestic product manufacturers continued to decrease during 2018 and 2019. In 2020, all the domestic product manufacturers had phased out HFCs in their production. The inter-annual fluctuation in the time series is due to observed changes in consumption. The variation of the consumed proportions of HFC-134a and HFC-152a also affect the time series in CO_2 equivalents, because of the great difference in their GWPs. Import of HFC-227ea metered dose inhalers were reported for the first time for 2013. Import of HFC-245fa aerosol products were reported for the first time for 2015. The emissions occurred in 2015 and 2016. Import of HFC-43-10mee aerosol products were reported for the first time for 2017. Due to confidentiality, HFC-227ea, HFC-245fa (for 2015 and 2016) and HFC-43-10mee emissions are reported aggregated with other confidential F gas emission sources in category CRF 2.H.3 Grouped confidential data of halocarbons and SF_6.

4.7.5.2 Methodological issues

Methods

The emissions model used in the category is from the 2006 IPCC Guidelines (p. 7.28).

$x = (1 – f)a + fb$,

where $f = 0.5$,

a = quantity of HFC and PFC contained in aerosol products sold in 2021, and
b = quantity of HFC and PFC contained in aerosol products sold in 2022.

The quantity of HFC and PFC contained in aerosol products sold in one year is equal to the amount of chemical consumed in the country minus the amount of chemical recovered for destruction or export in the year of consideration. A more detailed description of the model is given in Appendix_4a.

Table 4.7-31 Summary of the methods used in category CRF 2.F.4

Source category	Methods used and gases reported	Notes
Metered Dose Inhalers (CRF 2.F.4a)	Tier 2 HFC-134a, HFC-227ea (IE 2.F.4b, 2.H.3)	HFC-134a reported in category 2.F.4.b and HFC-227ea in category 2.H.3 due to confidentiality.
Aerosols and one-component foam (CRF 2.F.2b)	Tier 2 HFC-134a, HFC-152a, HFC-245fa (2015-2016), HFC-43-10mee	One-component foam cans are treated as aerosols in this inventory, cf. Section 2.3.6 of Oinonen (2003). Due to confidentiality, HFC-245fa and HFC-43-10mee emissions are reported aggregated with other confidential F gas emission sources in category CRF 2.H.3 Grouped confidential data of halocarbons and SF_6.

Emission factors

Default emission factor of 50% used for the calculation of emissions from aerosols is taken from the 2006 IPCC Guidelines.

Activity data

The activity data for calculating emissions from aerosols and metered dose inhalers are obtained from an annual survey of the Finnish companies manufacturing, importing and exporting aerosol products (MDI, sprays for dust removal and other industrial aerosols, tear gas, one-component foam). Altogether, 89% of the companies responded in the 2021 survey. Part of the activity data is confidential and cannot be presented here due to the low number of companies reporting activities.

4.7.5.3 Uncertainty assessment and time series’ consistency

Quantitative estimates of uncertainty are provided in Annex 2. The annex also documents assumptions made for the analysis. A description of the uncertainty analysis is included in Section 1.6.

2022 uncertainties for activity data and emission factors for category 2.F.4 were set as an expert judgement at Syke (Forsberg, 2021d). Uncertainty for emission factors were set at ±50% and for activity data at ±20%. The time series of HFC emissions from 2.F.4 has been calculated with the same methodology given in the 2006 IPCC Guidelines for the whole time series and is, therefore, considered consistent.

4.7.5.4 Category-specific QA/QC and verification

QA/QC procedures described in Section 1.5 are implemented in category 2.F.4. QC procedures are performed according to the QA/QC plan and the resulting findings, corrections and planned improvements are recorded in the annual QA/QC form. A bilateral quality meeting was held between the inventory unit and the sectoral expert in January 2024. The documentation and archiving of the 2.F.4 category are detailed in Section 1.2.3.

In the calculation of emissions from category 2.F.4, several general inventory quality control procedures have been performed as mentioned in 2006 IPCC Guidelines, Table 6.1. The correctness of the calculations is checked each year by reproducing a representative sample of the emission calculations manually and the use of appropriate units and conversion factors throughout the calculations is crosschecked simultaneously.

The category-specific QC procedures for category 2.F.4 include emission and activity data comparisons, as well as uncertainty estimates. The results are compared with those obtained using a simpler model, i.e. actual emissions are compared with potential emissions. The results of the comparison between the potential and actual emissions indicated that the actual emission estimates are at a reasonable level. The emission trends are graphed and explained. The quality of the activity data for each year is checked by comparing the data with the corresponding data of the three previous years. If unrealistic changes are noted, the correctness of the data is checked with the survey respondent.

The 2022 activity data of category 2.F including category 2.F.4 were compared with the data reported to the Finnish Safety and Chemicals Agency’s KemiDigi chemical register (see also Section 4.7.2.4). In the case of data identified as aerosol products in the register, the imported amount of HFC-152a reported to the register was lower compared to the amount in the inventory survey. In addition, import HFC-43-10mee data was reported to the register. However, the HFC-43-10mee data reported to the register was concealed due to confidentiality reasons. The total amount of HFC-134a belonging to the category aerosol products could not be identified from the register data. However, the total imported amount reported to the register was considerably lower compared to the total amount in the different inventory surveys.

4.7.5.5 Category-specific recalculations

No category-specific recalculations have been done since the previous submission.

4.7.5.6 Category-specific planned improvements

There are no planned improvements in this category.

4.8 Other product manufacture and use (CRF 2.G)

4.8.1 Introduction

Under the category Other product manufacture and use, Finland reports SF_6 emissions from use of electrical equipment and SF_6 and N_2O emissions from product use. Total emissions of this category were 0.04 Mt CO_2 eq. in 2022, which was 15% less than in 2021. These emissions have decreased 57% since 1990.

The SF_6 emissions from this category result from installation, use and disposal of electrical equipment. SF_6 emissions from electrical equipment totalled 0.02 Mt CO_2 eq. in 2022. In 2022, the emissions increased 5% compared to 2021. SF_6 emissions from electrical equipment are an exception amongst the F gases emission sources in Finland, since emissions from this source have decreased 51% compared to 1990. Reason for the decline is that environmental impacts of SF_6 became known and led to lower emissions due to the improved sealing of equipment and handling of the gas.

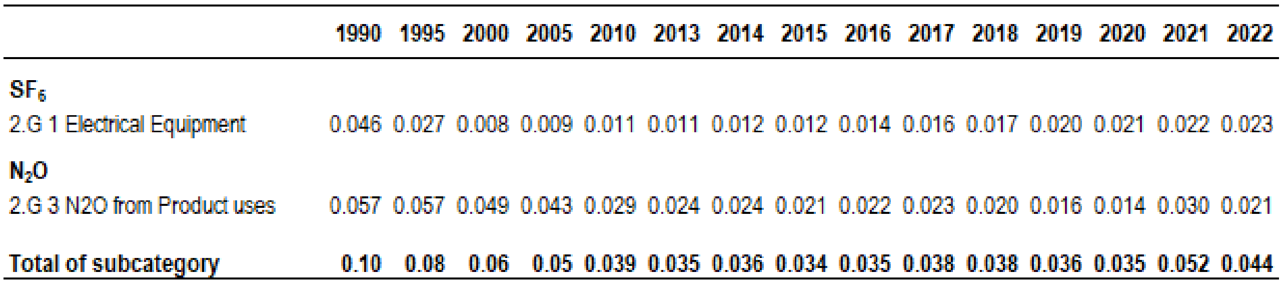
SF_6 emissions from category SF_6 and PFCs from other product use (2.G.2) result from SF_6 used in shoes and in research. SF_6 used in particle accelerators as trace gas, and in medical applications have been compiled under SF_6 emissions from research. However, emissions from this category cannot be reported separately due to confidentiality. Emissions are reported aggregated with other confidential F gas emission sources in category CRF 2.H.3 Grouped confidential data of halocarbons and SF_6.

N_2O emissions are from all uses of N_2O (also includes use as a propellant in aerosol products, primarily in the food industry) in Finland, and they are reported under Medical applications because emissions are calculated using production or import data as activity data and there are no information where the produced or imported N_2O have been used. In 2022, emissions from the use of N_2O were 0.02 Mt CO_2 eq. which was 29% lower than in 2021 and 63% lower than in 1990.

Table 4.8-1 Reported emissions, calculation methods and types of emission factors for the subcategory Other product manufacture and use in the Finnish inventory

CRF	Source	Emissions reported	Method	Emission factor
2.G.1	Electrical Equipment	SF_6, CF_4 IE (2.H.3)	Tier 2	CS
2.G.2	SF_6 and PFCs from other product use	SF_6 IE (2.H.3)	OTH	NA
2.G.3	N_2O from Product uses	N_2O	Tier 1, CS	CS

Table 4.8-2 Emissions by gas and subcategory (Mt CO_2 eq.)



	1990	1995	2000	2005	2010	2013	2014	2015	2016	2017	2018	2019	2020	2021	2022
SF_6															
2.G 1 Electrical Equipment	0.046	0.027	0.008	0.009	0.011	0.011	0.012	0.012	0.014	0.016	0.017	0.020	0.021	0.022	0.023
N_2O															
2.G 3 N2O from Product uses	0.057	0.057	0.049	0.043	0.029	0.024	0.024	0.021	0.022	0.023	0.020	0.016	0.014	0.030	0.021
Total of subcategory	**0.10**	**0.08**	**0.06**	**0.05**	**0.039**	**0.035**	**0.036**	**0.034**	**0.035**	**0.038**	**0.038**	**0.036**	**0.035**	**0.052**	**0.044**

4.8.2 Electrical equipment

4.8.2.1 Category description

The SF_6 emissions from this category result from installation, use and disposal of electrical equipment. The SF_6 emissions from this category peaked in 1990, as large amounts of electrical equipment were installed in 1990 and it coincides with the high level of economic activity in the country in general. Rather large amounts of equipment were installed still in 1991 but the emissions declined during the next years due to the most severe years of the early 1990s recession. After the recession, a rather large amount of electrical equipment was installed again in 1995 and 1996, and the amount of gas used for maintenance also increased. After the mid-1990s the trend declined again towards the end of the decade, as the environmental impacts of SF_6 became known and led to lower emissions. A slight annual increase in emissions have occurred during 2000s and in most recent years. The amount of SF_6 banked in equipment increases slightly faster. The improved sealing of equipment and handling of the gas can, therefore, be observed from the trends in the 2000s. Between 2022 and 2021, the emissions increased by 5% due to increased amount of SF_6 banked in equipment in Finland.

The use of CF_4 in electrical equipment was reported for the first time for the year 2015. The first circuit breakers with CF_4 were installed in Finland in 2015 and in 2016. Installation of CF_4 equipment was also reported for 2018, 2021 and 2022. No installation of CF_4 equipment was reported for 2017, 2019 and 2020. Due to confidentiality, the emissions are reported aggregated with other confidential F gas emission sources in category CRF 2.H.3 Grouped confidential data of halocarbons and SF_6. CF_4 is used in circuit breakers as a mixture with SF_6. Equipment with SF_6 and CF_4 mixture are considered more reliable extremely cold weather conditions. The CF_4 equipment have been installed in northern Finland where the outdoor temperature can decrease to very low level during the wintertime (Nummila, 2016).

4.8.2.2 Methodological issues

Methods

The inventory is based on the Tier 2 country-specific emission factor method of the 2006 IPCC Guidelines. Emissions are estimated separately for equipment manufacturing, use and disposal. Manufacturing refers to actual equipment manufacturing and on-site installation of equipment. The production of medium voltage SF_6 products began in one plant in Finland in 1991 and the plant was closed down at the end of 2010. The recovery in the CRF tables is treated as recovery itself and not emissions from recovery. Recovery is calculated with the simplified way of subtracting disposal emissions from the amount of SF_6 in products at decommissioning. Data of SF_6 in retiring equipment are available from 2002 onwards. Due to long lifetimes of the equipment and communication with the industry, the emissions from retiring equipment are considered negligible in the 1990s. A more detailed description of the method is presented in Appendix_4a.

Emission factors

The country-specific emission factors required for the Tier 2 method were developed by an expert group during 2014. The group was appointed by the Finnish Environment Institute (Syke), the organisation responsible for F gas emission inventory in Finland. In addition to Syke, the group consisted of members from the industry using SF_6 equipment (electricity transmission and distribution companies), a Finnish SF_6 equipment manufacturer, a research institute (Tampere University) and the National Authority for the GHG inventory (Statistics Finland). The emission factors are presented in Table 4.8-3.

Table 4.8-3 Emission factors for electrical equipment

Year	Manufacturing (%)	Use (%)	Disposal (%)
1990	15.00	1.00	NO
1995	10.00	1.00	NO
2000	1.80	0.50	NO
2001	1.40	0.50	NO
2002	1.20	0.50	1.50
2003	1.00	0.50	1.50
2004	0.80	0.50	1.50
2005	0.76	0.50	1.50
2006	0.81	0.50	1.50
2007	0.58	0.50	1.50
2008	0.68	0.50	1.50
2009	1.80	0.50	1.50
2010	1.73	0.50	1.50
2011	1.59	0.50	1.50
from 2012	0.25	0.50	1.50

The manufacturing EF in Table 4.8-3 consists of the equipment manufacturing part and the installation part that have been added up. The aggregated EF has been used in the calculations. The actual manufacturing of equipment took place in one plant in Finland between 1991 and 2010. The plant has delivered the EFs for the equipment manufacturing part. Due to confidentiality of the manufacturing part, only the aggregated EF can be shown in Table 4.8-2. The EF for 1990 is based on the GPG 2000. The expert group was unable to derive better country-specific data for 1990 and the recommendation was to use the default EF, which was considered suitable for Finnish conditions in the 1990s. The aggregated EF for 1991 was estimated to be at the same level as in 1990. The aggregated EF for 1995 has been previously received from the industry (Pihkala 1995). The installation part of the aggregated EF for 2000, 2005 and 2010 are the expert group's estimates. The EF's for 1992 to 1994, 1996 to 1999, 2001 to 2004 and 2006 to 2009 have been linearly interpolated. From 2010 onwards, the EF is estimated to stay constant**.**

The EFs for use (leakage from the bank and servicing, maintenance or failures of the equipment) and disposal of equipment are the expert group's estimates and are based, e.g., on IEC standards (International Electrotechnical Commission) and the companies' own follow-up of SF_6 balances over the years.

Activity data

The activity data for the calculation of SF_6 emissions from electrical equipment are obtained from an annual survey of the Finnish companies manufacturing, importing and exporting electrical equipment. In the 2022 survey, the response activity in this field of industry was 82%. In addition, the amount of SF_6 in products at decommissioning was received from the Finnish Electrical Equipment Industry's survey (conducted by Adato Energia Oy) to the owners of SF_6 equipment in Finland.

Historical activity data were checked parallel with the 2011 inventory in order to supplement the omissions, which were detected. For 1990 to 2001 the activity data (quantity of SF_6 banked in equipment) were adopted to match the amount calculated at Adato Energia Oy for 2001. Activity data for 1990 to 1998 are from a survey done by Syke in 1999. Data for 2000 and 2001 are from the annual surveys done by Syke. Data for 1999 are imputed based on the data for 1998 and 2000. From 2002, the amount of SF_6 banked in equipment is calculated based on the information received from the annual survey done by Syke and from Adato Energia Oy's survey.

4.8.2.3 Uncertainty assessment and time series' consistency

Quantitative estimates of uncertainty are provided in Annex 2. The annex also documents assumptions made for the analysis. A description of the uncertainty analysis is included in Section 1.6.

2022 uncertainties for activity data and emission factors for category 2.G.1 were set as an expert judgement at Syke (Forsberg, 2021d). Uncertainty for emission factors were set at ±40% and for activity data at ±20%. The time series of SF_6 emissions from 2.G.1 has been calculated with the same methodology for the whole time series and is, therefore, considered consistent.

4.8.2.4 Category-specific QA/QC and verification

QA/QC procedures described in Section 1.5 are implemented in the category 2.G.1. QC procedures are performed according to the QA/QC plan and the resulting findings, corrections and planned improvements are recorded in the annual QA/QC form. A bilateral quality meeting was held between the inventory unit and the sectoral expert in January 2024. The documentation and archiving of the 2.G.1 category are detailed in Section 1.2.3.

In the calculation of emissions from category 2.G.1, several general inventory quality control procedures have been performed as mentioned in 2006 IPCC Guidelines, Table 6.1. The correctness of the calculations is checked each year by reproducing a representative sample of the emission calculations manually and the use of appropriate units and conversion factors throughout the calculations is crosschecked simultaneously.

The category-specific QC procedures for category 2.G.1 include emission and activity data comparisons as well as uncertainty estimates. The results are compared with those obtained using a simpler model, i.e. actual emissions are compared with potential emissions. The emission trends are graphed and explained. The quality of activity data for each year is checked by comparing the data with the corresponding data of the three previous years. If unrealistic changes are noted, the correctness of the data is checked with the survey respondent.

The emission estimates and activity data are compared to the emission data collected by Adato Energia Oy’s survey. The Adato Energia Oy’s emission estimates are generally lower but the emission estimation methodology used by Adato is not identical compared to the GHG inventory and the emission estimates do not cover emissions from manufacturing or service work by subcontractors (Suur-Uski, 2009). In addition, the SF_6 activity data of category 2.G.1 are annually compared with the SF_6 data reported to the Finnish Safety and Chemicals Agency’s KemiDigi chemical register. However, the 2021 SF_6 data reported to the register was concealed due to confidentiality reasons.

During the preparation of the 2020 inventory submission, the implied emission factors for equipment manufacturing, use and disposal were compared to IEFs from other countries. IEFs were taken from the 2019 inventory submissions. The countries selected for comparison were, Denmark, France, Germany, Norway, Sweden and United Kingdom. The results showed that IEFs are consistent with other countries. Some variation in the IEFs was found in equipment manufacturing but generally other countries had a downward trend in their IEFs similar to Finland. Finland has the highest IEF in the early 1990s, but all the countries, except for Denmark, have considerably higher IEFs in the early 1990s compared to 2000’s. Denmark has a constant IEF for the whole time series. In the case of equipment use, UK has the highest IEF. The difference to other countries is especially large in the early 1990s. After UK, France also has higher IEF for the whole time series compared to other countries. All other countries are relatively close to one another with slightly higher IEFs for the 1990s. IEFs for equipment disposal were only available for France, Germany and Sweden. Germany had the same IEF as Finland in the early 2000’s. After the mid-2000s there was variation in Germany’s IEF and it was higher compared to Finland. France and Sweden also have a constant IEF for the whole time series. France has a slightly lower IEF and Sweden higher IEF compared to Finland.

4.8.2.5 Category-specific recalculations

SF_6 emissions from electrical equipment were recalculated for 2013 to 2021 due to addition of activity data from Adato Energia Oy’s survey previously missing from the inventory. The recalculation resulted only in minor increase of annual emissions (max. 5.1 kt CO_2-eq.) according to Table 4.8-4 below.

Table 4.8-4 Comparison of total SF_6 emissions (in kt CO_2 eq.) reported in category 2.G.1 in submissions 2022 and 2023

Year	Submission 2024	Submission 2023	Difference
2013	10.9	10.5	0.4
2014	11.8	11.5	0.3
2015	12.3	11.5	0.8
2016	13.6	12.0	1.6
2017	15.5	13.1	2.4
2018	17.2	14.2	3.0
2019	19.8	15.5	4.3
2020	21.2	16.5	4.7
2021	21.9	16.8	5.1

4.8.2.6 Category-specific planned improvements

There are no category-specific planned improvements.

4.8.3 SF_6 and PFCs from other product use

4.8.3.1 Category description

Category SF_6 and PFCs from other product use includes emissions of SF_6 used in shoes and in research. SF_6 used in particle accelerators as trace gas, and in medical applications have been compiled under SF_6 emissions from research. Emissions from this category cannot be reported separately due to confidentiality. Emissions are reported aggregated with other confidential F gas emission sources in category CRF 2.H.3 Grouped confidential data of halocarbons and SF_6.

4.8.3.2 Methodological issues

SF_6 emissions from research are reported with the “direct” method. Due to the small amount of SF_6 used in research, detailed emission estimation methods have not been seen reasonable and the emissions equal the SF_6 sold annually to the aforementioned applications. For the reporting of SF_6 from shoes “adiabatic property applications” of the 2006 IPCC Guidelines have been used (Vol. 3, Chapter 8, Equation 8.19, p. 8.31), but these emissions are estimated to have ended in 2007.

The activity data for the calculation of emissions are obtained from annual surveys of importers of special gases. In the 2022 survey, response activity was 56%.

4.8.3.3 Uncertainty assessment and time series’ consistency

Quantitative estimates of uncertainty are provided in Annex 2. The annex also documents assumptions made for the analysis. A description of the uncertainty analysis is included in Section 1.6.

The time series of SF_6 emissions from research and shoes have been calculated with the same methodology for the whole time series and are, therefore, considered consistent.

4.8.3.4 Category-specific QA/QC and verification

QC procedures are performed according to the QA/QC and verification plan and the resulting findings, corrections and planned improvements are recorded in the annual QA/QC form. Bilateral quality meeting was held between the inventory unit and the sectoral expert in January 2024.

In the calculation of emissions from category 2.G.2, several general inventory quality control procedures have been performed as mentioned in 2006 IPCC Guidelines, Table 6.1. The correctness of the calculations is checked each year by reproducing a representative sample of the emission calculations manually and the use of appropriate units and conversion factors throughout the calculations is crosschecked simultaneously.

The emission trends are graphed and explained. The quality of the activity data for each year is checked by comparing the data with the corresponding data of the three previous years. If unrealistic changes are noted, the correctness of the data is checked with the survey respondent.

4.8.3.5 Category-specific recalculations

There were done no category-specific recalculations.

4.8.3.6 Category-specific planned improvements

There are no category-specific planned improvements.

4.8.4 N_2O from product uses

4.8.4.1 Category description

Under N_2O from product uses, Finland reports emissions from the use of N_2O in hospitals and by dentists to relieve pain and for detoxification, from the use of N_2O in semiconductor manufacturing and emissions from the use of N_2O as propellant in aerosol products, primarily in the food industry.

In 2022, these emissions totalled 0.02 Mt CO_2 eq (0.05% of total emissions), emission from the use as propellant in aerosol products was 0.005 Mt CO_2 eq. The emission trend has been decreasing, the reduction has been 63% since 1990.

4.8.4.2 Methodological issues

The country-specific calculation method to calculate emissions of use of N_2O in hospitals, dentists, for detoxification and semiconductor manufacturing is consistent with the method described in the 2006 IPCC Guidelines. In the estimation of the N_2O emissions sales data are obtained from the companies delivering N_2O in Finland. For 1990 to 1999, the emissions have been assumed constant based on activity data obtained for 1990 and 1998. Since 2000, annual and more precise data have been received from the companies. The emission estimation is based on the assumption that all used N_2O is emitted to the atmosphere in the same year it is produced or imported to Finland.

It has been difficult to estimate emissions from aerosol products due to lack of information of the purchased amount of aerosol products because they are not included in sales or import data. Therefore, the average of emission factors used in central Europe has been used.

Activity data

For the estimation of N_2O emissions, data on production or importation are obtained from companies for 1990, 1998 and all years starting from 2000. In 2022, one company reported that they have continued to export and that has been also taken into account in the calculations.

Activity data for aerosol products are the amount of inhabitants in Finland.

Emission factors

The emission factor for N_2O use in medical applications is one, as all used N_2O is emitted to the atmosphere.

The emission factor for N_2O used in aerosol products (3.3 g N_2O/inhabitant in a year) is the average of four central European countries, which have reported N_2O emissions from aerosol products.

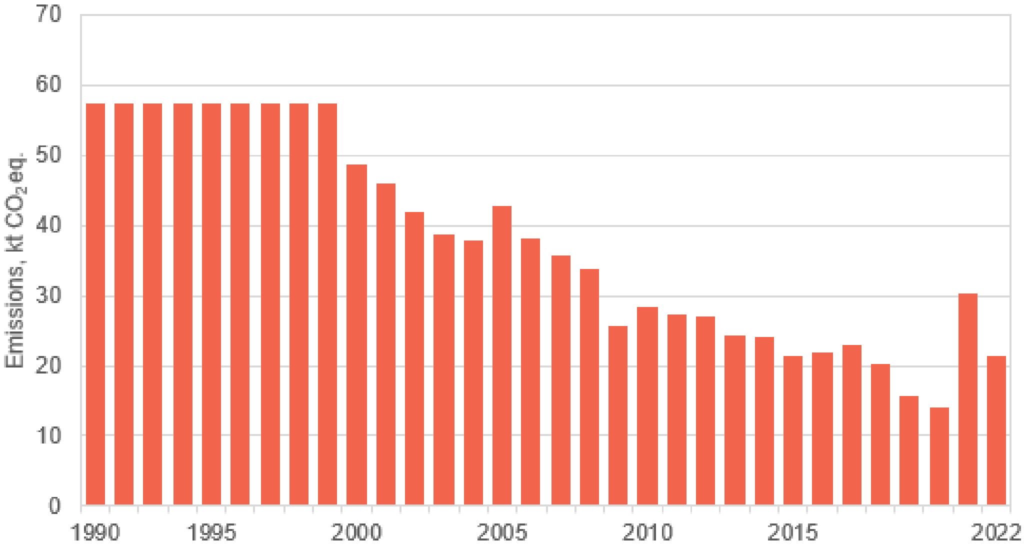


Figure 4.8-1 N_2O emissions from all uses of N_2O in Finland

4.8.4.3 Uncertainty assessment and time series' consistency

Quantitative estimates of uncertainty are provided in Annex 2. The annex also documents assumptions made for the analysis. A description of the uncertainty analysis is included in Section 1.6.

The uncertainty of emissions from N_2O use in 2021 was estimated at ±10%.

4.8.4.4 Category-specific QA/QC and verification

QA/QC procedures described in Section 1.5 are implemented in this category. QC procedures are performed according to the QA/QC plan and the resulting findings, corrections and planned improvements are recorded in the annual QA/QC form. The emission factor for N_2O used in aerosol products will be checked every fourth year and emissions will be recalculated if needed. A bilateral quality meeting or a quality desk review is held annually between the inventory unit and the sectoral expert. In the quality meeting in February 2024 the recalculations and improvement plan were discussed.

4.8.4.5 Category-specific recalculations

There were done no category-specific recalculations.

4.8.4.6 Category-specific planned improvements

There are no category-specific planned improvements.

4.9 Other (CRF 2.H)

4.9.1 Introduction

Under Category 2.H.3 Grouped confidential data of halocarbons and SF_6 (2.H.3), Finland reports the following sources and emissions of F gases that have been grouped due to confidentiality:

- HFC-23 from semiconductor manufacturing
- HFC-152a from foam blowing in 2015 to 2022
- HFC-227ea and HFC-365mfc from foam blowing in 2000 to 2006
- HFC-125, HFC-134a and HFC-227ea (2015 to 2016) from Fire protection
- HFC-227ea, HFC-245fa (2015 to 2016) and HFC-43-10mee from aerosols
- CF_4, C_2F_6 c-C_4F_8 and C_3F_8 (1990 to 2006, 2014 to 2022) from semiconductor manufacturing
- CF_4 from electrical equipment
- SF_6 from magnesium die casting (1994 to 2009 and 2012), semiconductor manufacturing, shoes (until 2007), ski wax (for 1999) and research

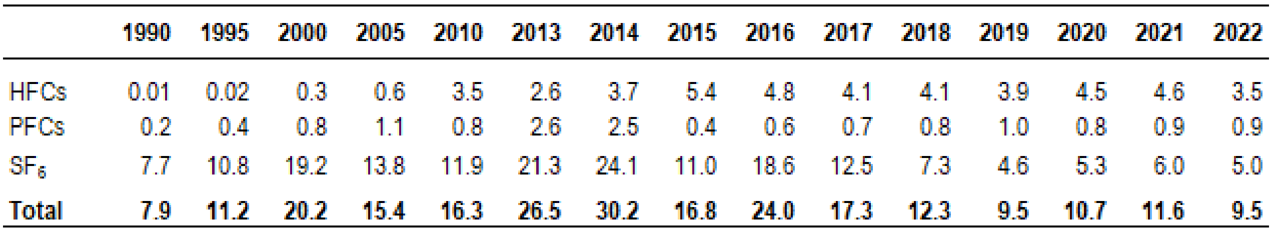
Non-fuel-based CO_2 emissions from the pulp and paper and food industries are estimated to be negligible in Finland. All N_2O and CH_4 emissions from the pulp and paper industry are reported as fuel-based emissions under CRF 1. Indirect CO_2 emissions from the forest industry, as well as from the food and drink processing are considered biological (see Chapter 9).

Total emissions of this category were 0.01 Mt CO_2 eq. in 2022. Emissions were 20% higher in 2022 compared to 1990, but there is a fluctuating emissions trend throughout the time series. In 2022 emission were only 0.2% of emissions of Industrial Processes and product use and 0.02% of the total greenhouse gas emissions.

Table 4.9-1 Reported emissions, calculation methods and types of emission factors for the subcategory Other in the Finnish inventory in 2022

CRF	Source	Emissions reported	Method	Emission factor
2.H.3	Grouped confidential data of halocarbons and SF_6	SF_6 HFCs PFCs	OTH, Tier 2 OTH, Tier 2 Tier 2	CS, D, NA CS, D CS, D

Table 4.9-2 Emissions by gas (kt CO_2 eq.)



	1990	1995	2000	2005	2010	2013	2014	2015	2016	2017	2018	2019	2020	2021	2022
HFCs	0.01	0.02	0.3	0.6	3.5	2.6	3.7	5.4	4.8	4.1	4.1	3.9	4.5	4.6	3.5
PFCs	0.2	0.4	0.8	1.1	0.8	2.6	2.5	0.4	0.6	0.7	0.8	1.0	0.8	0.9	0.9
SF_6	7.7	10.8	19.2	13.8	11.9	21.3	24.1	11.0	18.6	12.5	7.3	4.6	5.3	6.0	5.0
Total	**7.9**	**11.2**	**20.2**	**15.4**	**16.3**	**26.5**	**30.2**	**16.8**	**24.0**	**17.3**	**12.3**	**9.5**	**10.7**	**11.6**	**9.5**

4.9.2 Grouped confidential data of halocarbons and SF_6

4.9.2.1 Category description

Due to confidentiality, emissions from magnesium die casting (2.C.4), semiconductor manufacturing (2.E.1), fire protection (2.F.3) and SF_6 from other product use (2.G.2) are reported aggregated in this category. Emission estimation methods for 2.C.4, 2.E.1, 2.F.3 and 2.G.2 are described in Sections 4.4.3, 4.6.2, 4.7.4. and 4.8.3. In addition, individual gases' confidential emissions from individual years from 2.F.2, 2.F.4 and 2.G.1 are reported in this category. Emission estimation methods for those sectors are described in Sections 4.7.3.2, 4.7.5.2 and 4.8.2.2.

In 2022, the total F gas emissions from this category amounted to 0.01 Mt CO_2 eq. Emissions were 18% lower compared to 2021 mostly due to decreased emissions from research and fire protection. In 2022 emission from

2.H.3 were only 0.2% of emissions of Industrial Processes and product use and 0.02% of the total greenhouse gas emissions.

Overall, there is a fluctuating trend in the emissions from this category throughout the time series. The changes in the trends of shoe sales, magnesium die-casting and semi-conductor manufacturing and the phasing out of halons in the fixed fire prevention systems affect the emissions level in the 1990s and early 2000s. The majority of SF_6 emissions in the early 1990s originate from shoes. The peak level of SF_6 emissions from magnesium die-casting occurred in the mid-1990s. Use of SF_6 in shoes was first growing at the late-1990s and beginning of the 2000s, but later on, the activity declined. SF_6 emissions from semiconductor manufacturing were increasing throughout the time series. However in 2015, the emissions from semiconductor manufacturing decreased considerably since the largest domestic semiconductor manufacturer installed emission control technology also to the processes where F gases are used. During the recent years, the level of emissions is mostly determined by the amount of SF_6 used in research.

SF_6 is no longer used in running shoes nor in magnesium die-casting. The emissions from shoes are considered to have become negligible three years after the sale of SF_6-containing shoes ceased in 2004 and thus there have been no emissions from running shoes after the 2007 inventory. The use of SF_6 in magnesium die-casting ceased in 2012.

The level of HFC and PFC emissions from this category are smaller compared to SF_6. The emissions from fire prevention systems, and in the recent years also HFC-227ea emissions from aerosols and HFC-152a emissions from foams, affect most the emission trend of HFC emissions. In the case of PFC emissions, emissions from semiconductor manufacturing have the most significant effect on the emission trend.

In general, there are several trends that simultaneously affect emissions in this category and it is difficult to estimate how the category level emission trend will develop in the future. More detailed information on emission sources cannot be presented in the NID without revealing confidential data.

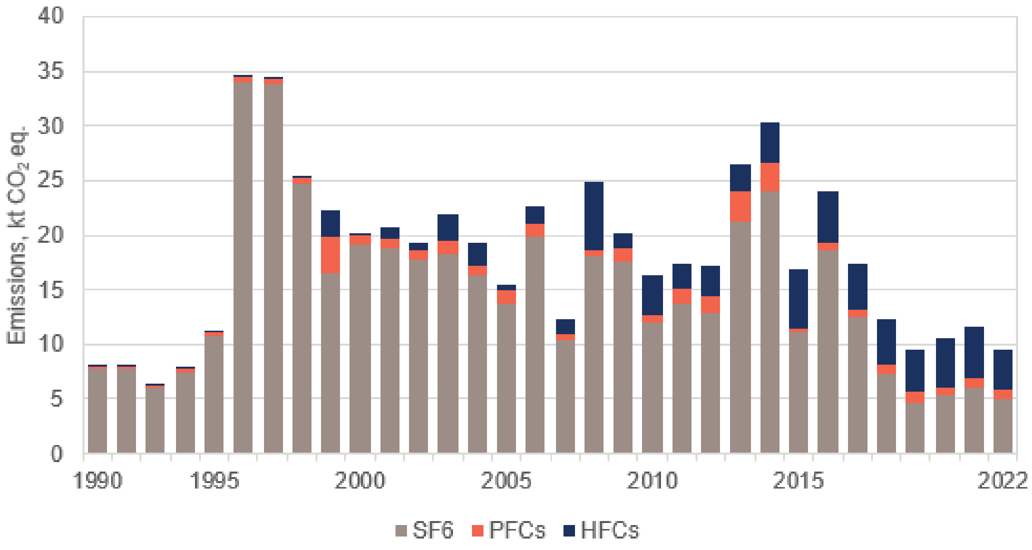


Figure 4.9-2 Grouped confidential data reported in 2.H.3

4.9.2.2 Methodological issues

Emission estimation methods for different categories reported under 2.H.3 are described in Sections 4.4.3, 4.6.2, 4.7.4. and 4.8.3.

4.9.2.3 Uncertainty assessment and time series' consistency

Quantitative estimates of uncertainty are provided in Annex 2. The annex also documents assumptions made for the analysis. A description of the uncertainty analysis is included in Section 1.6.

2022 uncertainties for activity data and emission factors for category 2.H.3 were set as an expert judgement at Syke (Forsberg, 2021d). Uncertainty for emission factors were set at ±60% and for activity data at ±50%.

Time series consistencies of SF_6 emissions from 2.C.4, HFC, PFC and SF_6 emissions from 2.E.1, HFC emissions from 2.F.3 and SF_6 emissions from 2.G.2 are presented in Sections 4.4.3.3, 4.6.2.3, 4.7.4.3 and 4.8.3.3, respectively.

4.9.2.4 Category-specific QA/QC and verification

QA/QC procedures described in Section 1.5 are implemented in the category 2.H.3. QC procedures are performed according to the QA/QC and verification plan, and the resulting findings, corrections and planned improvements are recorded in the annual QA/QC form. A bilateral quality meeting was held between the inventory unit and the sectoral expert in January 2024. The documentation and archiving of the 2.H.3 category are detailed in Section 1.2.3.

In the calculation of emissions from category 2.H.3, several general inventory quality control procedures have been performed as mentioned in 2006 IPCC Guidelines, Table 6.1. The correctness of the calculations is checked each year by reproducing a representative sample of the emission calculations manually, and the use of appropriate units and conversion factors throughout the calculations is crosschecked simultaneously.

The category-specific QC procedures for category 2.H.3 include emission and activity data comparisons. The emission trends are graphed and explained. The quality of activity data for each year is checked by comparing the data with the corresponding data of the three previous years. If unrealistic changes are noted, the correctness of the data is checked with the survey respondent.

4.9.2.5 Category-specific recalculations

There were done no category-specific recalculations.

4.9.2.6 Category-specific planned improvements

No planned improvements in this category.

Appendix_4a

The models used in calculating emissions from categories CFR 2.E, CRF 2.F and CRF 2.G

HFCs, PFCs and SF_6 from electronics industry (CRF 2.E.1)

Emissions from category 2.E.1 are calculated by the Tier 2a method of the 2006 IPCC Guidelines (Equations 6.2-6.6, pp. 6.10-6.11). Emissions are given by

$$E_i = (1-h)FC_i(1-U_i)(1-a_i d_i)$$

where, E_i = emissions of gas i, kg
FC_i = consumption of gas i, kg
h = fraction of gas remaining in shipping container (heel) after use, fraction
U_i = use rate of gas i (fraction destroyed or transformed in process), fraction
a_i = fraction of gas i volume used in processes with emission control technologies (company- or plant-specific), fraction
d_i = fraction of gas i destroyed by the emission control technology, fraction

By-product emissions of CF_4 are given by

$$BPE_{CF4,i} = (1-h)B_{CF4,i}FC_i(1-a_i d_{CF4})$$

$BPE_{CF4,i}$ = by-product emissions of CF_4 from the gas i used, kg
$B_{CF4,i}$ = emission factor, kg CF_4 created/kg gas i used
d_{CF4} = fraction of CF_4 by-product destroyed by the emission control technology, fraction

By-product emissions of C_2F_6 are given by

$$BPE_{C2F6,i} = (1-h)B_{C2F6,i}FC_i(1-a_i d_{C2F6})$$

$BPE_{C2F6,i}$ = by-product emissions of C_2F_6 from the gas i used, kg
$B_{C2F6,i}$ = emission factor, kg C_2F_6 created/kg gas i used
d_{C2F6} = fraction of C_2F_6 by-product destroyed by the emission control technology, fraction

By-product emissions of CHF_3 are given by

$$BPE_{CHF3,i} = (1-h)B_{CHF3,i}FC_i(1-a_i d_{CHF3})$$

$BPE_{CHF3,i}$ = by-product emissions of CHF_3 from the gas i used, kg
$B_{CHF3,i}$ = emission factor, kg CHF_3 created/kg gas i used
d_{CHF3} = fraction of CHF_3 by-product destroyed by the emission control technology, fraction

By-product emissions of C_3F_8 are given by

$$BPE_{C3F8,i} = (1-h)B_{C3F8,i}FC_i(1-a_i d_{C3F8})$$

$BPE_{C3F8,i}$ = by-product emissions of C_3F_8 from the gas i used, kg
$B_{C3F8,i}$ = emission factor, kg C_3F_8 created/kg gas i used
d_{C3F8} = fraction of C_3F_8 by-product destroyed by the emission control technology, fraction

Emissions are calculated for each gas FC on the basis of company-specific data on gas consumption.

HFCs from foam blowing (CRF 2.F.2)

Emissions of HFCs used as foam blowing agents for closed-cell foams are calculated using the Tier 2 model described in the 2006 IPCC Guidelines (Equation 7.7, p. 7.33). Emissions are a sum of manufacturing and first year emissions in the year *t*, and emissions from product use calculated from the gas banked at the beginning of the year *t*.

$$E_{t,i} = f_{M,i} M_{t,i} + f_{B,i} B_{t-1,i} + R_{t,i} - D_{t,i}$$

where $E_{t,i}$ = HFC blowing agent (actual) emissions from foam type *i* in year *t*,
$M_{t,i}$ = amount of HFC used in manufacturing foam type *i* in year *t*,
$f_{M,i}$ = manufacturing and first-year loss emission factor for foam type *i* (note that the emission factor is assumed time-independent),
$B_{t-1,i}$ = the amount of HFC blowing agents banked in foams of type *i* at the end of previous year (t-1) and hence, at the beginning of year *t*,
$f_{B,i}$ = annual loss emission factor for the foam type *i*,
$R_{t,i}$ = decommissioning losses of foam type *i* in year *t*, and
$D_{t,i}$ = the amount of HFC blowing agent destroyed in year *t* (recovered from foams of type *i*).

In Finland, retiring foam products are usually re-used as frost insulation or land filled without gas recovery. Therefore, the emissions are assumed to continue at the same rate as in the original use-phase until all of the blowing agent has been emitted. Thus it is assumed that
$R_{t,i} = 0$
$D_{t,i} = 0$

The total HFC blowing agent emissions are sums of the emissions from different foam types *i*.

The amount of HFC blowing agent banked in foam products at the end of the year is estimated by

$$B_{t,i} = B_{t-1,i}(1 - f_{B,i}) + M_{t,i}(1 - f_{M,i}) + Ip_{t,i} - Ep_{t,i}$$

where

$B_{t,i}$ = amount of HFC blowing agent banked in foam type *i* at the end of year *t*,
$Ip_{t,i}$ = HFC import in products of foam type *i* in year *t*,
$Ep_{t,i}$= HFC export in products of foam type *i* in year *t*

The total HFC blowing agent banked in foam products is a sum of the HFC banked in different foam types *i*.

HFC blowing agent emissions from open-celled foams are calculated using the Tier 2 Equation 7.8 described in the 2006 IPCC Guidelines (p. 7.34). The annual emissions are equal to the annual amount of HFC blowing agent used in manufacturing.

HFCs from aerosols and metered dose inhalers (CRF 2.F.4)

The emissions model used is from the 2006 IPCC Guidelines (p. 7.28)

$$x = (1 - f)a + fb, \qquad (1)$$
where f = 0.5,

a = quantity of HFC and PFC contained in aerosol products sold 2021, and
b = quantity of HFC and PFC contained in aerosol products sold in 2022.

f is dimensionless, *a* and *b* have dimensions of mass.

The equation above assumes that consumption equals sales of aerosol products to Finland. Sales is given by

$$Sales = I_c + I_p - E_p \qquad (2)$$

where I denotes imports and E exports.

Equation (2) is a vector consisting of quantities of HFCs. Subscripts c and p are used for bulk imports (imports in containers) and imports and exports in products (aerosols), respectively. Production of HFC propellants used in aerosols, bulk exports, as well as destruction, are all equal to zero (“not occurring” in the UNFCCC terminology), which is why they do not appear in (2).

Equation (2) defines a and b of Equation (1) as sums of the elements of *Sales* calculated for 2020 and 2021, respectively.

SF_6 and CF_4 from electrical equipment (CRF 2.G.1)

SF_6 and CF_4 emissions_from electrical equipment are calculated using the Tier 2 method of the 2006 IPCC Guidelines. Emissions are calculated by multiplying the national emission factors by the SF_6 and CF_4 consumption at each life cycle stage. Emissions are a sum of emissions from equipment manufacturing, equipment use and equipment disposal. Equipment manufacturing includes equipment manufacturing (SF_6 equipment from 1991 to 2011) and on-site installation of equipment. Emissions are given by

$$E_t = f_M M_t + f_U B_t + f_D D_t$$

where E_t = emissions in year t

f_M = emission factor for equipment manufacturing and on-site installation

M_t = amount of gas used in manufacturing and on-site installation of equipment in year t

f_U = emission factor for equipment use

B_t = amount of gas banked in equipment in year t

f_D = emission factor for equipment disposal

D_t = amount of gas in retired equipment in year t

The amount of gas banked in equipment is estimated by

$$B_t = B_{t-1} + I_t - D_t$$

where B_{t-1} = amount of gas banked in equipment in year $t-1$

I_t = amount of gas installed in equipment in year t

Appendix_4b

Emissions of the new F gases in Finland

The UNFCCC reporting guidelines encourage Annex I Parties to report emissions of the so-called new F gases for which GWP values are available. These gases include e.g. hydrofluoroolefins (HFOs), hydrofluorethers (HFEs), perfluoropolyethers (PFPEs) and fluorinated ketones. Information on the use of these new substances has been collected in Finland since 2010 and emissions have been calculated for 2010 to 2022. Emissions totalled 1.1 kt CO_2 eq. in 2022. Due to confidentiality, the annual emission estimates for 2010 to 2011 cannot be presented. The total emissions from 2010 to 2011 are 0.5 kt CO_2 eq. The emissions for 2010 to 2022 are presented in the table below. Included emissions are:

- HFO-1234yf (2.F.1.e for 2012 to 2022, 2.F.1.d for 2015 to2022, 2.F.1.a for 2016 to 2022, 2.F.1.c and 2.F.1.f for 2020 to 2022)
- HFO-1234ze (2.F.1.a for 2016 to 2022, 2.F.1.c and 2.F.1.f for 2020 to 2022 and 2.F.4 for 2018 to 2022)
- $C_6F_{12}O$ (2.F.3 for 2010, 2013 to 2018, 2021 and 2.F.4 for 2016 to 2018, 2021 to 2022)
- HFE-347 mcc3 (2.F.4 for 2014 to 2017 and 2019 to 2020)
- HFE-449sl (2.F.4 for 2010 to 2022)
- HFE-569sf2 (2.F.4 for 2010 to 2022)

In 2022, 70% of the emissions originate from HFEs in the aerosol sector and 20% from HFO-1234yf in mobile air-conditioning. These emissions are not reported in the CRF tables or included in the national total emissions.

Table 1_App_4b Total emissions of the new F gases for 2010 to 2022 (note that the emissions for 2010 to 2011 have been grouped due to confidentiality).

	2010-2011	2012	2013	2014	2015	2016	2017	2018	2019	2020	2021	2022
New F gases, kt CO_2 eq.	0.5	0.2	0.3	0.4	0.4	0.4	0.9	0.7	0.5	0.6	0.8	1.1

Appendix_4c

Refrigerant shares in categories CRF 2.F.1a, 2.F.1c and 2.F.1f

Commercial refrigeration (2.F.1a)

The share of refrigerants in centralized and stand-alone refrigeration systems in food retail stores and in professional kitchens in operation in Finland are presented in Figures 1_app_4c, 2_app_4c and 3_app_4c.

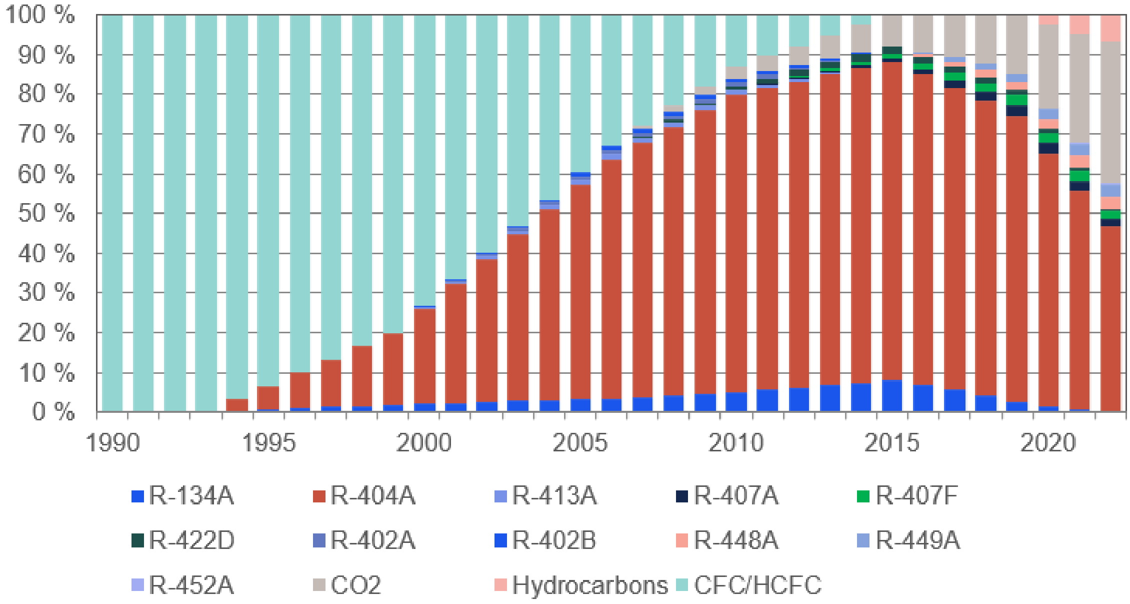


Figure 1_App_4c The share of refrigerants in centralized refrigeration systems in food retail stores in operation in Finland

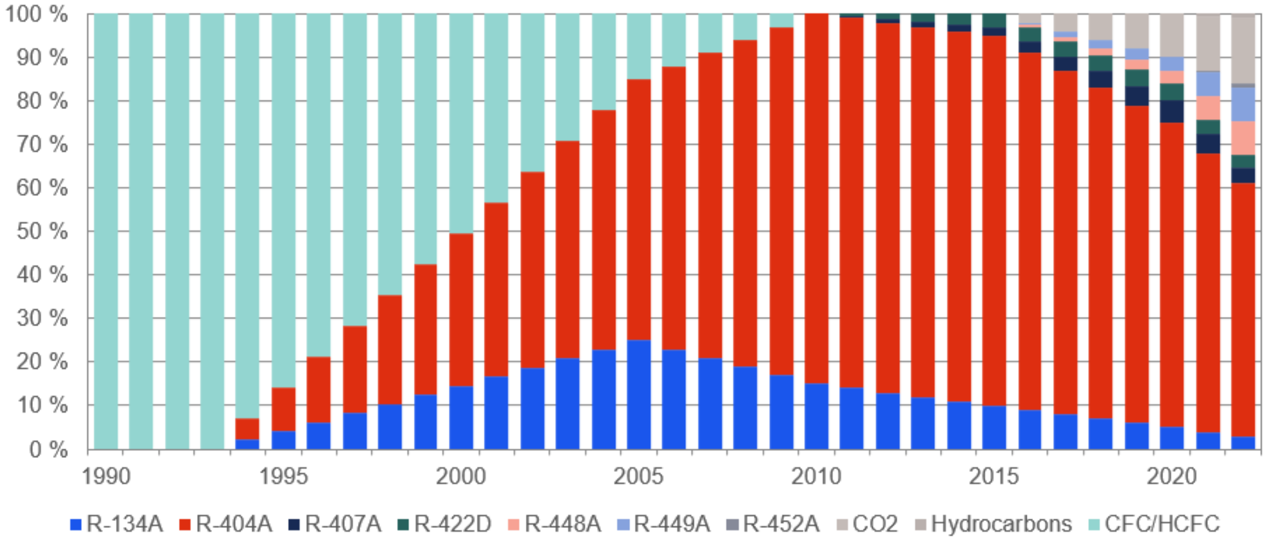


Figure 2_App_4c The share of refrigerants in centralized refrigeration systems in professional kitchens in operation in Finland

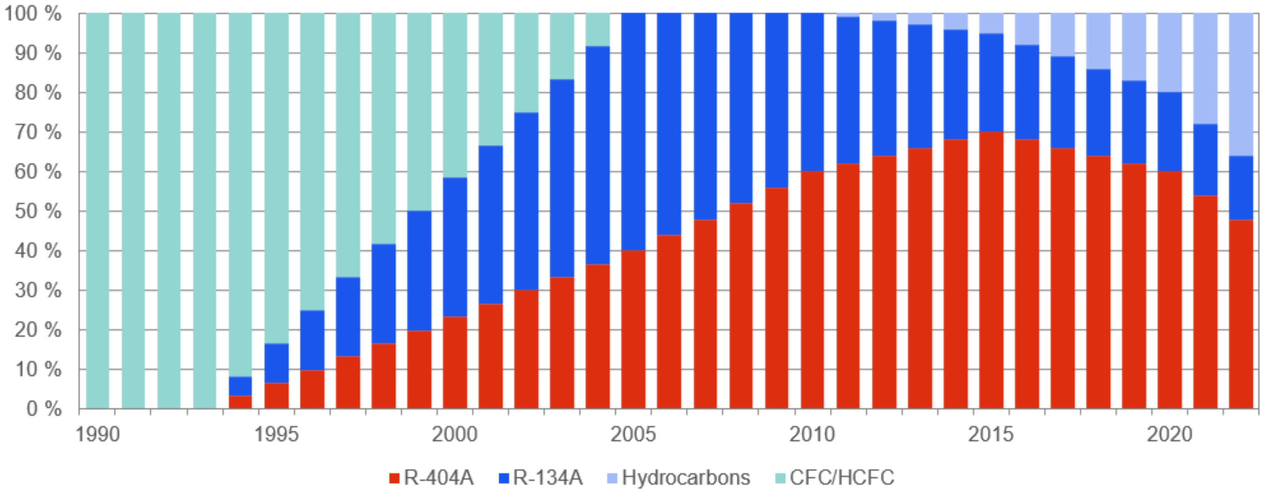


Figure 3_App_4c The share of refrigerants in stand-alone refrigeration units in food retail stores and in professional kitchens in operation in Finland

Industrial refrigeration (2.F.1c)

The share of refrigerants in annually on-site installed or factory charged industrial refrigeration equipment in Finland is presented in Figure 4_App_4c. Note that the CFC and HCFC refrigerants and widely used ammonia has not been taken into account when the total amount of refrigerant use has been assessed. This is due to lack of detailed data on the total annual amount of CFC/HCFC refrigerants and ammonia used.

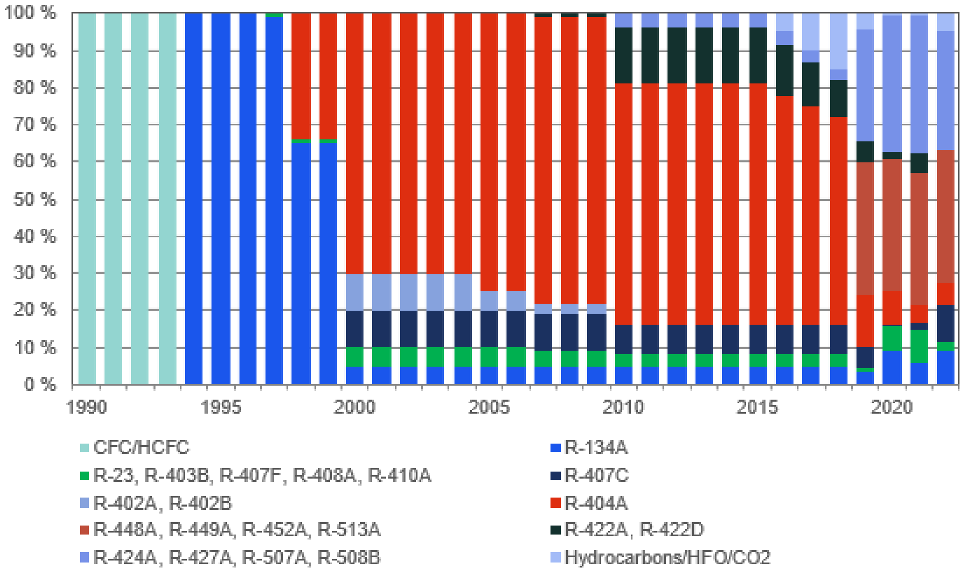


Figure 4_App_4c The share of refrigerants in annually on-site installed or factory charged industrial refrigeration equipment in Finland

The share of refrigerants in annually imported and exported industrial refrigeration equipment in Finland is presented in Figures 5_App_4c and 6_App_4c. The data concerning imported amounts is available from 2001 on and exported from 2003, while data on annual new additions of refrigerants into new systems is utilised for earlier years.

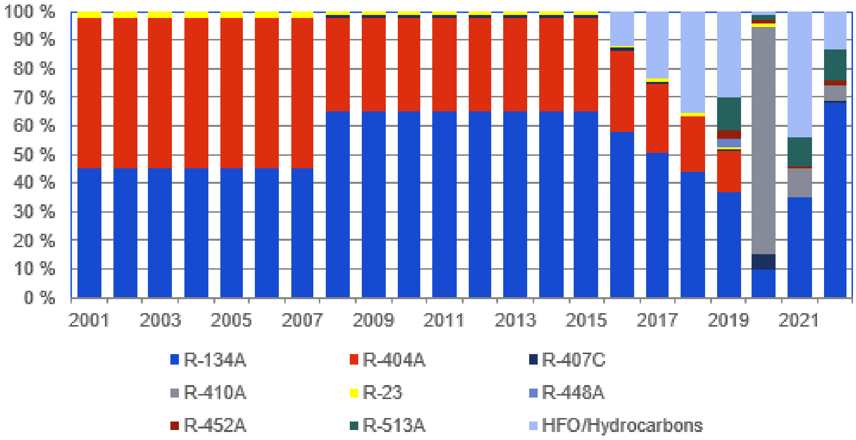


Figure 5_App_4c The share of refrigerants in annually imported industrial refrigeration equipment in Finland (data available from 2001)

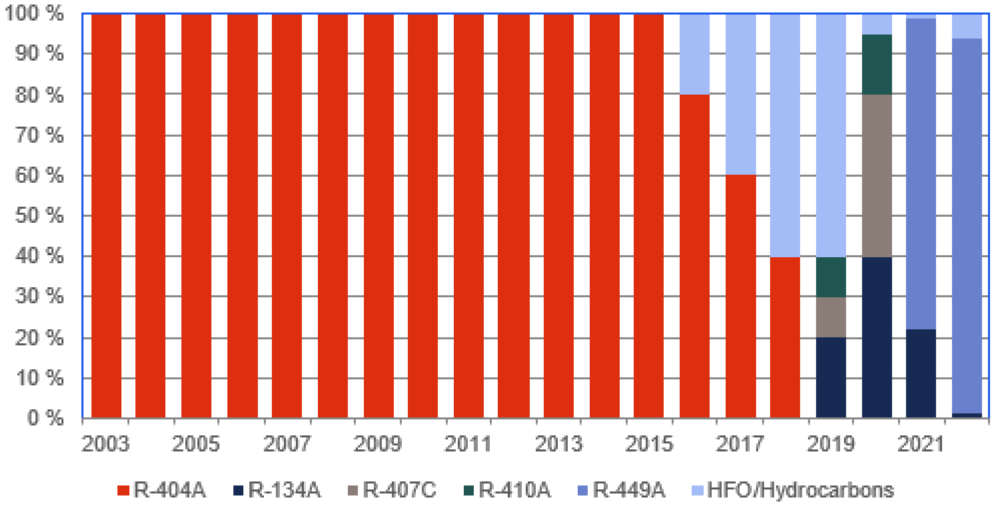


Figure 6_App_4c The share of refrigerants in annually exported industrial refrigeration equipment in Finland (data available from 2003)

Stationary air-conditioning (2.F.1f)

The share of refrigerants in annually sold and installed heat pumps in Finland are presented in Figure 7_App_4c, Figure 8_App_4c and Figure 9_App_4c. The shares in Figure 7_App_4c have been applied to ground source heat pumps, exhaust air heat pumps and air-to-water heat pumps. The shares in Figure 8_App_4c have been applied to air-to-air heat pumps in Finland. The shares in Figure 9_App_4c have been applied to annually installed large heat pumps in Finland.

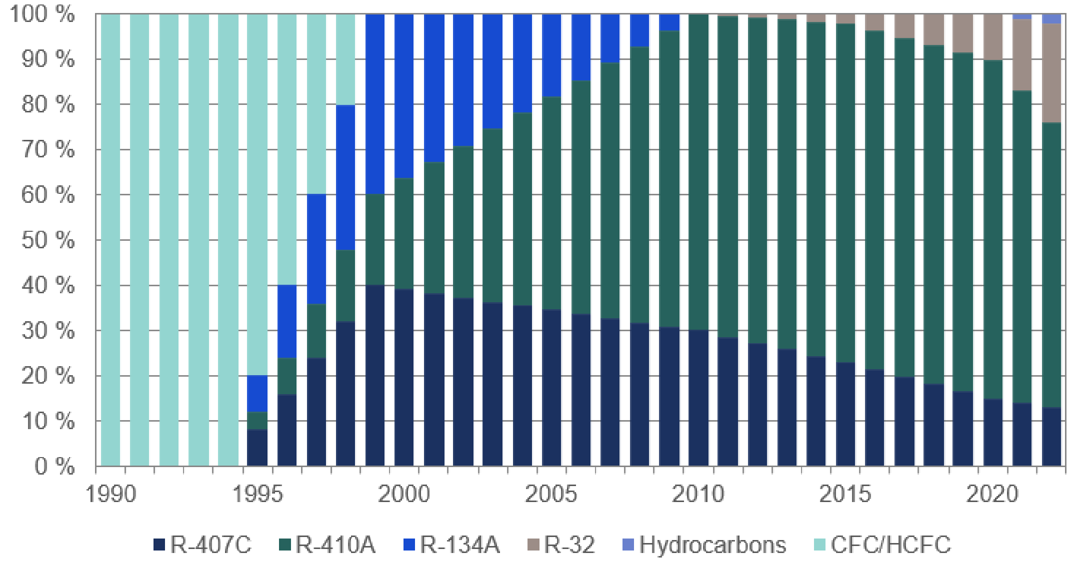


Figure 7_App_4c Share of refrigerants in annually sold ground source, exhaust air and air-to-water heat pumps in Finland

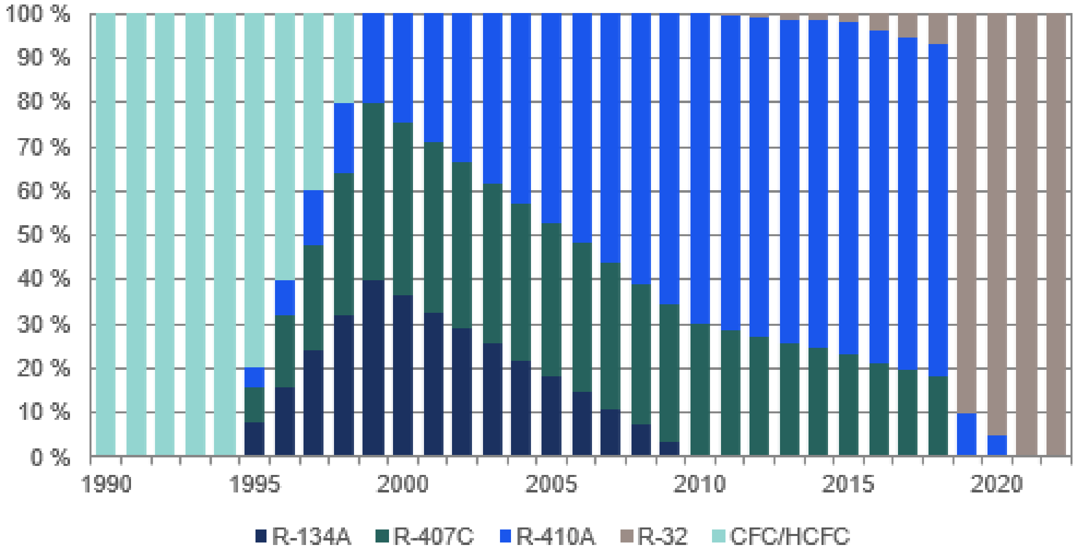


Figure 8_App_4c Share of refrigerants in annually sold air-to-air heat pumps in Finland

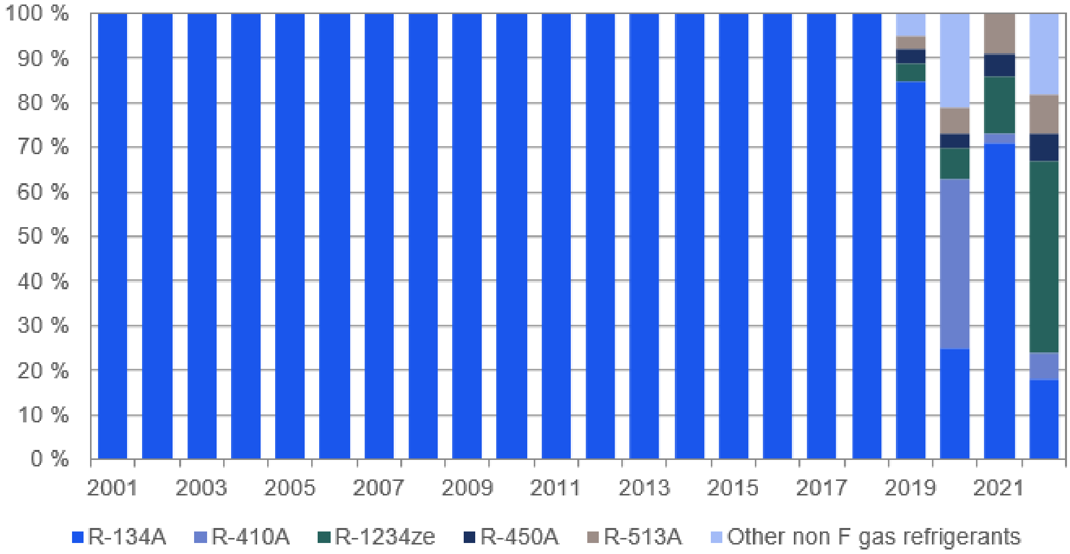


Figure 9_App_4c Share of refrigerants in annually installed large heat pumps in Finland

The share of refrigerants in annually on-site installed or factory charged other stationary air-conditioning equipment in Finland is presented in Figure 10_App_4c. Note that the 1990s data does not contain CFC/HCFC refrigerants due to lack of data on their total use.

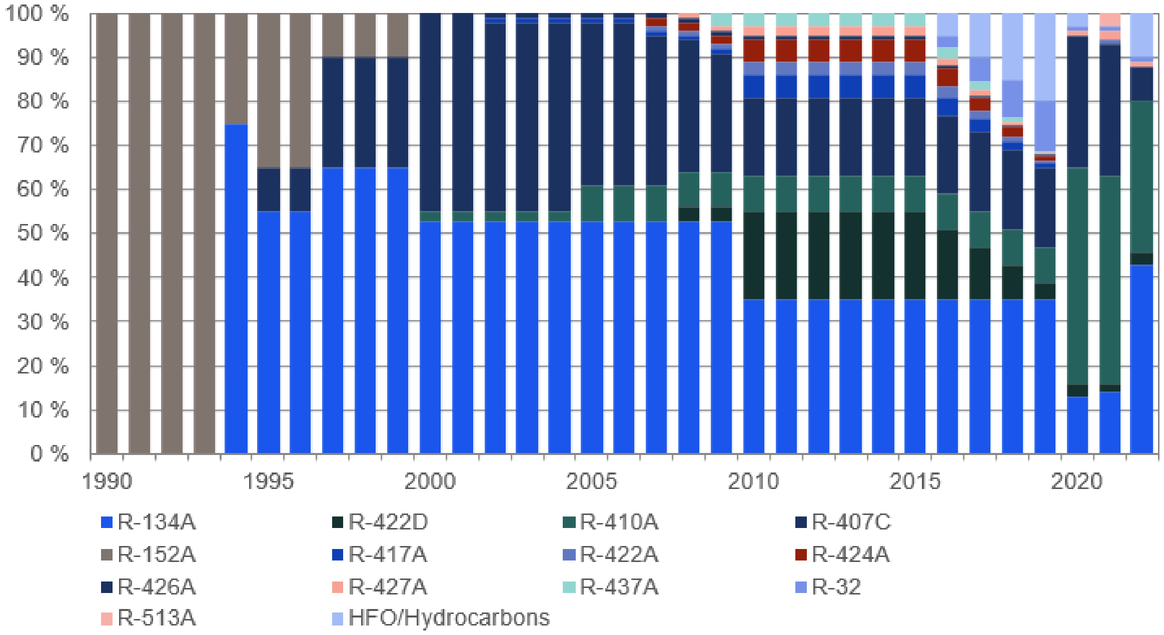


Figure 10_App_4c The share of refrigerants in annually on-site installed or factory charged other stationary air-conditioning equipment in Finland

Shares of refrigerants in annually imported and exported stationary air-conditioning equipment in Finland are presented in Figures 11_App_4c and 12_App_4c. The data concerning imported amounts is available from 2000 on, while data on annual new additions of refrigerants into new systems is utilised for years from 1990 to 1999.

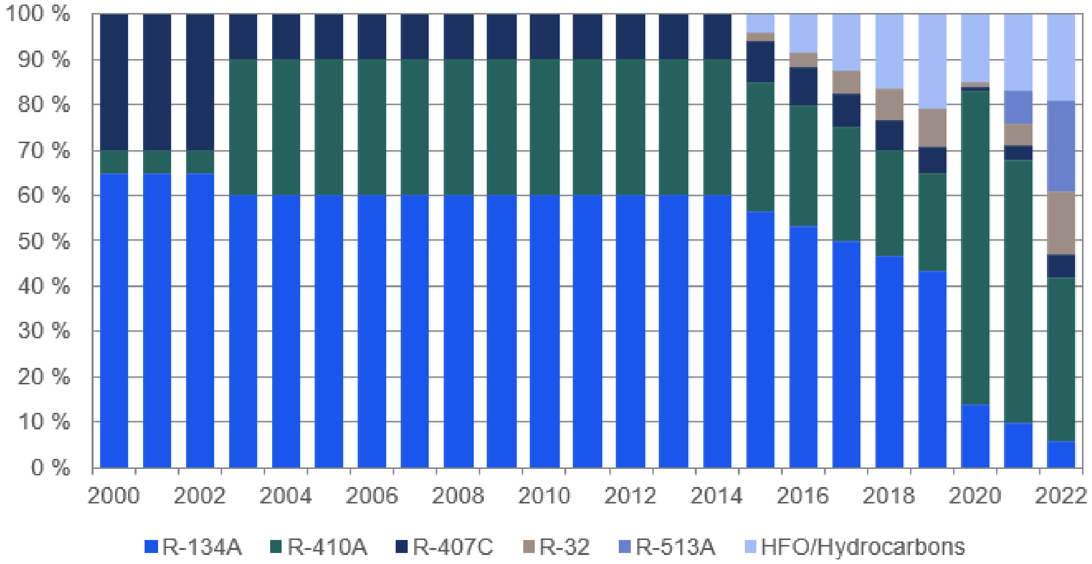


Figure 11_App_4c The share of refrigerants in annually imported other stationary air-conditioning equipment in Finland (data available from 2000)

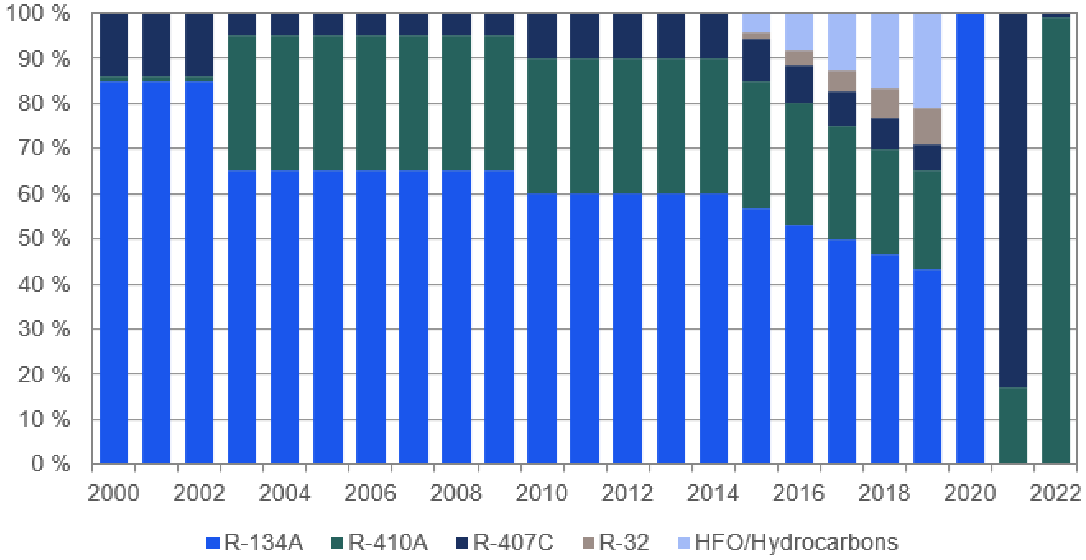


Figure 12_App_4c The share of refrigerants in annually exported other stationary air-conditioning equipment in Finland (data available from 2000)

5 AGRICULTURE (CRF 3)

5.1 Overview of the sector

5.1.1 Description and quantitative overview

Finland’s greenhouse gas emissions reported in the Agriculture sector in 2022 were 6.1 million tonnes of carbon dioxide equivalent (Mt CO_2 eq.) in total. Agriculture was the second largest greenhouse gas emission source sector after the energy sector with a 13% share of the total greenhouse gas emissions in 2022 (Figure 5.1-1).

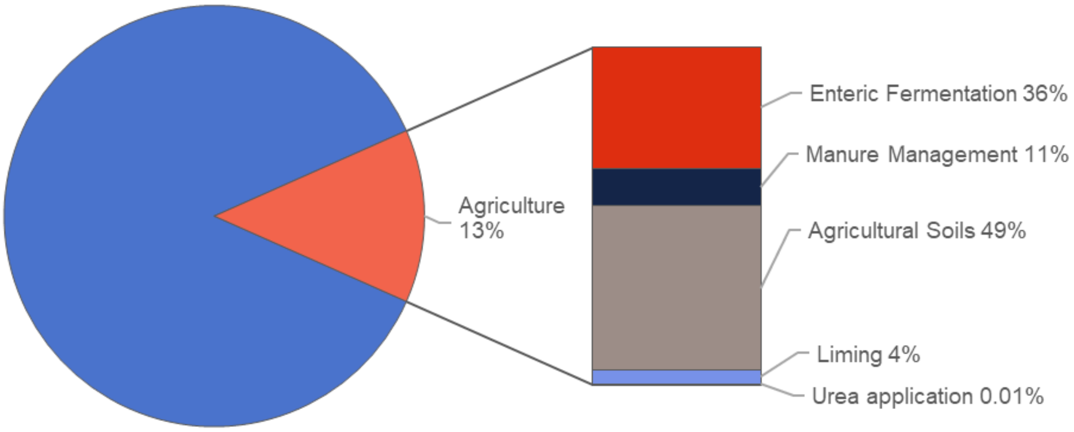


Figure 5.1-1 Agricultural emissions from the total greenhouse gas emissions in 2022

Agricultural greenhouse gas emissions in Finland consist of methane emissions from enteric fermentation of domestic livestock, methane and nitrous oxide emissions from manure management, direct and indirect nitrous oxide emissions from agricultural soils and carbon dioxide emissions from liming and urea fertilisation. Direct nitrous oxide emissions from agricultural soils include emissions from synthetic fertilisers, manure and sewage sludge applied to soils, urine and dung deposited on pasture, crop residues, drainage and management of organic soils for agriculture, and nitrogen mineralisation in mineral agricultural soils associated with the loss of soil organic matter that results from management change. Indirect nitrous oxide emission sources include emissions from atmospheric deposition and from nitrogen leaching and run-off to watercourses. Indirect nitrous oxide emissions are estimated also for manure management. Figure 5.1-3 and Figure 5.1-4 present sources and flows of nitrogen and magnitude of nitrous oxide emissions in the sector Agriculture from different sources according to the IPCC classification.

In 2022, the methane emissions from enteric fermentation were 36%, methane emissions from manure management 7%, nitrous oxide emissions from manure management 4% and nitrous oxide emissions from agricultural managed soils 49% of the total agricultural emissions. Liming and urea comprised 4% of the emissions. Field burning of agricultural crop residues has been prohibited since 2021. Rice is not cultivated and savannahs do not exist in Finland. A general assessment of completeness can be found in Section 1.7 and a more detailed assessment is included in Annex 5.

Emissions in the Agriculture sector have decreased by approximately 17% over the period 1990 to 2022 (Figure 5.1-2). Total agricultural emissions in 2022 remained almost at the same level as in 2021, because the slightly decreased emissions from enteric fermentation and manure management were counterbalanced by increased emissions from crop residues and N mineralization in mineral soils.

Finland’s membership in the EU since 1995 has resulted in changes in the economic structure of agriculture in Finland. As a result, the number of farms has decreased, the average farm size has increased (Farm Register

2010) and the livestock numbers have decreased. Additionally, the implementation of measures by farmers as part of an agri-environmental program aimed to minimizing nutrient loading into watercourses has led to a decrease in the use of nitrogen fertilizers, thereby reducing emissions in the Agriculture sector. The use of synthetic fertilisers has decreased by 56% from 1990 to 2022, making it the most significant factor contributing to reduced emissions. The decrease in CO_2 emissions from liming due to reduced use of lime is also significant. The area of cultivated organic soils has increased during the period 1990 to 2022, which has increased nitrous oxide emissions.

Some inter-annual variation between the years can be detected from the time series (Table 5.1-1). This is mainly caused by fluctuations in activity data between the years due to changes in animal numbers and in the manufacture and import of lime for agriculture. Changes in animal numbers are largely affected by agricultural policy and subsidies, and they particularly affect methane and nitrous oxide emissions from manure management. Emissions from manure management are also affected by the distribution of manure managed in different manure management systems, which varies depending on the animal species. Nitrous oxide emissions from managed soils are affected by the amount of synthetic fertilisers used annually, animal numbers and crop yields of cultivated crops, for example, which may have a large variation between the years.

Emissions from energy use in agriculture (e.g. fuel combustion in agricultural machinery, heating of agricultural buildings, etc.) are reported in the Energy sector (Chapter 3) and are not included in the emissions reported in the Agriculture sector (Figure 5.1-3).

Rounded values are often used in this inventory document; the accurate figures used in the calculation are presented in the CRF tables.

NMVOC emissions from agricultural sources are reported under CFR 3.B Manure management, CRF 3.D Agricultural soils and CRF 3.F Field burning of agricultural residues. These emissions are considered to be of biogenic origin and thus, indirect CO_2 emissions are not calculated for these emissions (see Chapter 9).

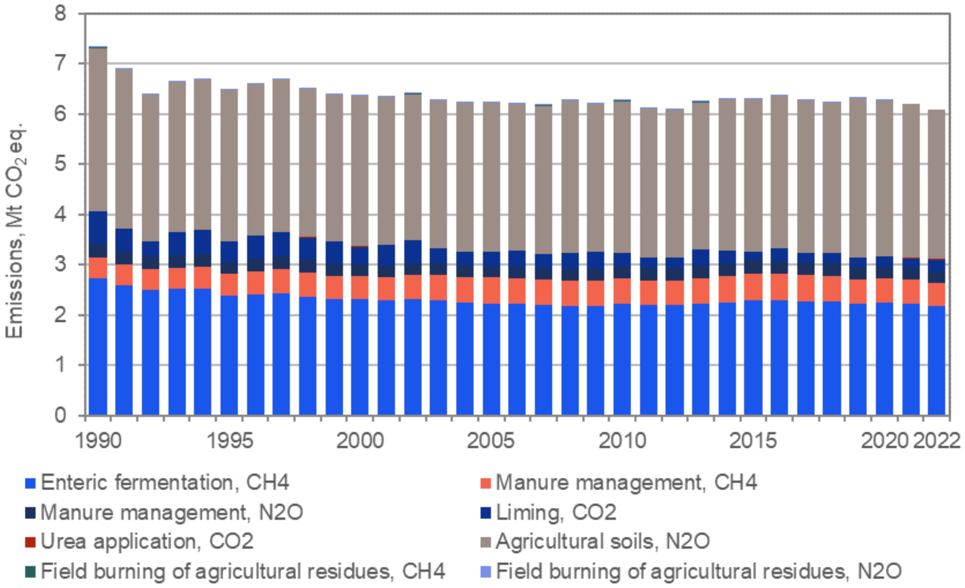


Figure 5.1-2 Trend in emissions in the Agriculture sector by category (Mt CO_2 eq.). The CH_4 and N_2O emissions from field burning of agricultural residues, as well as CO_2 emissions from urea application are very small or zero and, therefore, not discernible in the figure

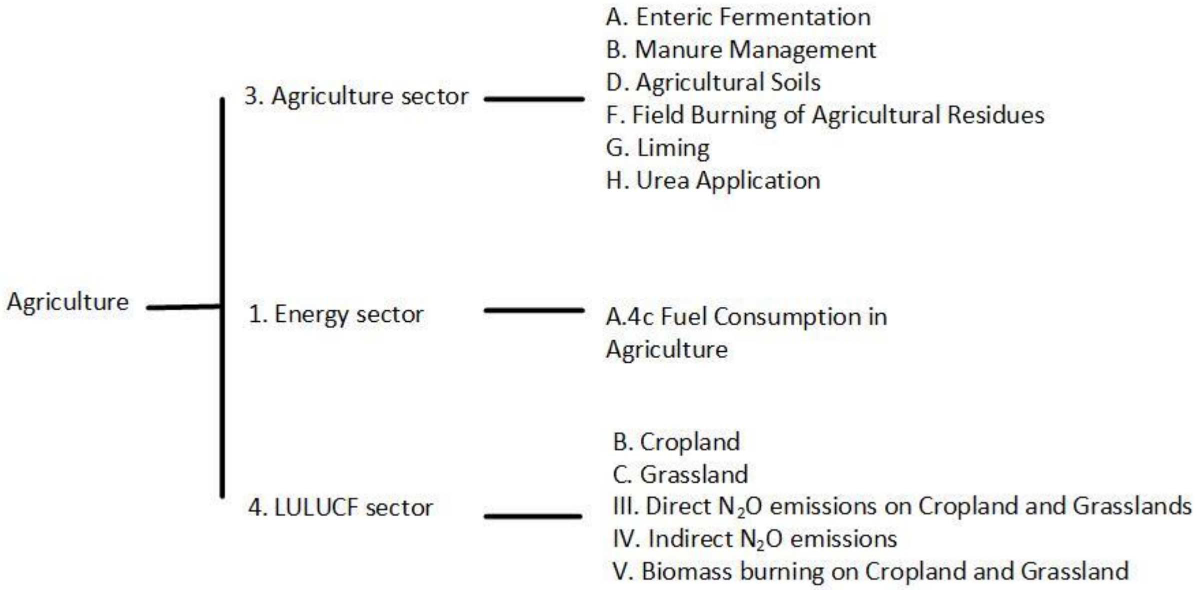


Figure 5.1-3 Agricultural sources of emissions and their reporting in the CRF categories in the national greenhouse gas inventory

Table 5.1-1 Finland’s greenhouse gas emissions from Agriculture by source and gas, Mt CO_2 eq.

	Enteric fermentation	Manure management		Agricultural soils	Burning of agri-cultural residues		Liming	Urea application	Total emissions			
				Mt CO_2 eq.					Mt CO_2 eq.			
	CH_4	CH_4	N_2O	N_2O	CH_4	N_2O	CO_2	CO_2	CH_4	N_2O	CO_2	CO_2 eq.
1990	2.72	0.42	0.27	3.26	0.003	0.0008	0.64	0.0054	3.14	3.53	0.65	7.32
1995	2.37	0.45	0.24	3.00	0.003	0.0007	0.41	0.0006	2.82	3.24	0.41	6.47
2000	2.31	0.46	0.23	2.99	0.003	0.0008	0.35	0.0008	2.78	3.23	0.35	6.36
2005	2.22	0.51	0.22	2.96	0.003	0.0006	0.29	0.0011	2.74	3.19	0.29	6.22
2010	2.22	0.50	0.24	3.02	0.002	0.0004	0.28	0.0016	2.72	3.26	0.28	6.25
2013	2.21	0.51	0.25	2.94	0.002	0.0006	0.31	0.0010	2.73	3.19	0.32	6.23
2014	2.25	0.53	0.26	3.01	0.002	0.0005	0.24	0.0017	2.78	3.27	0.25	6.29
2015	2.29	0.54	0.26	3.02	0.002	0.0005	0.16	0.0021	2.83	3.28	0.17	6.28
2016	2.29	0.53	0.25	3.02	0.002	0.0005	0.26	0.0028	2.82	3.28	0.26	6.35
2017	2.27	0.52	0.25	3.02	0.002	0.0005	0.19	0.0018	2.79	3.28	0.19	6.26
2018	2.26	0.52	0.25	2.99	0.002	0.0004	0.20	0.0015	2.77	3.24	0.20	6.22
2019	2.21	0.50	0.25	3.17	0.002	0.0006	0.19	0.0022	2.71	3.41	0.19	6.32
2020	2.23	0.49	0.24	3.11	0.002	0.0005	0.20	0.0016	2.72	3.35	0.20	6.28
2021	2.21	0.48	0.24	3.07	NO	NO	0.20	0.0012	2.69	3.30	0.20	6.20
2022	2.18	0.45	0.22	2.97	NO	NO	0.25	0.0078	2.63	3.19	0.26	6.07

5.1.2 Key categories

The key categories in agriculture are summarised in Table 5.1-2.

Table 5.1-2 Key categories in Agriculture (CRF 3) in 1990 and 2022 (Approach 1 and Approach 2)

IPCC category	Gas	Criteria	Method
3.A. Enteric Fermentation	CH_4	L, T	Tier 1, Tier 2, CS, OTH
3.B. Manure Management	CH_4	L, T	Tier 2
3.B. Manure Management	N_2O	L, T	Tier 2
3.D.a. Direct N_2O Emissions from Managed Soils	N_2O	L, T	Tier 1, Tier 2
3.D.b. Indirect N_2O Emissions from Managed Soils	N_2O	L, T	Tier 2
3.G. Liming	CO_2	L, T	Tier 1

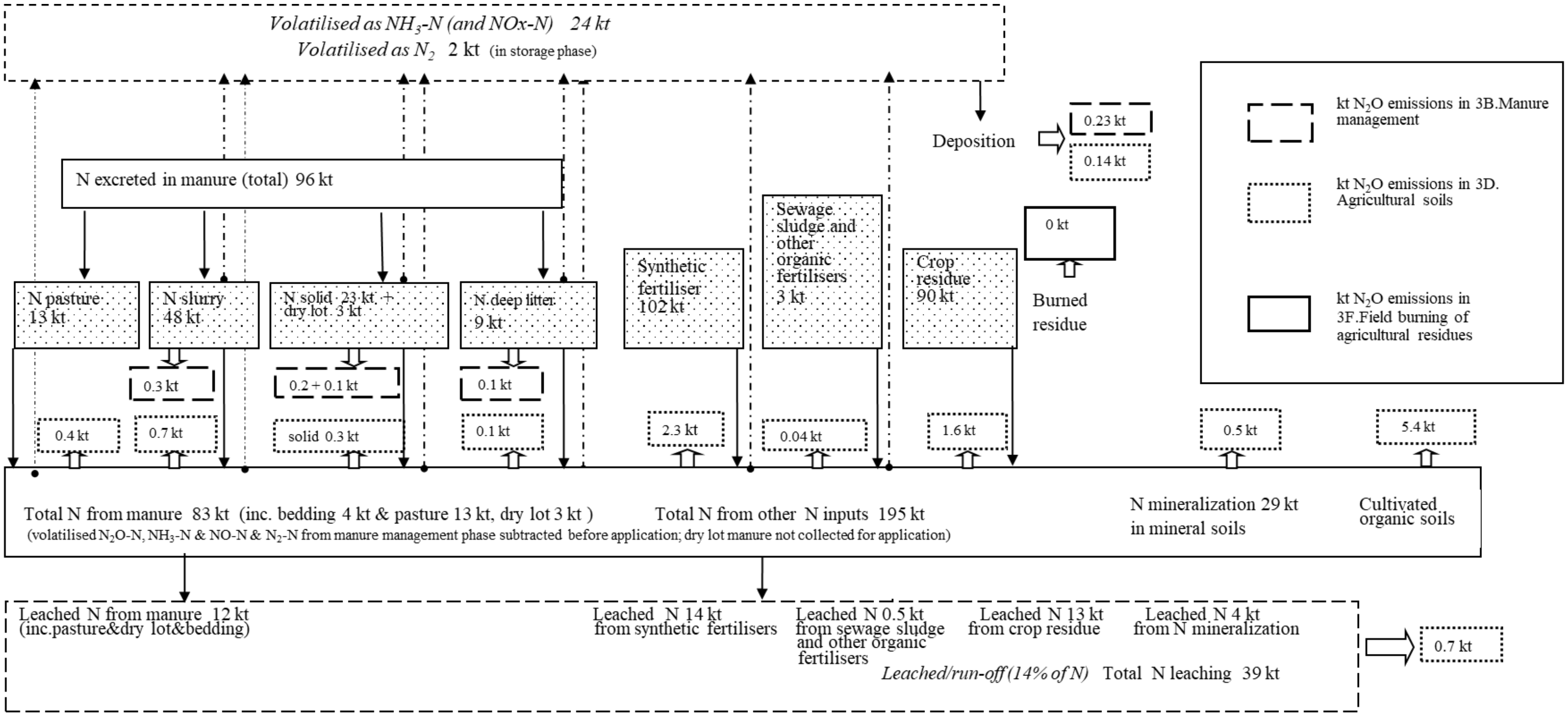


Figure 5.1-4 Nitrogen flows and nitrous oxide emissions in the Agriculture sector in 2022. Thin arrows denote N flows, of which dashed arrows show N volatilisation as ammonia, nitric oxide and dinitrogen. Bulk arrows denote N_2O emissions. Nitrogen flows are in kt N year^{-1} and emissions (dotted line) in kt N_2O year^{-1}. Figures are rounded, subtotals and totals calculated from unrounded values.

5.2 Enteric Fermentation (CRF 3.A)

5.2.1 Category description

Methane emissions from enteric fermentation of domestic livestock comprised 36% of total emissions in the Agriculture sector in Finland, being 2.2 Mt CO_2 equivalents in 2022.

This category includes emissions from cattle (dairy cows, suckler cows, bulls, heifers and calves), horses (including ponies), swine (fattening pigs, weaned pigs i.e. pigs weighing 20-50 kg, boars, sows and piglets), sheep, goats, reindeer and fur-bearing animals. Emissions from poultry are not estimated since a default method for the estimation of these emissions is lacking (see Table 5.2-1). There are no emissions from the enteric fermentation or manure management originating from the following livestock groups: buffalo, camels and llamas, deer, mules and asses, rabbit and ostrich.

Table 5.2-1 Reported emissions, calculation methods and types of emission factors for the subcategory Enteric Fermentation in the Finnish inventory

CRF	Source	Emissions reported	Method	Emission factor
3.A.1	Cattle			
	Dairy Cattle	CH_4	Tier 2	CS
	Non-Dairy Cattle	CH_4	Tier 2	CS
3.A.2	Sheep	CH_4	CS	CS
3.A.3	Swine	CH_4	CS	CS
3.A.4	Other livestock			
	-Goats	CH_4	Tier 1	D
	-Horses	CH_4	Tier 1	D
	-Poultry	NE1)	-	-
	- Reindeer	CH_4	CS	CS
	- Fur-bearing animals	CH_4	OTH	OTH

1) No methodology is available in the 2006 IPCC Guidelines to estimate emissions from enteric fermentation of poultry.

Methane emissions from enteric fermentation are produced as a by-product of the normal livestock digestive process. Feed consumed by the animal is fermented by the microbes in the animal's digestive system. This process is called enteric fermentation. Methane that is produced is exhaled by the animal (Gibbs et al. 2002). The most important animal group producing methane is ruminants (e.g. cattle and sheep) (www.fao.org) but other animals may also be significant emission sources if their number is large.

The emissions have decreased by 20% since 1990, especially due to the decreasing number of cattle (Table 5.2-2). From 1995 to 2022, the number of cattle declined by more than one third, from 1,360,000 to 844,000. The decline has slowed down over the last ten years. The decrease in cattle number over the time series has been counterbalanced by an increase in emission factors due to increased animal weights, size and milk production (see Figure 5.2-1 for the case of dairy cows). The emission estimate for 2022 (2.18 Mt CO_2) is almost the same as the one for 2021 (2.21 Mt CO_2).

Table 5.2-2 Methane emissions (kt) from enteric fermentation by animal type

	Cattle					Sheep	Swine	Other livestock					Total
	DC	SC	B	H	C	Sh	Sw	Ho	Po	G	F	R	
1990	53.9	1.0	8.4	11.4	14.3	0.9	1.3	0.7	0.1	0.03	0.2	4.8	97.0
1995	45.9	2.1	6.3	10.1	12.5	1.3	1.3	0.8	0.1	0.03	0.3	4.1	84.7
2000	45.1	2.0	6.7	10.2	11.1	0.8	1.3	0.9	0.1	0.04	0.3	4.0	82.6
2005	41.8	2.5	7.0	9.7	10.6	0.7	1.4	1.0	0.1	0.03	0.3	4.1	79.4
2010	39.8	4.1	7.8	9.7	10.0	1.0	1.4	1.2	0.2	0.02	0.3	3.9	79.3
2013	40.0	4.3	7.2	9.7	9.8	1.1	1.3	1.2	0.2	0.02	0.3	3.8	79.0
2014	41.2	4.4	7.3	9.6	10.0	1.1	1.3	1.2	0.2	0.02	0.3	3.7	80.4
2015	42.0	4.5	7.4	9.5	10.3	1.3	1.3	1.1	0.2	0.02	0.3	3.8	81.7
2016	42.3	4.5	7.3	9.2	10.4	1.3	1.2	1.1	0.2	0.02	0.3	3.8	81.7
2017	41.8	4.6	7.6	9.3	10.0	1.3	1.1	1.2	0.2	0.03	0.3	3.8	81.1
2018	41.8	4.6	7.3	9.0	10.1	1.3	1.1	1.2	0.2	0.03	0.2	3.7	80.6
2019	40.3	4.7	7.4	9.0	9.9	1.3	1.1	1.2	0.2	0.03	0.2	3.7	79.0
2020	41.0	4.9	7.0	8.9	10.2	1.2	1.1	1.2	0.2	0.03	0.2	3.9	79.7
2021	40.1	5.1	7.2	9.0	10.2	1.1	1.1	1.2	0.2	0.03	0.1	3.6	79.0
2022	39.2	5.2	7.2	9.0	9.8	1.2	1.0	1.1	0.2	0.03	0.1	3.7	77.7
Share of total (%) in 2022	50.5	6.7	9.3	11.6	12.7	1.5	1.3	1.4	0.3	0.0	0.1	4.7	100.0

DC=Dairy cows, SC=Suckler cows, B=Bulls, H=Heifers, C=Calves, Sh=Sheep, Sw=Swine, Ho=Horses, Po=Ponies, G=Goats, F=Fur animals, R=Reindeer, Poultry not estimated.

5.2.2 Methodological issues

5.2.2.1 Methods

Emissions from enteric fermentation of domestic livestock have been calculated by using the IPCC Tier 1 and Tier 2 methodologies presented in the 2006 IPCC Guidelines. The total emission is the sum of emissions from each category (2006 IPCC Guidelines, Chapter 10, p. 28).

Methane emissions from enteric fermentation of horses, ponies and goats have been calculated with the IPCC Tier 1 method by multiplying the number of the animals in each category with the IPCC default emission factor of the respective animal category as no national emission factor is available. The emissions from fur-bearing animals were calculated by multiplying the number of fur-bearing animals (minks, fitches, foxes, raccoon dogs) with the emission factor modified from the one used for piglets. The contribution of emissions from horses, swine, goats and fur-bearing animals to the total emissions from enteric fermentation is minor.

The Tier 2 method has been used for cattle. In the Tier 2 method, the emissions have been calculated as in the Tier 1 method above, but the emission factors have been calculated by using the gross energy intake (GE) estimations from country-specific calculations (Nousiainen et al. 2023, see also Section 5.2.2.3) and the default methane conversion rate from the 2006 IPCC Guidelines for cattle (6.5%), which is considered appropriate for Finnish conditions by the expert (Nousiainen, J.). Methane emissions from enteric fermentation have been identified as a key category, but only emissions from cattle meet the criteria given in the 2006 IPCC Guidelines for significant sub-categories.

For swine subgroups, the country-specific calculation method uses feeding information of Finnish pigs and the Evapig program (http://www.evapig.com/IMG/pdf/EvaPigManualEquations-3.pdf) and calculation formulas developed by a Finnish expert (Nousiainen, J.). Methane emissions from enteric fermentation of reindeer have been calculated by estimating the gross energy intake (GE) on the basis of literature (McDonald et al. 1988) by using national data for estimating dry matter intake and its composition (hay and lichen) and calculating the respective emission factor with the IPCC equation EF = (GE*Y_m* 365 days/year)/(55.65 MJ/kg CH_4). The same methodology has been used for estimating the GE and EF for sheep. Equations used for calculating the GE for sheep and reindeer are presented in more detail in Section 5.2.2.3.

Livestock characterisation (animal numbers, cattle weights and daily weight gains, milk production and fat content, digestible energy, pregnancy per cent) is consistent with the data used in nitrogen excretion calculations.

5.2.2.2 Activity data

Animal numbers are presented in Table 5.2-4 (and Appendix_5a). The numbers of cattle, sheep, swine, poultry and goats were obtained from the statistics database maintained by Natural Resources Institute Finland (Luke 2021a), as well as from the Yearbook of Farm Statistics published annually (2003 to 2014) by Luke. The date for the animal data differs, for example, depending on the EU farming subsidy application date. Cattle numbers are from 1 May or June, poultry from 1 April or May, sheep and goats from 1 May or June. The animal group of swine is divided into the subgroups fattening pigs, boars, weaned pigs, sows and piglets. As the subgroup data was not available for the earliest years, the total number of swines is divided into subgroups for the years 1990 to 1994 according to an average distribution in 1995 to 2005 (spring data). Since 2015, the weight category subgroup data were no longer available in the spring data of swine numbers and as a consequence, the December information had to be taken as an activity data. The December animal numbers are based on a query sent to a sample of piggeries by Farm Statistics (Luke) and only since 2007 the swine numbers of December can be considered reliable as the sampling method had been improved. Therefore, spring animal numbers of 1990-2006 (1 April or May or June; all piggeries) were adjusted to represent the animal numbers in December by using the average ratio of (subgroup) swine numbers in December and spring (2007 to 2014) as a conversion factor. Numbers of sows and boars were not adjusted but used as such. Detailed feeding, excretion and methane production calculation of swine requires a categorization of swine numbers into different weight groups, but this categorization is no longer available from official statistics after 2021. Therefore, from now on the age categorization (piglets < 3 months, fattening/breeding pigs 3 to 8 moths, boars and sows > 8 months) data of December swine numbers are taken and converted to the weight-based categorization using an estimation model that was built based on the overlapping animal number data in age and weight categories for the years 2013-2020. These estimated swine numbers are the same as used for Eurostat statistics.

The number of horses (on 31 December) is received from the Finnish Trotting and Breeding Association (Suomen Hippos, http://www.hippos.fi/in_english).

The annual cub production statistics from the Finnish Fur Breeders' Association FIFUR (https://fifur.fi/en) are used as an estimate for the annual number of fur-bearing animals.

The number of reindeer is taken from the Yearbook of Farm Statistics or the E-Yearbook of Food and Natural Resource Statistics, or, for the years 2020 onwards, obtained directly from Luke Statistical Services. It describes the number of reindeer left alive at annual round-up.

Table 5.2-3 Source of data for animal numbers

Group	Data received	References
Cattle	1 May/1 June	Yearbook of Farm Statistics, 2015 onwards Luke statistics database
Swine*	1 April/1 May/1 June; 1 December	Yearbook of Farm Statistics, 2015-2020 Luke statistics, 2021 onwards Eurostats statistics; subgroups for years 1990-1994: average distribution in 1995-2005 (spring); spring numbers include all piggeries, December numbers are from a sample query
sows	1 April/1 May/1 June; 1 December	1995-2006 spring numbers; 2007 onwards from December
piglets	spring (modified); 1 December	1990-2006 modified spring numbers; 2007 onwards from December
boars	1 April/1 May/1 June; 1 December	1995-2006 spring numbers; 2007 onwards from December
veaned pigs	spring (modified); 1 December	1990-2006 modified spring numbers; 2007 onwards from December
fattening pigs	spring (modified); 1 December	1990-2006 modified spring numbers; 2007 onwards from December
Poultry	1 April/1 May	Yearbook of Farm Statistics, 2015 onwards Luke statistics database
Horses	31 December	Finnish Trotting and Breeding Association
Sheep	1 May/1 June	Yearbook of Farm Statistics, 2015 onwards Luke statistics database
Goats	1 May/1 June	Yearbook of Farm Statistics, 2015 onwards Luke statistics database
Reindeer	reindeer left alive at round-up	Yearbook of Farm Statistics/Luke Statistical Services
Fur animals	annual cub production	the Finnish Fur Breeders' Association

*Swine: see details in text 5.2.2.2

5.2.2.3 Emission factors and other parameters

Emission factors for methane emissions from enteric fermentation are presented in Table 5.2-5. Annual cattle, swine and sheep emission factors are calculated for the inventory year in question.

Cattle

Country-specific emission factors for cattle, categorized into the subgroups of dairy cows, suckler cows, bulls, heifers and calves, were calculated with the Tier 2 method for cattle by using country-specific GE estimates in the Equation 10.21 of 2006 IPCC Guidelines. The calculation of GE requires data on animal weights, average daily weight gains, milk production per dairy cow and suckler cow, pregnancy and digestible energy of forage. This information is sourced from agricultural statistics and registries, and, where necessary, further processed by an expert from Luke (Vattulainen, J.). The calculation uses the same feed data (Table 5.3-5) as the calculation of N excretion in Section 5.3, Manure management (CRF 3.B). The IPCC 2006 default CH_4 conversion factor Y_m is used for all cattle, but the emission for calves is estimated based on the GE without the period during which calves are fed with milk and assumed not to emit methane.

The emission factors have shown an increasing trend in the time series since the early 1990s due to increases in GE. For example, the GE for dairy cows increased from the 258 MJ/animal/day in 1990 to 371 MJ/animal/day in 2022, resulting in an increase in the emission factor from 110 kg CH_4/animal/a in 1990 to 158 kg CH_4/animal/a in 2022 (Figure 5.2-1).

Typical feeding for each cattle subgroup, including dairy cows, bulls, heifers and calves is based on feed consumption data from Pro Agria (Rural advisory services) and expert judgements. For dairy cattle, detailed production surveillance cattle feeding data obtained from Pro Agria are utilised. This data are available since 2010 and covers circa 80% of Finnish cattle. For the years 1990–2010, feeding is a combination of the oldest production surveillance data from Pro Agria and feeding recommendations (Luke 2023). The weighting of feeding recommendations increases as we move backward in the time series, such that the 1990 is solely based on feeding recommendations. For non-dairy cows, typical feeding is derived from expert evaluations and nutrient requirements (Luke 2023), and the chemical compositions of fodder are derived from the national feed tables (Luke 2023). Diet's GE content is calculated from the feed composition based on the equation by Jentsch et al. (2003).

$$GE,\ MJ/\ kg\ DM = 0.0236 \times CP + 0.0398 \times CF + 0.0189 \times NDF + 0.0173 \times NSC,$$

where CP is crude protein, CF crude fat, NDF fiber and NSC non-soluble carbohydrates in the diet (g/kg DM).

Energy digestibility (DE, expressed as % of GE) represents the proportion of feed energy (%) not excreted with faeces. A distinct DE value has been calculated for each cattle group for each year to reflect changes in animal feed. It was calculated using the empirically derived formula by Ramin & Huhtanen (2013).

$$\text{Energy digestibility (g/kg)} = -11.3 + 0.977 \times \text{organic matter digestibility.}$$

The live weights of cattle are estimated based on slaughter weights and ages derived from the Finnish Food Safety Authority Evira/Finnish Food Authority (2001–2022), as described in Nousiainen et al. (2023). The slaughter weights are converted to live weights using McKiernan et al. (2007) dressing percentage estimates. Richards's equation (DeNise and Brinks 1985 for beef cattle, Perotto et al. 1992 for dairy cattle) is used for calculating the mature weight for dairy cows and suckler cows. The figure for bulls is 1.5 times dairy cow mature weight, while the mature weight of heifers and calves is based on the weighted average of dairy and suckler cows and bulls.

Cattle live weights and mature weights are presented in Table 2 in Appendix 5a (Source: Vattulainen, J., activity data for weights received from the Cattle Register).

The amount of milk produced per dairy cow and the fat content of milk are given in Table 5.2-6. Data on milk production (litre/animal/a) and fat content are obtained from the Yearbook of Farm Statistics or from the Statistics database of Luke. The specific gravity value of 1.030 kg/litre is used to express the amount of milk produced as kg/animal/a for the whole time series. The milk production of suckler cows is estimated to remain constant at 1,452 kg/a (Source: Nousiainen, J.).

Swine

The country-specific EFs for swine are calculated for the subgroups of sows, piglets, fattening pigs, boars and weaned pigs based on their feed uptake. The Evapig-based calculation method (Evapig 2008, p. 13) is laborious to use for the entire time series, therefore a ratio was developed which links the methane amount (by Evapig) to the energy consumption in feed units. The energy content of one feed unit is 9.3 MJ, equivalent to the energy content of 60 hectolitres of barley having a dry matter content of 86% (MTT 2006). Both the chemical composition and methane amount were available in 13 typical pig feed mixtures. The formulas are (J. Nousiainen):

- Methane E/ Feed units = (Age factor + 0.02997 * crude fiber (%) + interaction * crude fiber (%))
- Age factors: growing pigs 0.004479, adult pigs 0.01075
- Interaction (age*cfib): growing pigs −0.01748, adult pigs 0.000

Therefore, when the feed unit consumption is known, the methane energy (MJ/year) can be obtained by multiplying consumption with the ratio, and methane (kg/year) is calculated by dividing the methane energy by the methane energy value (55.65).

Reindeer

The emission factors for sheep and reindeer are calculated according to Equation 10.21 in the 2006 IPCC Guidelines (page 10.31) and gross energy according to the following equation (McDonald et al. 2011 p. 417):

$$GE\left(\frac{MJ}{kg}\right) = 0.0226 * CP + 0.0407 * EE + 0.0192 * CF + 0.0177 * NFE$$

where CP is crude protein, EE is ether extract, CF is crude fibre and NFE is nitrogen free extracts (CP, EE, CF and NFE are expressed as g/kg, the constants as MJ/g).

The reindeer are estimated (Nieminen et al., 1998) to feed on lichen in winter (215 days) and hay in summer (150 days). The energy consumed by each male reindeer is estimated to be 420 feed units hay and 409 feed units lichen, the energy consumed by each female reindeer 420 feed units hay and 366 feed units lichen. The feed units are converted to dry matter by dividing them by 0.8 feed unit/kg dm, based on energy-to-mass ratios of hay (Tuori et al 2002) and lichen (Salo et al 1990). The GE is calculated separately for hay and lichen. For hay, CP=120, EE=25, CF=360 and NFE=420 (MTT 2004). For lichen CP=30, EE=20, CF=350 and NFE=580 (Salo et al 1990). For male and female reindeer, the GE (MJ/animal/day) is calculated as follows: ((GE (MJ/kg) for lichen * kg dm lichen+ GE (MJ/kg) for hay * kg dm hay)/365 days. The EF for both animal types is calculated with Equation 10.21 in the 2006 IPCC Guidelines (page 10.31). Y_m is 6%. The EF is an average of male and female reindeer: 19.9 kg CH_4/animal/a.

Sheep

The emission factor for average sheep is calculated annually on the basis of forage consumption and the number of animals in different sheep categories. IPCC default values (2006 IPCC Guidelines, Table 10.13) are used for Y_m. Lambs younger than 2 months are assumed not to emit methane.

The intensity of sheep production systems in Finland varies considerably, and the number and weights of sheep fluctuate seasonally. The variation and fluctuation are considered in the calculation method. The data on feed consumption and content, sheep numbers, and slaughter weights are the same as those used in the calculation of the nitrogen excretion of sheep for the emissions from sheep manure.

Forage consumption and feed content data for different kinds of sheep production systems is derived from Pro Agria advisory service (Pro Agria 2022). The same forage consumption is used for the entire time series. Pasturing time is set to 33 per cent. Sheep numbers are derived from the Finnish Food Authority (2022) from four points along the calendar year and altogether nine sheep categories based on age, sex and reproductive status. Slaughter weights for ewes and slaughter lambs in different kinds of production systems are derived from the Finnish Food Authority (2022). The weights of sheep in other categories are derived from ewe weights based on Muir et al. (2008): using the dressing percentage of 0.39 for ewes and a mature weight coefficient of 1.2 for rams relative to ewes. Growth curves for slaughter sheep are calculated with a dressing percentage of 0.44 for meat breeds and 0.42 for native breeds (Friggens et al. 1997).

The detailed sheep number and slaughter weight data are available only from the year 2010 onwards. For the year 1990 to 2009 the sheep weights and growth are calculated based on ewe numbers and ewe slaughter weights, using the ratio of different sheep categories in 2010-2022 to ewe numbers and weights. For the years 1990 to 1995, the source data is so low in quality that average values are used.

Horses and goats

IPCC default emission factors are used for calculating methane emissions from enteric fermentation of goats and horses (Tier 1 method). As no separate EF is available for ponies, the same EF is used as for horses.

Fur-bearing animals

The EF for fur-bearing animals is based on the country-specific EF for piglets weighted by a ratio of average live weights of fur-bearing animals and piglets. The digestive systems of swine and fur-bearing animals are similar i.e., both are monogastric animals. The country-specific EF for piglets is scaled using the ratio of the weights (fur-bearing animals/piglets) raised to the 0.75 power to obtain the EF for fur-bearing animals in accordance with the guidance in the 2006 IPCC Guidelines, Vol. 4-2, Section 10.2.4. This results in an EF of 0.07 kg of methane per animal per year. No IPCC default EF exists for fur-bearing animals.

Table 5.2-4 Animal numbers in Finland (x 1,000)

	Cattle		Sheep	Swine[4]	Other livestock				
	DC	NDC[1]			P[5]	Ho[2]	G[3]	F[6]	R
1990	490	870	103	1 339	9 663	45.4	5.9	3 346	239
1995	399	749	159	1 356	10 358	49.9	6.0	3 981	208
2000	364	692	100	1 257	12 570	57.4	8.6	3 806	203
2005	319	640	90	1 360	10 538	63.8	6.9	4 108	207
2010	289	636	126	1 340	9 587	74.3	4.9	3 597	194
2013	283	629	136	1 258	11 981	75.0	4.5	4 186	192
2014	285	629	138	1 223	12 577	74.6	4.4	4 537	187
2015	285	630	155	1 239	12 927	74.2	4.5	4 696	191
2016	282	627	156	1 197	13 445	74.2	4.8	3 788	191
2017	275	618	156	1 108	13 136	74.4	5.3	3 730	193
2018	271	611	155	1 041	14 140	74.4	5.4	3 460	185
2019	262	595	145	1 062	14 360	74.3	5.9	3 102	188
2020	260	587	140	1 104	13 577	74.0	6.0	2 181	195
2021	254	591	131	1 094	13 832	74.0	5.9	2 044	182
2022	248	586	132	998	14 356	72.0	6.3	1 311	185

DC=Dairy cattle, NDC=Non-dairy cattle (Suckler cows, Bulls, Heifers, Calves), P=Poultry, Ho=Horses (incl. Ponies), G=Goats, F=Fur-bearing animals, R=Reindeer.

[1] Includes suckler cows, bulls (>1 year), heifers and calves (<1 year). The number presented describes the numbers on 1 May or 1 June (Sources: Statistics database of Natural Resources Institute Finland, Yearbook of Farm Statistics).

[2] Source: Finnish Trotting and Breeding Association (Suomen Hippos).

[3] The number of goats was not available for the year 1991, and the average of numbers for the years 1990 and 1992 was used.

[4] see details for swine in Chapter 5.2.2.2

[5] Includes laying hens, chickens, cockerels, broiler hens, broilers, turkeys and other poultry. The number of broilers, cockerels, turkeys and other poultry for 1991-1994 was not available, data obtained by linear interpolation. The number of broiler hens was not available for 1990-1994, data obtained by linear extrapolation. Data for turkeys and other poultry for 1996 were not available; the average for 1995 and 1997 was used.

[6] Includes minks, fitches, foxes and racoons. Describes the number of produced cubs, see details in Section 5.2.2.2.

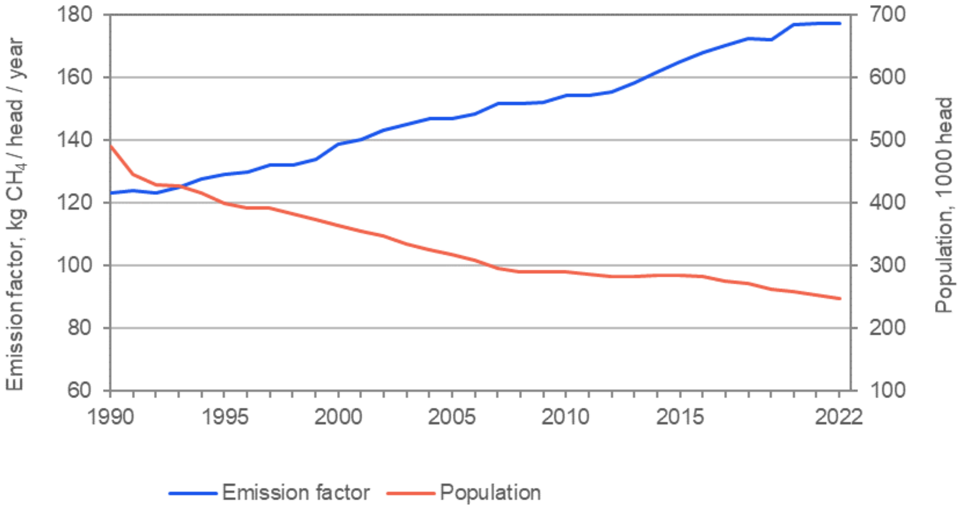


Figure 5.2-1 Development of the emission factor and population of dairy cows

Table 5.2-5 Emission factors for methane emissions from enteric fermentation in 2022

	Animal type	Emission factor (kg CH_4 / animal/a)	EF type	Method for calculating EF
Cattle	Dairy cow	158.1	Country-specific	IPCC, Tier 2
	Non-dairy cattle IEF	53.3	Country-specific	IPCC, Tier 2
	Suckler	79.6	Country-specific	IPCC, Tier 2
	Bulls	70.6	Country-specific	IPCC, Tier 2
	Heifers	65.5	Country-specific	IPCC, Tier 2
	Calves	35.0	Country-specific	IPCC, Tier 2
Sheep		8.6	Country-specific	Country-specific
Swine	Sows	3.8	Country-specific	Country-specific
	Piglets	0.1	Country-specific	Country-specific
	Fattening pigs (>50 kg)	1.3	Country-specific	Country-specific
	Boars	3.5	Country-specific	Country-specific
	Weaned pigs (20-50 kg)	0.6	Country-specific	Country-specific
	Swine average IEF	1.0	Country-specific	Country-specific
Other	Horses	18	IPCC default	IPCC, Tier 1
	Goats	5	IPCC default	IPCC, Tier 1
	Fur animals	0.07	OTH	IPCC, OTH
	Reindeer	19.9	Country-specific	Country-specific

Table 5.2-6 Data of milk properties used for calculating methane emissions from enteric fermentation

Year	Fat content of milk[1] (%)	Milk production / dairy cow[2] (kg/a)
1990	4.35	5 713
1995	4.34	6 161
2000	4.23	6 990
2005	4.16	7 730
2010	4.26	8 133
2013	4.28	8 216
2014	4.28	8 447
2015	4.31	8 573
2016	4.32	8 658
2017	4.35	8 790
2018	4.34	8 910
2019	4.39	9 074
2020	4.39	9 309
2021	4.42	9 167
2022	4.40	9 155

[1] Source: Statistics database of Natural Resources Institute (Luke) Finland. Assumed to be the same for dairy cows and suckler cows.

[2] Sources: Yearbook of Farm Statistics, Statistics database of Natural Resources Institute Finland (Luke). The specific gravity value of 1.03 was used to convert l/animal/a to kg/animal/a.

5.2.3 Uncertainty assessment and time series' consistency

Quantitative estimates of uncertainty are provided in Annex 2. A description of the uncertainty analysis is included in Section 1.6.

The uncertainties in emissions from enteric fermentation are estimated by applying the Tier 2 Monte Carlo simulation directly to the LUKEagri emission calculation model. Uncertainty estimates of animal numbers were based on knowledge of the reliability and coverage of the data collection. For example, cattle have individual earmarks that enable very accurate assessment of animal numbers (uncertainty of ±3%) but the uncertainty in animal numbers for other species in farms is higher (±5%). The uncertainty in animal numbers is estimated to be the highest for reindeer (±10%). Also, other factors, for example, uncertainty in cattle weights and in weight gain affect uncertainty.

The uncertainty in the Tier 2 method for evaluating emissions from enteric fermentation of cattle was assessed by estimating uncertainty in each calculation parameter and combining uncertainties using the Monte Carlo simulation. Uncertainty in animal weight, weight gain, GE, DE, milk production and fat content of milk for each cattle subgroup was estimated utilising knowledge of the deviation in diet composition, weights of the animal population and in milk production. Information on measurement instruments reflecting a possible systematic error was also used. The most important parameter affecting the uncertainty was the methane conversion rate (Y_m)for which the uncertainty from the 2006 IPCC Guidelines was used. . For goats and horses, the default EF uncertainties of ±30% and ±50% were used, respectively. For the national EFs of swine, reindeer and sheep, the uncertainties are estimated to be ±10%, -90...+250% and ±40%, respectively. For fur-bearing animals, the EF is modified from the one used for piglets, and its uncertainty is estimated to be -70...+150%.

As the same calculation methods are used for the whole time series 1990 to 2022, the time series can be considered consistent. However, for some years, animal numbers have not been available (for example the number of goats in 1991 and the number of broilers in 1991, 1992, 1993, 1994), so linear interpolation of the data from adjacent years has been used to obtain the data. The animal numbers of some animal groups are obtained from different months in spring. These changes in the date of statistics data are not discernible in the animal number graphs suggesting that they do not create inconsistency. Numbers of swine are from spring (modified) or December (see Section 5.2.2.2 for details). Animal numbers in different swine subgroups obtained from the spring data (1990 to 2014; previous figures, all piggeries) do not differ markedly from the animal numbers of modified spring data (1990 to 2006; adjusted to represent the animal numbers in December) nor from the data of December (2007 onwards; a sample of piggeries). The difference is about 10% (from 4% to 16%). Temporal trends in the previously used and contemporary swine number time series are similar. Therefore, it can be considered that time series for swine numbers are consistent.

5.2.4 Category-specific QA/QC and verification

The quality objectives and the QA/QC plan for the Finnish greenhouse gas inventory at the national inventory level are presented in Section 1.5. The QC procedures are performed according to the QA/QC plan in order to attain these quality objectives. A bilateral quality meeting is held annually between the inventory unit and the sectoral expert. In the 2024 quality meeting we discussed about the changes for 2022 inventory (e.g. revision of cattle diet data, GE and DE calculations) and also a review feedback and future development plans regarding updates for country-specific poultry and swine feeding and excretion calculations.

Quality Control (QC) procedures applied to the category Enteric fermentation (CRF 3.A):

The QA/QC plan for the agricultural sector includes the QC measures presented in the 2006 IPCC Guidelines (Vol 1, Chapter 6, Table 6.1). These measures are implemented every year during preparation of the agricultural inventory. If errors or inconsistencies are found, they are documented and corrected. The QC checklist (LUKEagri check) is used during the inventory. The check includes, for example, checking of formulas, links between sheets and evaluating correctness of parameters used with cross-checks to previous years.

A checklist (LUKEagri check) is used for ensuring consistency of the activity data in different sections of the agricultural inventory. The checklist is a list of the activity data with a column for marking the result of the check. Graphs are used to compare animal numbers with previous years. With respect to the quality of the data collection, Luke Statistical Services which provides data of animal numbers, has a description of the data collection process. Part of this description is in English on page: http://stat.luke.fi/en/tilasto/163/kuvaus/1016. A more detailed description is provided in Finnish on page: http://stat.luke.fi/tilasto/36/laatuseloste/3921.

Quality assurance and verification:

Every year we check the availability of new data for updating the emission factors. When new research results are published, the current emission factors are reconsidered. For 2022 inventory (2024 submission), the enteric fermentation emissions of cattle were revised. This revision was prompted by the adoption of a country-specific gross energy (GE) calculation method, which involved utilizing detailed feeding data from ProAgria (Rural advisory services) based on the feeding of the production surveillance cattle. As a result, the entire time series 1990-2022 was renewed. See Section 5.5.2.

Formulas and cell references used in Lukeagri calculation sheets have been regularly reviewed, compared with the 2006 IPCC Guidelines and updated by researchers working in the inventory as necessary. The 2022 submissions calculations have been compiled by researchers in the inventory T. Silfver and X. Tarpio.

Luke has a steering group that monitors the scientific quality of the greenhouse gas inventory concerning Agriculture and LULUCF. Improvements to the agricultural inventory are made wherever is possible and in accordance with the recommendations/suggestions of the UNFCC Expert Review teams and the EU Technical Expert Review teams, which are responsible for reviewing the inventory. Also, a meeting among Nordic sector experts is organized annually, where the countries compare their calculation methods and emission factors.

5.2.5 Category-specific recalculations

As a result of the adoption of a country-specific cattle gross energy (GE) calculation method (see Section 5.2.2.3 for further details), the emissions from cattle were recalculated for the entire series from 1990 to 2021. Also, a new methane emission factor (EF) value for calves was calculated based on the assumption that calves do not emit methane during the period when fed with milk. These updates lead to a slight increase in enteric fermentation emissions from cattle only during the first year of the time series (+3 kt CO_2 eq. in 1990), followed by a decrease towards the end of the time series, with the largest reduction being -127 kt CO_2 eq. in 2010. Overall, the updates resulted in a decrease in total enteric emissions by around 3% throughout the entire time series, representing an average decrease of 71 kt CO_2 eq. in enteric emissions (-79 kt CO_2 eq. in 2021).

5.2.6 Category-specific planned improvements

We will re-examine and update swine and poultry diet data and excretion calculations for the 2025-2026 submissions based on the results from a recent project on swine and poultry excretion.

5.3 Manure Management (CRF 3.B)

5.3.1 Category description

In 2022, emissions from manure management were 0.6 kt N_2O and 16.2 kt CH_4 in total 0.7 Mt CO_2 equivalents. Nitrous oxide emissions from manure management were 4% and methane emissions 7% of total emissions in the Agriculture sector in 2022.

This emission source covers manure management of domestic livestock. Finland reports both nitrous oxide (N_2O) and methane (CH_4) emissions from manure management of cattle (including dairy cows, suckler cows, heifers, bulls and calves), swine (including fattening pigs, weaned pigs (20 to 50 kg), boars, sows and piglets), horses, goats, sheep and poultry. Emissions from the manure of reindeer and fur-bearing animals are also included (Table 5.3-1). There are no emissions from manure management originating from the following livestock groups: buffalo, camels and llamas, deer, mules and asses, rabbits and ostrich.

Table 5.3-1 Reported emissions according to the classification of the CRF tables, calculation methods and types of emission factors for the subcategory CRF 3.B Manure Management in the Finnish inventory.

CRF	Source	Emissions reported	Method	Emission factor
3.B.1	Cattle			
	Dairy Cattle	CH_4	Tier 2	CS
		N_2O	Tier 2	D
	Non-Dairy Cattle	CH_4	Tier 2	CS
		N_2O	Tier 2	D
3.B.2	Sheep	CH_4	Tier 2	CS
		N_2O	Tier 2	D
3.B.3	Swine	CH_4	Tier 2	CS
		N_2O	Tier 2	D
3.B.4	Other livestock			
	-Poultry	CH_4	Tier 2	CS
		N_2O	Tier 2	D
	-Horses	CH_4	Tier 2	CS
		N_2O	Tier 2	D
	-Goats	CH_4	Tier 2	CS
		N_2O	Tier 2	D
	-Fur-bearing animals	CH_4	Tier 2	CS
		N_2O	Tier 2	D
	-Reindeer	CH_4	Tier 2	CS
		N_2O	Tier 2	D

Source	Emissions reported	Method	Emission factor
Anaerobic lagoon	NO	NA	NO
Liquid system	N_2O	Tier 2	D
Daily spread	NO	NA	NO
Solid storage and dry lot	N_2O	Tier 2	D
Pasture, range, and paddock[1]	N_2O (3.D.3)	Tier 1	D
Composting[2]	Emissions negligible	NA	NE
Digesters[3]	Emissions negligible	NA	NE
Burned for fuel or as waste[4]	NO	NA	NO
Other [5]	N_2O	Tier 2	D

[1] Emissions from pasture are calculated under manure management but reported in the CRF subcategory 3 D.3 Agricultural soils/ Pasture, range and paddock manure.

[2] Emissions negligible, see Section 5.3.2.2, Manure management systems for details

[3] Emissions negligible, see Section 5.3.2.2, Manure management systems for details

[4] Not estimated as burning of manure is very rare

[5] Other AWMS (animal waste management system) is deep litter

Nitrous oxide is produced through the processes of nitrification and denitrification, it is a by-product of nitrification and an intermediate of denitrification (2006 IPCC Guidelines). Methane is produced in manure during decomposition of organic material by anaerobic and facultative bacteria under anaerobic conditions (Jun et al., 2002). The emissions are dependent on the amount of organic material in the manure, the manure management system and climatic conditions.

Direct nitrous oxide emissions from manure management have first decreased and then increased in the time series. Cattle numbers have decreased, which explains the decreasing trend. Nitrogen excretion figures, however, have increased over time for many animals, including cattle. The share of cattle slurry with crust has also increased over time, therefore, increasing direct emissions from slurry (see Figure 5.3-3 for the case of dairy cows). Floating covers are considered identical with natural crust in the Finnish inventory. The number of horses increased from 1990 to 2011 and that has a slight effect on the rising trend. There is a decrease of 0.1% in the 2022 direct nitrous oxide emissions compared to 1990 (Table 5.3-2 and Figure 5.3-1). The direct emission of 2022 is 0.04% smaller than in 2021. Cattle and swine numbers have decreased from 2020. Indirect nitrous oxide emissions have not fluctuated much in the time series but show a slight decrease in the most recent years (Table 5.3-3). A decline in the number of fur animals since 2018 is seen as a marked decrease in nitrous oxide emissions. Total direct and indirect nitrous oxide emissions in 2022 are 0.2% lower than in 1990 and 0.05% lower than in 2021 (Table 5.3-2, Table 5.3-3).

Methane emissions from manure management have increased by 7% since 1990 (Table 5.3-4). This is due to an increase in the number of animals kept in slurry-based systems (see Figure 5.3-3 for the case of dairy cows and Figure 5.3-4 for swine). Slurry-based systems increase methane emissions per animal compared with solid storage or pasture. The emission in 2022 was 6% smaller than in 2021 mostly due to the decline in cattle and swine numbers.

Total emissions from manure management have decreased by 2% between 1990 and 2022. The fluctuation in the emissions from manure management is related to both changes in animal numbers, which are largely dependent on agricultural policy, and to changes in the distribution of the manure management systems. In 2022 the emissions were 5.4% lower than in 2021. N_2O emissions decreased by 5.3% and CH_4 emissions by 5.5%.

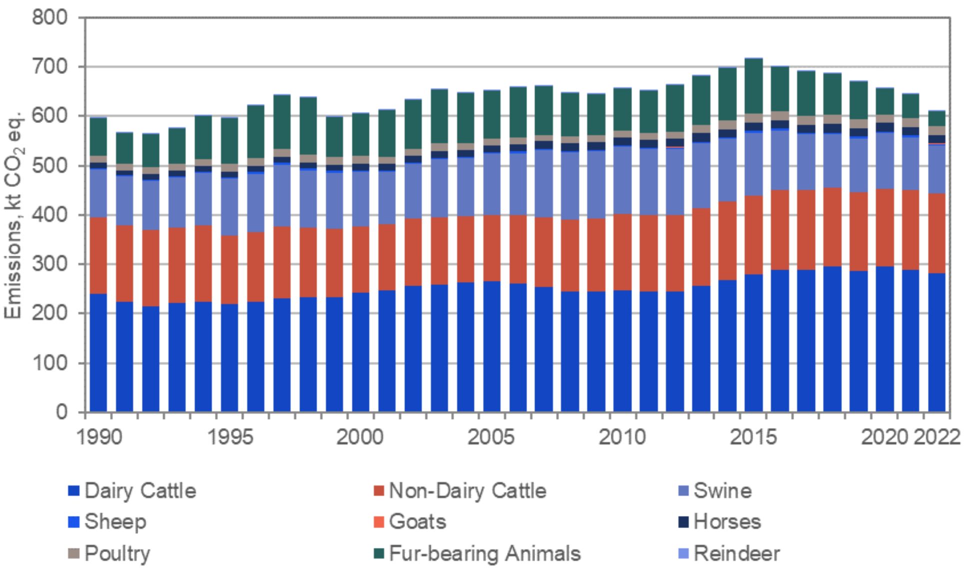


Figure 5.3-1 Emissions of manure management by animal type, kt CO_2 eq.

Table 5.3-2 Direct nitrous oxide emissions (kt) from manure management by animal type (emissions from pasture not included, they are reported under CRF 3.D Agricultural soils/Pasture, range and paddock manure)

Year	Cattle					Sheep	Swine	Other livestock					Total
	DC	SC	B	H	C			P	Ho	G	F	R	
1990	0.25	0.01	0.06	0.05	0.11	0.01	0.09	0.03	0.03	0.0006	0.04	NO	0.67
1995	0.21	0.02	0.04	0.04	0.08	0.01	0.06	0.03	0.03	0.0007	0.06	NO	0.57
2000	0.20	0.02	0.04	0.04	0.07	0.01	0.06	0.02	0.04	0.0009	0.05	NO	0.55
2005	0.16	0.02	0.05	0.04	0.07	0.01	0.06	0.02	0.04	0.0008	0.07	NO	0.53
2010	0.20	0.03	0.06	0.05	0.09	0.01	0.05	0.02	0.04	0.0004	0.06	NO	0.60
2013	0.22	0.04	0.05	0.06	0.09	0.01	0.04	0.02	0.05	0.0004	0.07	NO	0.65
2014	0.23	0.04	0.05	0.06	0.09	0.01	0.04	0.02	0.05	0.0004	0.08	NO	0.66
2015	0.23	0.04	0.06	0.06	0.10	0.01	0.04	0.02	0.05	0.0004	0.09	NO	0.68
2016	0.23	0.04	0.05	0.05	0.10	0.01	0.04	0.02	0.05	0.0004	0.07	NO	0.66
2017	0.23	0.04	0.06	0.05	0.09	0.01	0.04	0.02	0.05	0.0004	0.07	NO	0.66
2018	0.23	0.04	0.05	0.05	0.09	0.01	0.04	0.02	0.05	0.0004	0.06	NO	0.65
2019	0.23	0.04	0.05	0.05	0.09	0.01	0.04	0.02	0.05	0.0005	0.06	NO	0.65
2020	0.24	0.04	0.05	0.05	0.10	0.01	0.04	0.02	0.05	0.0005	0.04	NO	0.64
2021	0.24	0.04	0.05	0.05	0.10	0.01	0.04	0.02	0.05	0.0005	0.04	NO	0.63
2022	0.23	0.04	0.05	0.05	0.09	0.01	0.03	0.02	0.05	0.0005	0.02	NO	0.60
Share of total (%) in 2022	38.0	7.1	8.7	8.7	15.3	1.3	5.4	3.7	7.6	0.1	3.9		100.0

The sum of the shares may differ from 100 due to rounding. DC=Dairy cows, SC=Suckler cows, B=Bulls, H=Heifers, C=Calves, P=Poultry, Ho=Horses&Ponies, G=Goats, F=Fur animals, R=Reindeer

Table 5.3-3 Indirect N_2O emissions from manure management (kt)

Year	Indirect N_2O emissions
1990	0.35
1995	0.32
2000	0.32
2005	0.32
2010	0.30
2013	0.31
2014	0.31
2015	0.32
2016	0.30
2017	0.30
2018	0.29
2019	0.28
2020	0.27
2021	0.26
2022	0.24

Table 5.3-4 Methane emissions from manure management by animal type (kt)

Year	Cattle					Sheep	Swine	Other livestock					Total
	DC	SC	B	H	C			P	Ho	G	F	R	
1990	6.19	0.08	0.92	0.89	1.50	0.02	2.70	0.28	0.10	0.001	2.29	0.09	15.07
1995	5.85	0.15	0.82	0.89	1.41	0.03	3.53	0.32	0.10	0.001	2.73	0.08	15.91
2000	6.79	0.20	0.87	0.89	1.24	0.02	3.33	0.35	0.11	0.001	2.61	0.07	16.49
2005	7.98	0.28	0.87	0.83	1.15	0.02	3.86	0.31	0.14	0.001	2.81	0.08	18.32
2010	6.98	0.29	1.06	0.98	1.02	0.03	4.40	0.32	0.16	0.001	2.46	0.07	17.77
2013	7.09	0.25	1.01	1.07	1.01	0.03	4.34	0.39	0.16	0.001	2.87	0.07	18.28
2014	7.39	0.25	1.03	1.09	1.04	0.03	4.17	0.41	0.16	0.001	3.11	0.07	18.76
2015	7.79	0.26	1.04	1.09	1.06	0.04	4.16	0.41	0.16	0.001	3.22	0.07	19.29
2016	8.14	0.26	1.03	1.07	1.08	0.04	3.99	0.42	0.16	0.001	2.59	0.07	18.87
2017	8.12	0.27	1.06	1.09	1.05	0.04	3.69	0.42	0.16	0.001	2.55	0.07	18.53
2018	8.34	0.27	1.03	1.08	1.07	0.04	3.53	0.45	0.16	0.001	2.37	0.07	18.40
2019	8.00	0.27	1.03	1.08	1.05	0.04	3.60	0.45	0.16	0.001	2.12	0.07	17.87
2020	8.24	0.29	0.98	1.07	1.07	0.03	3.66	0.43	0.16	0.001	1.49	0.07	17.50
2021	8.11	0.30	1.01	1.08	1.07	0.03	3.47	0.43	0.16	0.001	1.40	0.07	17.13
2022	7.94	0.30	1.02	1.08	1.04	0.03	3.21	0.45	0.15	0.001	0.90	0.07	16.19
Share of total (%) in 2022	49.0	1.9	6.3	6.7	6.4	0.2	19.8	2.8	1.0	0.0	5.5	0.4	100.0

The sum of the shares may differ from 100 due to rounding. DC=Dairy cows, SC=Suckler cows, B=Bulls, H=Heifers, C=Calves, P=Poultry, Ho=Horses&Ponies, G=Goats, F=Fur animals, R=Reindeer

5.3.2 Methodological issues

5.3.2.1 Methods

Nitrous oxide

Direct N_2O emissions from manure management and the indirect N_2O emissions that result from the volatilization of ammonia and nitrogen oxide in manure management are calculated using the *Nitrogen mass flow model* (Grönroos et al. 2009, https://helda.helsinki.fi/handle/10138/38030). Leaching from manure management is calculated separately.

The Nitrogen mass flow model (Grönroos et al. 2009) integrates all ammonia and nitrous oxide emissions from manure in the same calculation model. For manure storage, NO-N and N_2 losses are also estimated. The Nitrogen mass flow model calculates emissions in each phase of the manure management chain: from N excreted from animals to animal shelter to manure storage to application on fields or deposition on pastures (Figure 5.3-2). The model takes into account NH_3 abatement techniques (such as storage covers) and manure spreading techniques in the respective phases of the manure management chain. Emissions from the application of manure and synthetic fertilisers on fields are addressed in Section 5.5, Agricultural soils. A description of nitrogen flows concerning the year 2021 is presented in Figure 5.1-4 and in Appendix_5b.

The Nitrogen mass flow model was originally developed for the Finnish air pollutant inventory under the UNECE Convention on Long-range Transboundary Air Pollution, but it has subsequently been adopted to the use of the greenhouse gas inventory as well. Using the same model for the greenhouse gas and air pollutant inventories ensures the transparency of the calculations and the consistency of activity data and parameters between the two inventories. The greenhouse gas inventory uses the 2009 model version updated with more recent data on manure management systems (Grönroos 2014), data on bedding use (M. Hellstedt 2016) and the newest EFs for nitric oxide and dinitrogen volatilization from manure (EMEP/EEA 2016).

In calculating the direct nitrous oxide emissions from manure management (CRF 3.B), the Nitrogen mass flow model follows the IPCC methodology (2006 IPCC Guidelines, Eq. 10.25). Nitrogen excretion of each animal category, calculated by Luke (see Section 5.3.2.2), is distributed between the manure management systems: slurry, solid storage, deep litter and dry lot. Slurry is further divided into slurry with natural/floating cover and no natural/floating cover. Solid storage is further divided into dung and urine mixed and dung and urine separated. The share of urine nitrogen in manure is estimated to be 55%, based on cattle manure qualities. Dry lot is used as a category for cattle and horses only. The distribution of manure into management systems is country-specific data, based on survey results and expert judgement (Grönroos 2014, see 'Manure management systems' under Section 5.3.2.2). The distribution changes over the time series. The amount of nitrogen entering each manure management system is multiplied with the IPCC's system-specific default emission factor. The emission factors used are presented in Table 5.3-6.

In calculating the indirect N_2O emissions from volatilization in manure management, the Nitrogen mass flow model estimates the volatilization of ammonia, dinitrogen and nitrogen oxide in each phase of the manure management chain: animal shelter, storage filling, storage, and manure application. The emissions from manure application are addressed in Section 5.5, Agricultural soils. Dry lot volatilization (4.4% of nitrogen) is added to the amount volatilized during manure management.

In total, ca. 20% of manure nitrogen volatilizes as NH_3-N and NO-N during manure management ($Frac_{GASMS}$), and 3% to 4% as N_2. The losses of nitrogen as N_2 during storage are relatively low, owing to the large proportion of manure being separated into urine and dung in solid storage MMS. Nitrous oxide emissions are calculated from the volatilized nitrogen using the IPCC methodology and default emission factors (2006 IPCC Guidelines, Eq. 10.27, Table 11.3).

Leaching is calculated using 2019 Refinement to the 2006 IPCC Guidelines, default emission factor (Table 11.3). Only leaching from dry lots is estimated for manure management systems, other systems are considered liquid tight as required by the Finnish environmental legislation (Ministry of the Environment 2021:17 Guidelines for environmental protection in animal husbandry).

Methane

Methane emissions from manure management are calculated in the same generic way as emissions from enteric fermentation, i.e. by multiplying the number of the animals in each category with the emission factor for each category (2006 IPCC Guidelines, Eq. 10.22 on page 10.37). In Finland, the Tier 2 method is used for all animal categories, which has required the development of national emission factors based on detailed data on animal characteristics and manure management systems. The emission factor for each cattle subcategory has been calculated according to Equation 10.23 in the 2006 IPCC Guidelines (page 10.41).

5.3.2.2 Activity data

Animal numbers

Animal categories included in the Nitrogen mass flow model are the same as for enteric fermentation (cattle, swine, sheep, horses, goats, fur-bearing animals and reindeer) and also poultry is included.

Animal numbers used for calculating nitrous oxide and methane emissions from manure management are otherwise the same as those used for calculating methane emissions from enteric fermentation except for the number of sows and piglets in the calculations of N_2O emissions from manure management. To avoid double counting the number of piglets is not taken into account but N excretion for sows and piglets is calculated for the single “sows and piglets” unit.

Nitrogen excretion per animal

Annual nitrogen excretion per animal has been calculated by an animal nutrition expert in Luke (Vattulainen, J.) (Appendix_5a). The values of animal-specific nitrogen excretion rates were based on nutrient balance calculations. N excretion for different animal classes is calculated as N intake minus N in growth and output (e.g. milk/eggs/calf). Feed consumption data and nutrient requirements are used in calculating the nitrogen intake (Table 5.3-5). The nitrogen content of feed is estimated either per dry matter or per energy unit. The ratio of digestible protein to total protein is calculated based on several feed mixtures. For example, for growing cattle, growth curves are utilised to obtain the energy need from feed and then the nitrogen content in feed is estimated from feed consumption data (per energy unit).

The reason for the increasing trend in N excretion rates is the increased production level of animals (e.g., amount of milk per cow, for example) demanding higher nitrogen intake. Thus, nitrogen excretion has increased even though N utilisation has improved. Nitrogen utilisation has been incorporated into the calculations via feeding recommendations. The reasons for improved utilisation are e.g., selective breeding (fodder for production: fodder for maintenance -ratio has improved) and specified feeding (protein content of feed has declined for some animals due to addition of pure amino acids).

For all animal groups, excluding horses and fur-bearing animals, the main sources of information are the agricultural statistics. The most important ones are the number of farm animals, the milk, meat and egg production and the slaughter weights. In the case of animals that live less than one year (swine, poultry), replacement of animals with new ones is taken into account in the calculations. The need to update the N excretion rates is evaluated annually in cooperation with the animal nutrition expert.

Table 5.3-5 Sources of feed data for calculating N excretion per animal. For cattle and sheep, the same data are used in the calculation of the emissions from enteric fermentation (CRF 3.A) in Section 5.2

Animal category	**Data source**	**Data provider**
Cattle	Feed tables, feeding recommendations and data	Pro Agria advisory service, https://www.Pro Agria.fi/en, Luke 2023, https://www.luke.fi/feedtables
Swine	Feed tables and protein recommendations	Luke 2023, https://www.luke.fi/feedtables
	Feed contents	Feed producers
Sheep	Forage consumption and feed content	Pro Agria advisory service
Goats	Feed tables Agricultural calendar	Pro Agria advisory service
Horses/ponies	Feed tables	Saastamoinen and Teräväinen 2007
Poultry	Feed tables Feed contents	Lohmann Tierzucht 1998, https://lohmann-breeders.com/ Feed producers
Reindeer	Guidebook on reindeer feeding	Nieminen et al. 1998
Minks, fitches, foxes and raccoon dogs	Feed tables Feed contents	http://www.profur.fi

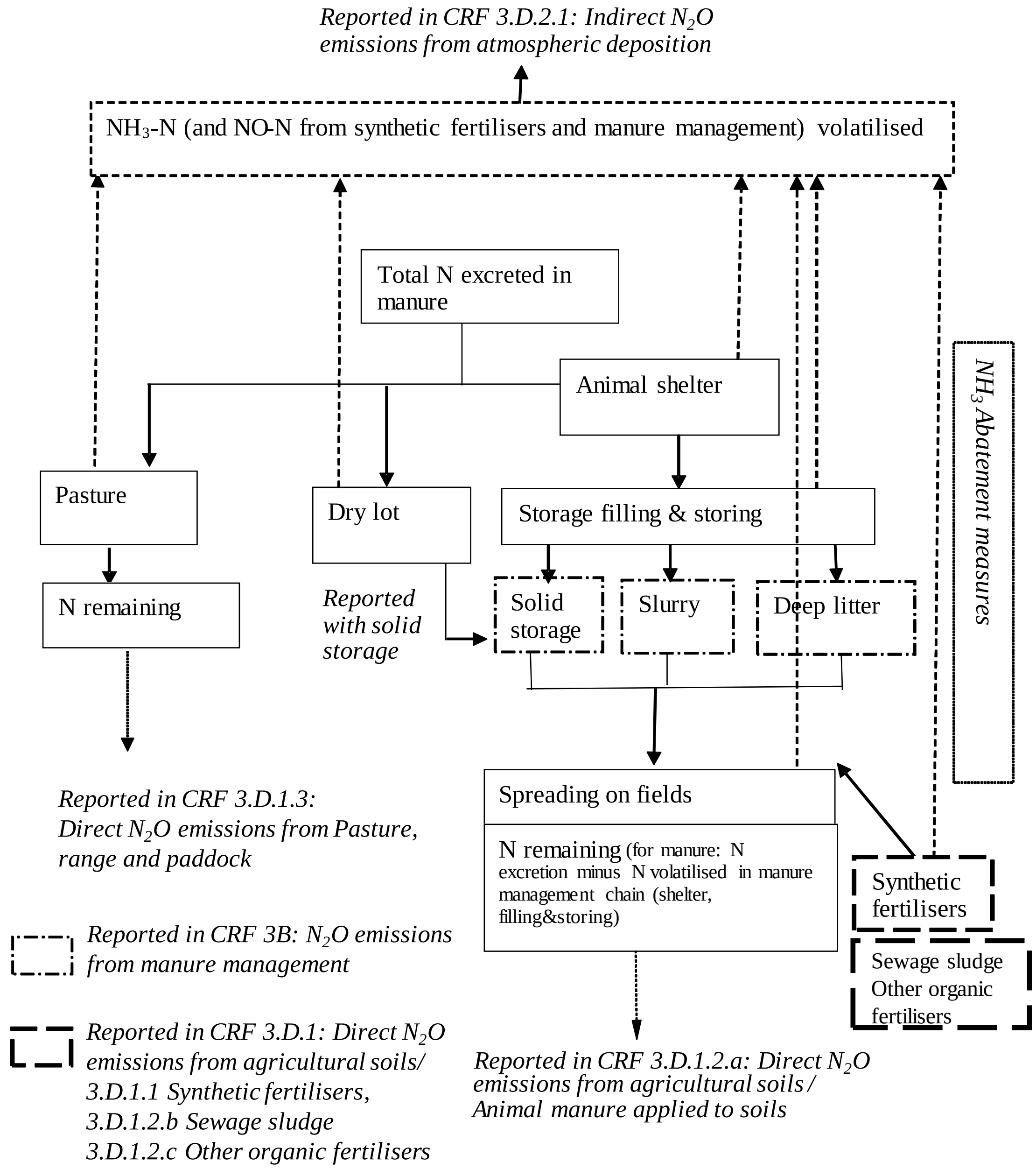


Figure 5.3-2 Distribution of manure N in the N flow model and reporting of direct and indirect N_2O emissions from manure and synthetic fertilisers. Solid arrows describe N flows and broken arrows describe volatilised N as NH_3-N (and NO_x-N in case of synthetic fertilisers and manure storing). The magnitude of N_2O emissions from each source is not presented here but in Figure 5.1-4**.** Dry lot manure remains in dry lot but is reported with solid storage

Cattle

The feed intake of dairy cows is calculated based on feed consumption data from Pro Agria (Rural advisory services) based on the feeding of the production surveillance cattle (detailed data available since 2011), as well as nutrient requirements (Luke 2023), particularly for the years 1990-2010. For non-dairy cows, feed intake is based on expert evaluations and nutrient requirements (Luke 2023). The nitrogen intake of each cattle subgroup changes over time, reflecting changes in diet.

For calves, heifers and bulls, the annual Richards’ function growth curves (DeNise and Brinks 1985 for beef cattle, Perotto et al. 1992 for dairy cattle) are first estimated from the dairy and beef cow mature weights (Nousiainen et al. 2023). Heifers are divided into slaughtered and recruitment animals. The exact ages of slaughtered animals are available from 2000 onwards; for the years before 2000 they are estimated according to the situation in 2000 and 2001. With the growth curve, the daily weight and growth values can be calculated. The energy and nutrient requirement are calculated based on these values (Luke 2023).

Swine

The values of animal category-specific nitrogen excretion rates (Nex) are based on animal feeding nutrient balance calculations. The calculation method is close to the one presented by Fernández et. al 1999. The excretion rate is obtained by subtracting the nitrogen included in animal products and growth (N retention) from the nitrogen intake (N intake) through feeding. In the balance calculations, N excretion of piglets and N excretion of farrowed sows combined is the first unit. The second unit in the calculations is N excretion of sows not farrowed (gilts). The N excretion value for sows with piglets (given in Table 3 in Appendix 5a in the NID) is derived as weighted average of N excretion of sows farrowed (including piglets) and of gilts, and the relative proportion of the number of animals in both units is obtained from the official agricultural statistics. Finally, this N excretion value of sows with piglets is multiplied with the total number of sows (which includes both types of sows, farrowed and gilts) from the official agricultural statistics.

For sows with piglets, the necessary information is obtained from agricultural statistics. For growing pigs, the calculations are based on feed conversion results of FABA breeding central station testing and the estimated difference between breeding station results and common farm conditions, as well as several feeding experiments. The nitrogen content of feed is estimated from the digestible protein recommendations. Also, feeding examples (Komulainen 1989, Kyntäjä et al. 1999 and Siljander-Rasi et al. 2006) are utilised.

Horses and ponies

For horses and ponies, the statistics of the Finnish Trotting and Breeding Association, Suomen Hippos are used. Nitrogen excretion is in most cases calculated with nitrogen balance estimation, which is similar to the methods described by Smith and Frost (2000) and Smith et al. (2000). The feed tables and feeding recommendations, later only referred to as feeding recommendations, by Salo et al. (1990), Tuori et al. (1996), Tuori et al. (2000), MTT (2004), and MTT (2006) are used. The nitrogen consumption of horses and ponies is estimated according to the feeding recommendations and feeding examples presented in Saastamoinen and Teräväinen (2007). The calculations are based on the group distribution and estimated use of horses and ponies according to the statistics of Suomen Hippos. The nitrogen excretion is the difference between nitrogen intake of horses and ponies and nitrogen amount in culled horses and ponies (about 7% of the horse and pony population) divided by the total horse population.

Sheep with lambs

Sheep nitrogen excretion is calculated by subtracting the estimated nitrogen retention for growth, lambs, wool and milk from the nitrogen intake through feeding. The nitrogen retention in wool is based on the publications by Agricultural Research Council (1980) and McDonald et al. (2011), ewe milk production on Treacher & Caja (2002). The data on feed consumption and content, sheep numbers, and slaughter weights are the same as used in the calculation of the emissions from enteric fermentation (Section 5.2.2).

Goats with gilts

The feed intake of goats was calculated according to the feeding recommendations and diet examples (Komulainen 1997). Milk production per goat was assumed as 741 kg and live weight as 50 kg.

Poultry

For poultry, nitrogen intake is estimated with feed consumption per kg of eggs, per one slaughtered or full-grown bird. The feed utilisation values were obtained from commercial poultry breeders and several Finnish feeding experiments. The nitrogen content of feed originates from commercial concentrate manufacturers and feeding recommendations. The nitrogen excretion of other poultry, which includes ducks, geese, ranched pheasants, ranched mallards, guinea fowl, quails, is estimated equal to that of laying hens.

Fur-bearing animals

For fur-bearing animals, nitrogen intake is based on the amount of feed consumed per one produced cub according to the feeding recommendations. Nitrogen content of feed is available from laboratory results published in the journal “Turkistalous” between 1990 and 2007. N excretion for fur-bearing animals is calculated from the basis of feeding recommendations (MTT 2004; MTT 2006) and the cub production statistics of the Finnish Fur Breeders Association.

Reindeer

For reindeer, nitrogen excretion is not estimated but the value for goats is used, based on both animals being small-sized ruminants. Based on data and estimate from the Sami parliament of Sweden (Sametinget), the average weight of a reindeer is 64 kg (NIR Sweden 2021). The average weight of a goat in Finland in 2018 was 45 kg (data from Finnish Food Authority). Sheep differ from goats and reindeer in their nitrogen excretion pattern because of the wool production. In Finland reindeer are nowadays commonly given supplementary feeding in the winter season (Pekkarinen et al. 2015). The supplementary feeding in Finland reduces the difference in diets between reindeer and goats.

Manure management systems

For the greenhouse gas inventory, the reported manure management systems are slurry, solid storage, deep litter, dry lot and pasture. ‘Solid’ includes urine and dung, either together or separated (Table 4 in Appendix_5a).

The distribution of manure management systems is estimated using different data sources as no statistics available for inventory purposes exist in Finland. Manure management distribution is surveyed by Luke Statistical Services, but the implementation of the survey does not fulfil all the needs of the inventory. The survey results, however, can be used to estimate the distribution if better data are not available. The distribution of manure management systems was estimated in 2009 using data from the Information Centre of the Ministry of Agriculture and Forestry (now part of Luke), the results of a questionnaire sent to Regional Employment and Economic Development Centres and to Regional Environment Centres, and estimates of two experts (Sipilä, I. and Kapuinen, P. MTT in Grönroos et al, 2009). The method has been described in Grönroos et al. (2009). As the questionnaire did not result in enough information, a new questionnaire (Grönroos 2014) was sent to farmers in 2013 (to 11 120 farms, stables or fur farms, approximately 23% answered). Based on the answers, activity data of shares of manure management systems for 1990 to 2005 were kept the same as before (except for dairy) but from 2006 onwards the values were updated. The 2012 management system data was updated and the years from 2006 to 2011 were interpolated. The values from 2013 onwards are based on an estimated trend between 2012 and 2021 (e.g., the share of slurry is assumed to continue to increase). The share of manure in dry lots (1-3% of excreted manure) is a rough estimate (Pitkänen 2014a), which will be updated when more data are available.

In November 2021, Luke Statistical Services published new farm survey results on the distribution of manure management systems in 2020. Based on these results, the distribution of manure management systems, particularly the share of deep litter for dairy cattle were updated, the years from 2013 to 2020 were interpolated and for 2021-2022 the same distribution was used as in 2020.

Manure composting and biogas are excluded from the inventory, because acquiring data for the time series of emissions would require disproportionate resources considering the size of emissions. Methane emissions from anaerobic digestion and N_2O emissions from composting are negligible (see Table 2 in Annex 5).

The 2013 questionnaire (Grönroos 2014) included questions concerning composting. The results suggest that approximately 5% of all “dry manure” (deep litter & solid manure) is composted, most of it is passive windrow composting (N_2O default EF is 0.01). This means max. 7 kt CO_2 eq. more emissions for “N_2O manure” (and a decrease in methane emissions from manure).

Biogas production in Finland is currently small, but the development of the production is being monitored by the Finnish GHG inventory for a possible rapid growth in the future. In 2013 there were 12 farm-scale biogas plants (using mostly cattle and some swine manure, some also grass) in Finland (Huttunen and Kuittinen 2014) and 5 centralised plants, which use manure along with other material in their process. It was calculated (MCFslurry (0.17) * B_o * VSstorage * 0.67, m^3/kg of VS, where MCF is methane conversion factor, B_o is maximum CH_4 producing capacity for manure (m^3/kg of VS), VS is volatile solids excreted (kg)) that the methane emissions from stored digestate would be about 70 to 90 tonnes of methane per year. The estimate of manure input (30,000 to 50,000 t) to the farm-scale plants is both an expert judgement (S. Luostarinen 2015) and an estimate based on methane production of plants. In centralised plants, the digestate goes to the post digestion pool and after that to processing (separation, for example) and is not stored as slurry. By the end of 2022 the number of farm-scale biogas plants had risen to 30 operational plants (Statistics Finland 2023).

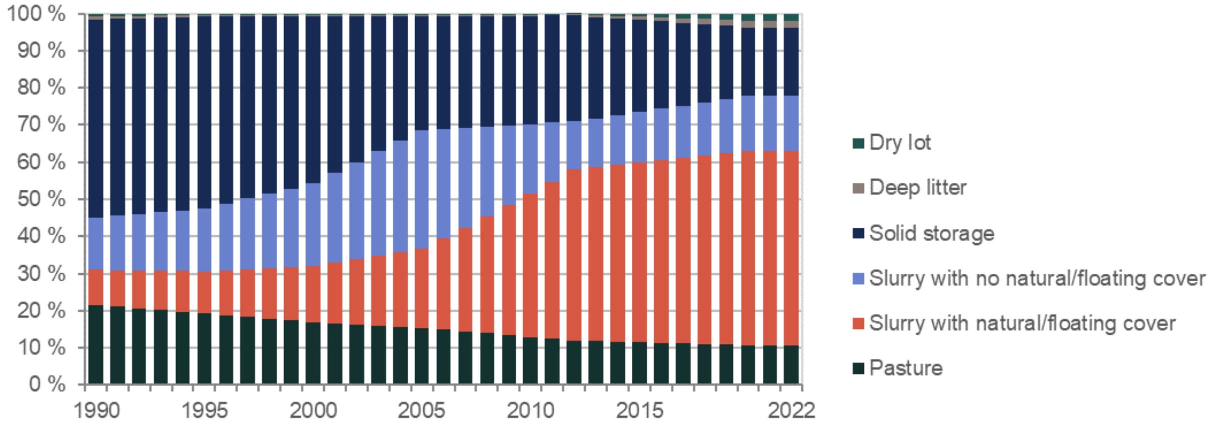


Figure 5.3-3 Fraction of manure of dairy cows in different manure management systems

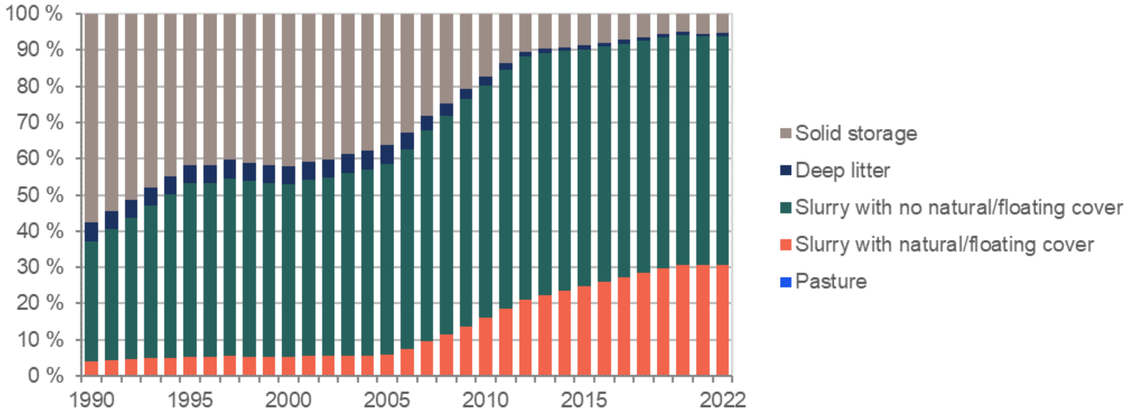


Figure 5.3-4 Fraction of manure of swine in different manure management systems

5.3.2.3 Emission factors and other parameters

Nitrous oxide

The IPCC default nitrous oxide emission factors have been used for each manure management system. Defaults were used as no national emission factors were available. The manure management systems included in the inventory are pasture, solid storage, deep litter, dry lot and slurry (Table 5.3-6).

For slurry, emission factors 0.005 and 0 were used for natural/ floating cover and no natural/floating cover, respectively. The distribution on slurry N into these categories is based on survey results (Grönroos 2014). Most floating covers used in Finland are permeable (Grönroos J., unpublished data). The same emission factor was used for natural crust and floating cover because permeable covers have been found to function similarly to natural crusts (a review by VanderZaag et al. (2008)), although more research on the effect of different covers on greenhouse gas emissions would be needed. The 2019 Refinement to the 2006 IPCC Guidelines (Table 10.21) recommends, on the basis of an extensive literature review, to use the N_2O EF for natural crust for all covers but notes that little research has been conducted on the topic.

EF for solid storage (dung and urine together or dung and separated urine) is the same as for slurry with natural crust/floating cover.

Ammonia volatilisation parameters during manure management are based on a thorough literature review, including reduction potentials of different abatement measures (Grönroos et al. 2009). For dry lot, ammonia volatilisation is at the moment the same as for pasture until better estimates are acquired. Emission factors for nitric oxide and dinitrogen volatilization are derived from the EMEP/EEA Guidebook 2016 (EMEP/EEA 2016).

EFs for indirect N_2O emissions from manure management are default values for deposition (EF = 0.01, IPCC 2006) and leaching (EF = 0.011, IPCC 2019). Country-specific fraction (0.144) is used for $Frac_{Leach}$ (Huttunen et al. 2023).

Table 5.3-6 IPCC default emission factors for nitrous oxide from manure management and related uncertainties

Manure management system	Emission factor (kg N_2O-N/kg)	Uncertainty range of EF	Source of the Uncertainty Estimate
Slurry with cover (natural or floating)	0.005	-50% / +100% (lognormal)	2006 IPCC Guidelines
Slurry without cover	0	-50% / +100% (lognormal)	2006 IPCC Guidelines
Solid storage (incl. urine)	0.005	-50% / +100% (lognormal)	2006 IPCC Guidelines
Deep litter (cattle & swine)	0.01	-50% / +100% (lognormal)	2006 IPCC Guidelines
Poultry manure with litter	0.001	-50% / +100% (lognormal)	2006 IPCC Guidelines
Dry lot	0.02	-50% / +100% (lognormal)	2006 IPCC Guidelines

Methane

The country-specific emission factors for each cattle subcategory have been calculated using the IPCC Tier 2 methodology (2006 IPCC Guidelines, Eq. 10.23 on page 10.41). In the calculation of emission factors, both IPCC default values and country-specific data have been used. Emission factors are presented in Table 5.3-8.

For cattle, emission factors have been calculated based on a country-specific ash content of feed, the default values for the proportion of urine in volatile solids excretion, and default values for Methane Producing Potential (Bo) and Methane Conversion Factor (MCF) from the 2006 IPCC Guidelines (Eq. 10.24, Tables 10A-4 & 10A-5, Table 10.17, see also Table 5.3-7). The country-specific values of calculated digestible energy (DE) and gross energy intake (GE) for cattle from enteric fermentation are used in calculating volatile solids excretion (VS_i) according to the IPCC equation (2006 IPCC Guidelines, Eq. 10.24 on page 10.42). For swine as well as for other animals, emission factors have been calculated using the 2006 IPCC Guidelines' default values for Methane Producing Potential (Bo), Methane Conversion Factor (MCF, see table below) and volatile solids excretion (VS_i). VS values for piglets (0.04) and weaned pigs (0.17) are from an expert (J. Nousiainen) and so are VS values for most poultry (broilers, turkeys, cockerels, chickens and broiler hens). For reindeer, it is assumed that all manure is deposited on pastures and for fur-bearing animals it is assumed that all manure is managed as solid. Concerning reindeer and fur-bearing animals, see page 10.83 Table 10.A-9 in the 2006 IPCC Guidelines. Data on the distribution of different manure management systems are based on the survey data incorporated into the Nitrogen mass flow model (see 'Manure management systems' under Section 5.3.2.2). For slurry, emission factors 0.1 and 0.17 were used for natural/ floating cover and no natural/floating cover, respectively. Most floating covers used in Finland are permeable (Grönroos J., unpublished data), which have been found to function similarly to natural crusts (a review by VanderZaag et al. 2008), although more research on the effect of different covers on greenhouse gas emissions would be needed.

Table 5.3-7 Methane conversion factors used for manure management

MCF	%
Slurry without natural crust or floating cover	17
Slurry with natural crust or floating cover	10
Solid storage (including urine)	2
Deep litter (cattle, swine)	17
'Deep litter' (poultry)	1.5
Deep litter (sheep, goats, horses)	1
Dry lot	1
Pasture	1
Fur-bearing animals	8
Reindeer	2

Table 5.3-8 Country-specific emission factors in 2022 used for calculating methane emissions from manure management

Animal category	Emission factor (kg CH_4/head/year)
Cattle	
Dairy cattle	32.01
Non-dairy cattle	
Suckler cows	4.63
Bulls	9.96
Heifers	7.87
Calves	3.69
Sheep	0.25
Swine	3.18
Fattening pigs	4.85
Boars	6.79
Weaned pigs	2.62
Sows	6.79
Piglets	0.59
Other livestock	
Poultry	0.032
Laying hens	0.06
Chickens	0.02
Cockerels	0.04
Broiler hens	0.04
Broilers	0.02
Turkeys	0.05
Other poultry	0.03
Horses	2.14
Goats	0.18
Fur animals	0.68
Reindeer	0.36

5.3.3 Uncertainty assessment and time series’ consistency

Quantitative estimates of uncertainty are provided in Annex 2. A description of the uncertainty analysis is included in Section 1.6.

The uncertainties in manure management are estimated by applying the Tier 2 Monte Carlo simulation directly to the emission calculation models (LUKEAgri calculation sheet and Nitrogen mass flow model). Animal numbers and related uncertainties used for manure management are the same as for enteric fermentation (see Section 5.2.3).

Uncertainties in the direct nitrous oxide emission factors from manure management are - 50…+100% (2006 IPCC Guidelines). The uncertainty estimates of the methane emission factor for manure management for all species (±30%) are based on the uncertainty estimates of other countries, i.e. Norway, the Netherlands, the USA (Rypdal & Winiwarter 2001) and the UK (Charles et al. 1998), complemented with expert judgement (Monni et al. 2007). Uncertainty could be reduced by collecting more information about the distribution of different manure management systems used in Finland and by gathering data from gas flux measurements to study the suitability of the IPCC default emission factors to the boreal climate.

The uncertainty in nitrogen excretion values varies between animal species, from 2% to 15%, except for reindeer (25%). The amount of N excreted annually by reindeer is very uncertain. Currently, because of the lack of data, the value for goats has been used. Also, B_o and VS_i for fur-bearing animals and vS_i for reindeer are uncertain. However, these emissions are very small and, therefore, the contribution to the total uncertainties is also small.

As the same calculation methods are used for the whole time series 1990 to 2022, the time series can be considered consistent. See Section 5.2.3 about animal numbers. Concerning manure management data, interpolation/extrapolation was used to combine new and previous data and predict future development (see Section 5.3.2.2. Manure management systems).

5.3.4 Category-specific QA/QC and verification

The quality objectives and the QA/QC plan for the Finnish greenhouse gas inventory at the national inventory level are presented in Section 1.5. The QC procedures are performed according to the QA/QC plan in order to attain these quality objectives. A bilateral quality meeting is held annually between the inventory unit and the sectoral expert. In the 2024 quality meeting we discussed about the inspection feedback and future development plans, such as the status of the recently accomplished detailed farm survey on the distribution of manure management systems, and the progress regarding updates for national N excretion calculations for swine and poultry.

A comparative assessment: How the annual average population influences nitrogen excretions values and N2O emissions from manure management

For the 2022 inventory, we compared the nitrogen excretions values of short-lived animals, specifically fattening pigs and broilers, with those derived using the annual average population. Monthly swine numbers for the years 2008-2022 were obtained from the Finnish Food Authority for this comparison. An annual average was then calculated from the monthly values for each year. Since this data is categorized by age, it required conversion into weight-based classification using an estimation model to obtain fattening pig numbers and facilitate comparison with the inventory, which uses the December animal numbers as activity data (see Chapter 5.2.2.2). Regarding broilers, the annual average population of broilers was calculated using Equation 10.1 from the IPCC 2006 guidelines. This involved diving the total number of slaughtered broilers by 365 and then multiplying the result by 36.5 days, representing the typical lifespan of broilers in Finland according to the Finnish poultry industry. Broiler slaughtering data was sourced from Luke’s meat production statistics.

In the comparative assessment, nitrogen excretions values for fattening pigs and broilers were calculated using the same method as in the inventory, where the number of animals does not influence nitrogen excretion value. It is consistently calculated per animal and is based solely on slaughter weight data and feeding recommendations. Thus, changes in animal numbers do not affect individual nitrogen excretion but do impact total nitrogen excretion over the year, as nitrogen excretion is multiplied by the total number of animals. Based on this information, we calculated how the annual average number of animals affects the N_2O emissions from manure management of fattening pigs and broilers. The emissions were, on average, -0.4 kt CO_2 eq. (7%) smaller for fattening pigs from 2008 to 2022 and, on average, -0.1 kt CO_2 eq. (11%) smaller for broilers from 1990 to 2022 (Figure 5.4-5).

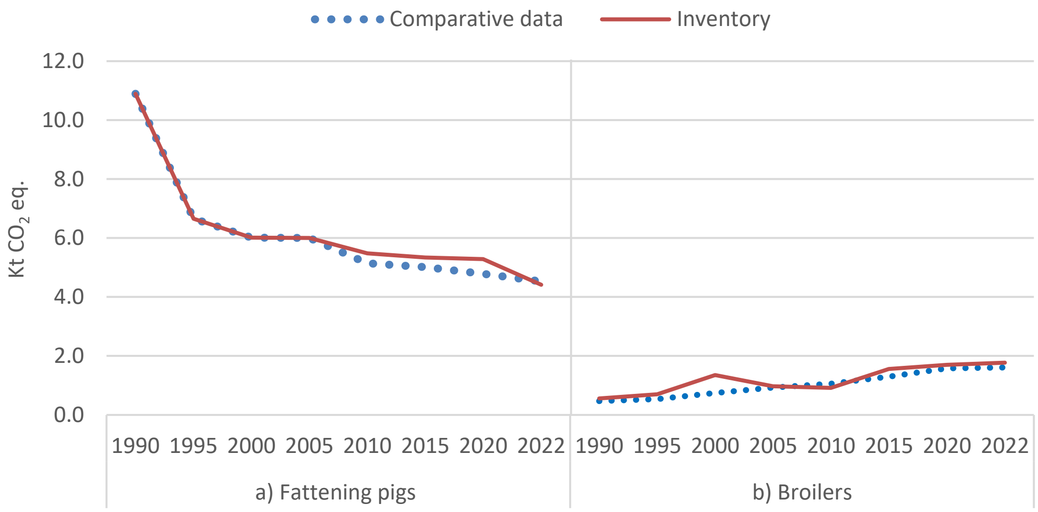


Figure 5.3-5 The nitrogen oxide emissions (kt CO_2 eq.) from manure management for a) fattening pigs and b) broilers, utilizing both the annual average animal numbers and the animal numbers from the inventory

Quality Control (QC) procedures applied to the category Manure management (CRF 3.B):

The QA/QC plan for the agricultural sector includes the QC measures presented in the 2006 IPCC Guidelines (Vol 1, Chapter 6, Table 6.1). These measures are implemented every year during preparation of the agricultural inventory. If errors or inconsistencies are found, they are documented and corrected. The QC checklist (LUKEagri check) is used during the inventory. The check includes, for example, checking of formulas, links between sheets and evaluating correctness of parameters used with cross-checks to previous years.

The LUKEagri calculation sheet has a check for N_2O manure management to ensure that the Nitrogen mass flow model and the calculation sheet use the same activity data. No errors were detected. Additionally, the results from the Nitrogen mass flow model are compared with simpler calculations built in LUKEagri calculation sheets to examine possible problems with the model.

A checklist (LUKEagri check) is used for ensuring consistency of the activity data in different sections of the agricultural inventory. The checklist is a list of the activity data with a column for marking the result of the check. Graphs are used to compare manure system data with previous years.

Quality assurance and verification:

Every year we check the availability of new data for updating the emission factors. When new research results are published, the current emission factors are reconsidered. For example, the CH_4 and N_2O emissions from cattle were revised due to the adoption of a new country-specific calculation method for cattle excretion (Nousiainen et al. 2023). The adoption of this method lead to a revision of gross energy (GE) and digestible energy (DE values for the entire time series from 1990 to 2022 and affected on the calculations of volatile solids needed for estimating methane emissions.

Formulas and cell references used in Lukeagri calculation sheets have been regularly reviewed, compared with the 2006 IPCC Guidelines and updated by the researchers working in the inventory. The 2022 submission calculations have been made by researchers in the inventory, T. Silfver and X. Tarpio.

Luke has a steering group that monitors the scientific quality of the greenhouse gas inventory concerning Agriculture and LULUCF. Improvements to the agricultural inventory are made wherever is possible and in accordance with the recommendations/suggestions of the UNFCC Expert Review teams and the EU Technical Expert Review teams, which are responsible for reviewing the inventory. Also, a meeting among Nordic sector experts is organized annually, where the countries compare their calculation methods and emission factors.

5.3.5 Category-specific recalculations

Due to the implementation of a new method for country-specific cattle excretion (Nousiainen et. al. 2023), the N_2O and CH_4 emissions from cattle were renewed for the entire time series 1990-2022. These revisions resulted in an increase in manure management CH_4 emissions from cattle at the beginning of the time series, particularly in 1990, by about +9 kt CO_2 eq. However, as the time series progressed, emissions experienced a decline, reaching the largest reduction of around -28 kt CO_2 eq. in 2009. Additionally, these revisions also impacted nitrous oxide emissions from cattle manure management, showing an +8-+18 kt CO_2 eq. increase particularly during the years 1990-1999. However, there was a slight decrease in emissions towards the end of the series, with the largest -8 kt CO_2 eq. reduction in 2012. In total, the cumulative effect of these updates led to a reduction of -9 kt CO_2 eq. in total emissions from manure management in 2021.

5.3.6 Category-specific planned improvements

We will re-examine and update swine and poultry N excretion data and calculations for the 2025-2026 submission based on results from a recent project on swine and poultry excretion.

The effects of different slurry cover materials on methane and nitrous oxide emissions have been investigated based on available research results and international knowledge exchange in order to improve the emission factors. As of yet, the existing data are not sufficient to estimate the effects. We plan to continue to monitor the scientific literature and other similar sources, both domestic and international, to obtain more information on the effect of different types of cover on emissions and will consider applying any new EFs or parameters available. Additionally, a more comprehensive farm survey, better aligned with the inventory requirements, has been conducted, and the new results are anticipated to be incorporated in the 2025 submission. This will coincide with the adoption of the revised Nitrogen flow model (Grönroos et al., 2017).

5.4 Agricultural Soils (CRF 3.D)

5.4.1 Category description

Nitrous oxide emissions from agricultural soils (CRF 3.D) are a significant emission source comprising 49% of total agricultural emissions in 2022, being 3.0 Mt as CO_2 equivalents.

Direct N_2O emissions (CRF 3.D.a) include emissions from synthetic fertilisers, animal manure (including bedding) and sewage sludge and other organic fertilisers applied to soils, urine and dung N deposited on pasture, crop residues, drainage/management of organic soils and mineralisation due to management change on mineral soils. Indirect N_2O emissions (CRF 3.D.b) include emissions arising from nitrogen volatilised as ammonia (NH_3) and other oxides of nitrogen (NO_x; from synthetic fertilisers), as well as nitrogen leached from the sources mentioned above (except organic soils). Indirect N_2O emissions from manure management systems are reported in CRF 3.B. See Appendix 5b for details of manure and bedding nitrogen.

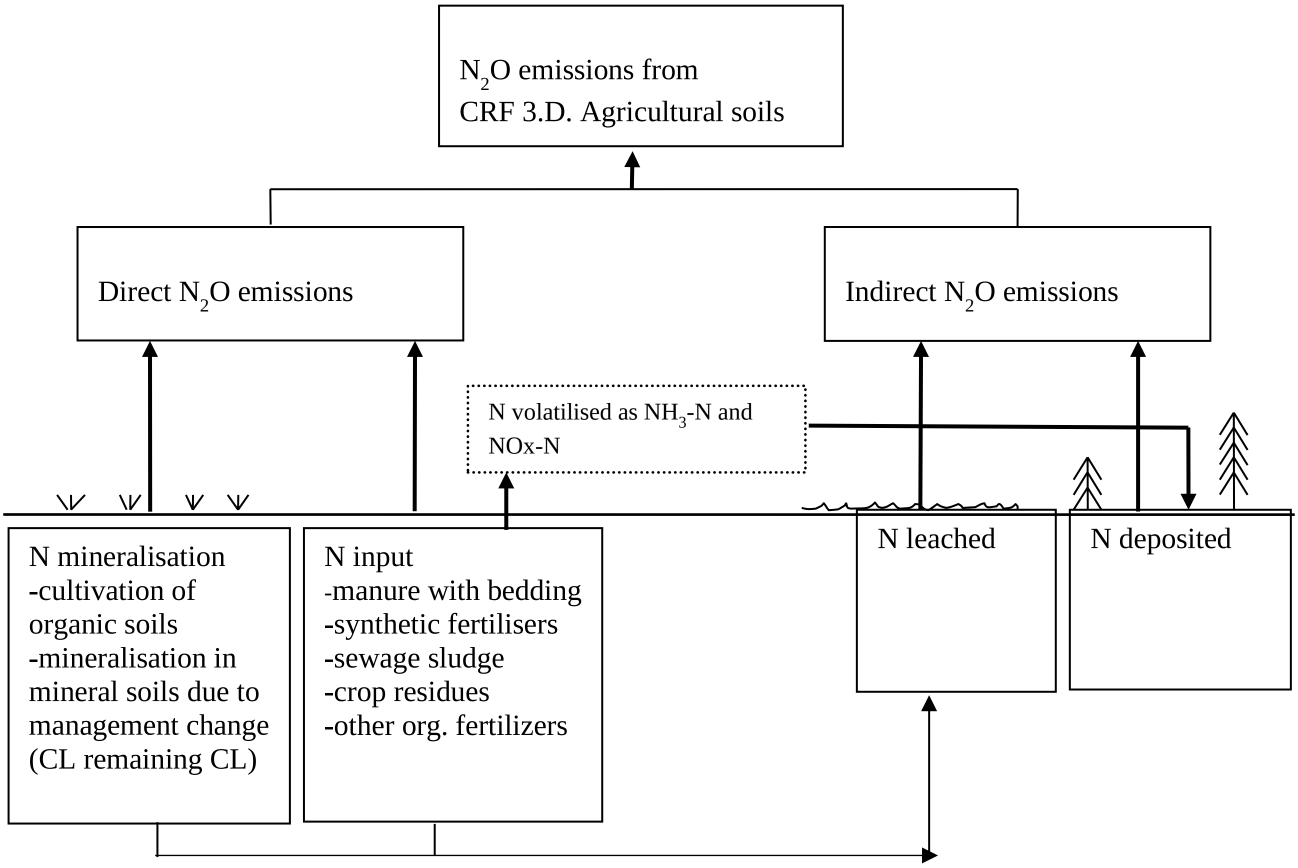


Figure 5.4-1 Reported emissions under the subcategory Agricultural Soils CRF 3.D in the Finnish inventory

Table 5.4-1 Reported emissions, calculation methods and types of emission factors for the subcategory Agricultural Soils in the Finnish inventory

CRF	Source	Emissions reported	Methods	Emission factor
3.D.a	Direct Soil Emissions			
	- Synthetic Fertilisers	N_2O	Tier 1	D
	- Animal Manure Applied to Soils	N_2O	Tier 1	D
	- Municipal Sewage Sludge Applied to Soils	N_2O	Tier 1	D
	- Other Organic Fertilizers Applied to Soils	N_2O	Tier 1	D
	- Pasture, Range and Paddock Manure	N_2O	Tier 1	D
	- Crop Residue	N_2O	Tier 1	D
	- Mineralisation associated with loss of soil organic matter (mineral soils)	N_2O	Tier 2	D
	- Cultivation of Histosols	N_2O	Tier 2	D, CS*
3.D.b	Indirect N_2O Emissions			
	- Atmospheric Deposition	N_2O	Tier 2	D
	- Nitrogen Leaching and Run-off	N_2O	Tier 2	D

*both country-specific and IPCC Wetlands Supplement emission factors used

Nitrous oxide is produced in agricultural soil as a result of microbial nitrification-denitrification processes. The processes are driven by drivers like the availability of mineral nitrogen substrates and carbon, soil moisture, temperature and pH. Thus, addition of mineral nitrogen enhances the formation of nitrous oxide emissions (Smith et al., 2004). Nitrous oxide emissions also arise as a result of the mineralisation of soil organic matter, which is particularly intensive in cultivated organic soils.

Agricultural production changed considerably in the beginning of the 1990s due to Finland's decision to join the EU. Many farms were given up and the area of fallow more than doubled in 1990 to 1991. Therefore, the cultivated area decreased by 13% (Luke 2021b). Fallows are areas that receive less fertilisers, or not at all, compared to actively cultivated fields. The area of fallow almost halved in 1994 to 1995 as Finland joined the EU in 1995. At the same time the total cultivated area with fallow diminished when some of the area was transferred to other land use. After that, there has been some increase in the amount of total cultivated area with fallow and it is now close to the level in the beginning of the 1990s. There have not been great changes in the amount of fallow after 1995.

Nitrous oxide emissions from agricultural soils have decreased by 1%, from 12.3 kt in 1990 to 11 kt in 2022 (Table 5.4-2, Figure 5.4-2). The main reason for the decreasing trend is the reduced use of synthetic fertilisers. Declining emissions from pasture also have some effect: a smaller proportion of animals are kept on pastures, thus emissions from pastures have declined. The emissions from cultivated organic soils have increased as a result of the increased area of organic soils in cultivation. However, the area of organic grassland (included in the calculation according to the 2006 IPCC Guidelines) is decreasing. The emissions from agricultural soils in 2022 were 3% lower than the emissions in 2021, mainly due to a decrease in emissions from the use of synthetic fertilizers. This decline is most likely a result of the impact of the global political and economic situation on the availability and prices of fertilizers.

Table 5.4-2 Direct and indirect nitrous oxide emissions from agricultural soils by category (kt)

	Direct emission sources								Indirect emission sources		Total
	S	MS	MP	C	SW	OF	O	M	A	L	
1990	3.19	1.05	0.49	1.17	0.02	0.01	3.93	NA	0.15	0.91	10.93
1995	2.73	0.98	0.40	1.14	0.02	0.01	3.78	0.05	0.14	0.82	10.07
2000	2.34	0.98	0.37	1.16	0.01	0.01	3.88	0.36	0.13	0.80	10.05
2005	2.09	1.00	0.35	1.22	0.01	0.01	4.19	0.19	0.14	0.75	9.94
2010	2.19	1.00	0.33	1.15	0.02	0.01	4.32	0.20	0.14	0.75	10.12
2013	1.93	1.02	0.32	1.22	0.03	0.01	4.44	0.06	0.14	0.70	9.86
2014	2.06	1.03	0.32	1.23	0.03	0.01	4.48	0.07	0.14	0.73	10.09
2015	2.00	1.05	0.32	1.32	0.03	0.01	4.51	0.05	0.14	0.70	10.13
2016	1.93	1.03	0.32	1.25	0.04	0.00	4.54	0.20	0.14	0.71	10.14
2017	1.94	1.01	0.31	1.27	0.04	0.01	4.56	0.15	0.14	0.71	10.14
2018	1.93	1.01	0.31	1.10	0.03	0.01	4.59	0.23	0.14	0.69	10.05
2019	2.05	1.00	0.31	1.32	0.04	0.01	4.64	0.36	0.14	0.76	10.63
2020	1.95	1.00	0.31	1.22	0.04	0.01	4.70	0.35	0.14	0.73	10.43
2021	2.04	0.98	0.31	1.10	0.04	0.01	4.74	0.25	0.14	0.70	10.29
2022	1.42	0.94	0.30	1.26	0.04	0.01	4.79	0.41	0.12	0.65	9.95

The sum of the shares may differ from 100 due to roundings.
S=synthetic fertilisers, MS= manure (with bedding) applied to soils, MP=manure deposited on pastures by grazing animals, C=crop residues, M=Mineralisation on mineral soils, O=cultivation of organic soils, SW=sewage sludge application, A=atmospheric deposition, L=leaching and run-off, OF=Other Organic Fertilizers

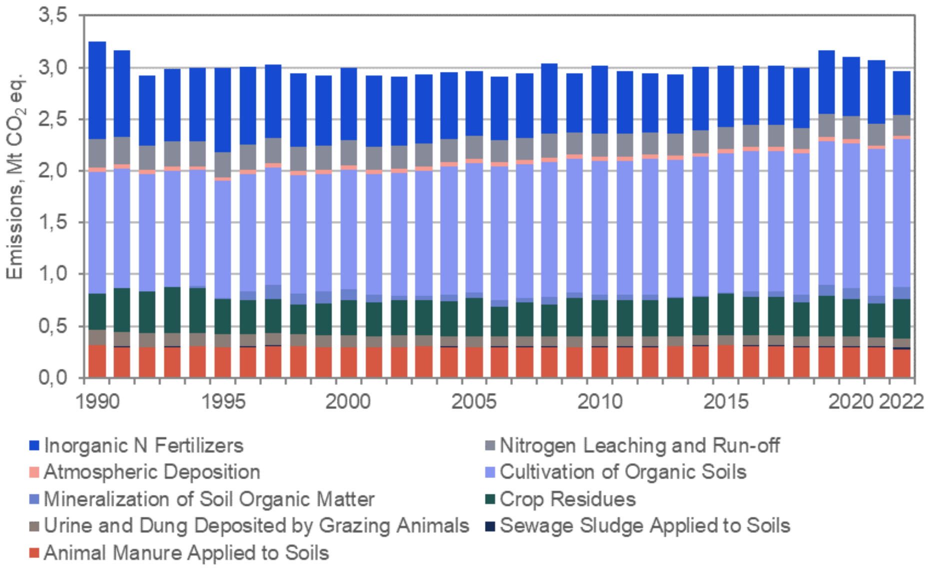


Figure 5.4-2 Nitrous oxide emissions from agricultural soils (atmospheric deposition, nitrogen leaching and run-off are indirect emissions, all other direct), Mt CO_2 eq. Emissions from other organic fertilisers are not included in the figure because they would not be discernible (see the table above for exact figures)

5.4.2 Methodological issues

5.4.2.1 Methods

Emissions have been calculated using the 2006 IPCC Guidelines' methodology and its 2019 Refinement. Direct emissions have been calculated using the Equation 11.1 on page 11.7. Indirect N_2O emissions have been calculated using Equation 11.9 for atmospheric deposition and 11.10 for leaching and run-off (2006 IPCC Guidelines page 11.21). Activity data sources of this category are presented in Table 5.4-3 and emission factors in Table 5.4-8. Default EFs are used for direct soil emissions (except for organic soils) and for indirect N_2O emissions (Table 5.4-1). For synthetic fertilisers and manure, the Nitrogen mass flow model has been used in the calculation. Nitrogen inputs from synthetic and organic fertilisers are presented in Table 5.4-4. N flows and N_2O emissions from the Agriculture sector are presented in Figure 5.4-1.

Nitrous oxide emissions from the atmospheric deposition are calculated from the total amount of NH_3-N volatilised in the application of synthetic fertilisers (incl. NO-N), manure, sewage sludge and other organic fertilisers (potato cell sap and meat and bone meal), as well as manure excreted on pastures, by multiplying the total amount of nitrogen volatilised with the default emission factor for atmospheric deposition (see Table 5.4-8). Fractions volatilised from the application of synthetic fertilisers and manure are presented in Table 5.4-9.

Runoff occurs in Finland (Vuorenmaa et al. 2002). Nitrous oxide emissions from leaching and run-off are calculated as a fraction of the nitrogen input to soils: from synthetic fertilisers, from manure including pasture and bedding, sewage sludge and other organic fertilisers, from crop residues, and from the nitrogen mineralisation associated with the loss of soil organic matter that results from management change. The national Frac(LEACH) (Table 5.4-9) and EF (Table 5.4-8) from the 2019 Refinement to the IPCC 2006 Guidelines are used. Leaching and runoff from the cultivation of organic soils are not estimated.

Synthetic fertilisers and manure

Emissions from the application of synthetic fertilisers and manure to agricultural soils, as well as pasture emissions, are calculated in the Nitrogen mass flow model (Grönroos et al. 2009), except for leaching/run off.

Direct emissions from synthetic fertiliser application (CRF 3.D.a1) are calculated by multiplying the total N from the synthetic fertilisers sold by the default emission factor provided in IPCC 2006 Guidelines. The indirect N_2O emissions from synthetic fertiliser application that result from the volatilization of ammonia and nitrogen oxide are calculated considering the different fertiliser types, grassland/arable land division and placement fertilisation (Grönroos et al. 2009). The emission factors for the volatilization are obtained from the EMEP/CORINAIR Emission Inventory Guidebook 2007 (EEA 2007). In Finland, placement fertilisation is typically used for cereals. Based on the emission reduction efficiencies of different manure application and emission abatement methods, it is assumed that placement fertilisation reduces ammonia volatilisation by 50% compared to surface application of synthetic fertilisers (Grönroos et al. 2009). Thus, emission factors for arable land are multiplied by 0.5 except for nitrogen solutions for which placement fertilisation is not used (EEA 2007; Grönroos et al. 2009).

Manure includes all applied manure, also composted manure which is not calculated separately. Volatilised nitrogen (as NH_3-N, NO-N, N_2 and N_2O-N) from manure management systems is subtracted from the amount of total manure nitrogen entering the manure systems before calculating direct N_2O emissions from manure applied to soils (CRF 3.D.a2a). Bedding nitrogen is added to manure nitrogen entering the soil. Estimates for bedding use are obtained from the Finnish Normative Manure system developed by the Natural Resources Institute Finland (Luke) and the Finnish Environment Institute (Syke) (Luostarinen et al. 2017). The current Nitrogen mass flow model used in the GHG inventory uses estimates from the June 2016 system version (M. Hellstedt 2016), which differ slightly from the published estimates.

Direct emissions from manure application are calculated using the IPCC default emission factor (2006 IPCC Guidelines, Table 11.1). Indirect N_2O emissions that result from the volatilisation of ammonia during and after spreading of manure are calculated by taking into account the type of field (arable/plant covered/stubble), the application method, and various NH_3 abatement measures (for example, incorporation with ploughing in less than 4 hours, injection) and their ability to reduce ammonia emissions in fields. More detailed information about the model parameters is found in Grönroos et al. (2009) page 13. Dry lot dung and urine are not applied to fields but are assumed to stay on the ground of the corrals similar to pasture. Dry lot emissions are calculated in Manure management Section 5.3.

Calculating the amount of manure excreted on pasture requires data on the length of the pasture season and time spent outside. For dairy cattle, it has been estimated that 60 to 100% of cows (depending on the year) spend nights inside (11 to 12 hours) during pasture season. The length of the pasture season has been estimated to be 125 to 112 days for dairy cows, 140 to 170 for suckler cows, 130 to 140 for heifers, 100 to 130 for calves, 140 to 180 for horses and ponies, 140 to 150 for sheep and goats, 365 for reindeer, and 0 for bulls, swine (with some exceptions), poultry and fur-bearing animals (Grönroos et al. 2009, Grönroos 2014).

Direct emissions from dung and urine on pasture are calculated using the IPCC default emission factors (2006 IPCC Guidelines, Table 11.1). The indirect N_2O emissions that result from the volatilisation of ammonia are calculated using emission factors 0.03 and 0.1 for ammonia volatilization from dung and urine, respectively (Grönroos et al. 2009), and the IPCC default emission factor (2006 IPCC Guidelines, Table 11.3) for N_2O emission from the volatilized ammonia. Volatilisation results in total loss of 4.4% of nitrogen as ammonia from pastures.

Leaching is calculated from the amount of synthetic fertiliser nitrogen sold each year and from the total amount of manure nitrogen applied to soil. Cover crops are assumed to decrease nitrogen leaching by 50% (Valkama et al. 2015). Leaching from pasture is calculated from the total amount of nitrogen deposited in the ground in urine and dung. The IPCC default emission factor (2019 Refinement to the 2006 IPCC Guidelines, Table 11.1) and a national 0.144 $Frac_{Leach}$ estimate (Huttunen et al. 2023) is used in the calculations.

Sewage sludge and other organic fertilisers

Sewage sludge N applied to agricultural soils (CRF 3.D.a2b) is calculated from the total amount of sewage sludge, nitrogen content of the sludge, and the share of sludge used on agricultural lands. Other organic fertiliser N applied to soils (CRF 3.D.a2c) is calculated from the quantity and N content of the potato cell sap and meat and bone meal manufactured for agricultural use.

Direct nitrous emissions for both are calculated by multiplying the N by the IPCC default emission factor. Indirect N_2O emissions from deposition are calculated assuming that the share of volatilised ammonia is the same as for applied manure (including bedding) and manure to pasture, FracGasm approximately 8 to 9%. Leaching is calculated using $Frac_{Leach}$ 0.144 (Huttunen et al. 2023) and EF_{Leach} 0.011 kg N_2O-N / kg N leached (IPCC 2019 default). Cover crops are assumed to decrease nitrogen leaching by 50% (Valkama et al. 2015).

Crop residues

In principle, crop residue calculation follows the 2006 IPCC Guidelines with small refinements. N_2O emissions are now calculated based on all cultivated plants in Finland, including the areas of crop failure caused by, for example, exceptional weather conditions. Cover crops are also included. Plants are divided into 12 groups: winter wheat, spring wheat, rye, barley, oat, turnip rape, rape, legumes (peas, beans) and vegetables, potato, sugar beet, silage and cover crops. Emissions from beans and vegetable residues are calculated similarly as for peas. Both aboveground and belowground crop residues are included. Straw used for bedding is excluded. The calculation is described in more detail in Appendix_6j. Crop yields vary from year to year, as well as the cultivated area, which cause fluctuations in crop residue emissions. Leaching is calculated using 0.144 (Huttunen et al. 2023) and EF_{Leach} 0.011 kg N_2O-N / kg N leached (IPCC 2019 default). Cover crops are assumed to decrease nitrogen leaching by 50% (Valkama et al. 2015).

Cultivation of organic soils

Nitrous oxide emissions from cultivated organic soils have been calculated with the IPCC methodology by dividing the area of agricultural organic soils into soils with annual and perennial plants and abandoned fields and using country-specific EFs.

Mineralisation due to management change on mineral soils

The amount of nitrogen mineralised from loss in soil organic C in mineral soils through change in management practices is calculated using the Tier 3 method for the carbon losses and Equation 11.8 in the 2006 IPCC Guidelines (page 11.16). Net soil carbon losses are calculated as described in Section 6.5 using the Yasso07 soil carbon model (Appendix 6e). C:N ratio of the soil organic matter (13) is a country-specific estimate (Sheehy et al. 2013). EF for direct and indirect (EF_{Leach}) emissions are defaults, leached fraction ($Frac_{Leach}$) is a national estimate (Huttunen et al. 2023). Cover crops are assumed to decrease nitrogen leaching by 50% (Valkama et al. 2015). Mineralisation emissions due to management changes in Cropland remaining cropland are reported under Agricultural soils 3D (including leaching), other N_2O emissions from mineralisation are reported under the LULUCF sector, in the CRF category 4(III).

5.4.2.2 Activity data

Activity data are country-specific and obtained mainly from the Statistical services of Luke (Table 5.4-3). The amount of synthetic fertilisers sold annually has been obtained from the annual agricultural statistics (Luke). The annual reports for all fertilizer manufactures for the year 2022 were not received on time by the statistical services at the Natural Resources Institute Finland (Luke) for the inventory. The delay is attributed to a change in the schedule, particularly the adoption of a new submission system for the annual reports at the Finnish Food Authority, which has proven to be more demanding than expected. As a result, estimates for nitrogen fertilizer quantities for the year 2022 are calculated based on the change between 2021 and 2022 in the fertilizer quantities of those companies for which data has already been obtained for 2022. The assumption is that the change in fertilizer quantities between 2021 and 2022 for the companies with the missing data for 2022 is equal to that of the companies included in the data. The estimated share of nitrogen quantity for missing companies in the total nitrogen quantity of agricultural synthetic fertilizers is 11.6 %. Animal numbers for the calculation of emissions from manure applied to soils are the same as those used for calculating enteric fermentation and manure management emissions (Table 5.2-4, Appendix 5a). The distribution of different manure management systems and the amount of nitrogen excreted per animal are the same as those used for calculating nitrous oxide emissions from manure management.

The total annual amount of sewage sludge and the nitrogen content of the sludge are taken from the YLVA (formerly VAHTI) environmental monitoring database (Section 1.3 and Annex 6). The share of sewage sludge used on agricultural lands is based on a combination of published information, expert estimation and linear interpolation (Table 5.4-3). While the nitrogen content of the sludge was updated for 2022, the total annual amount of sewage sludge was not available on time for the inventory. Consequently, the 2021 value was used for sludge spread on the agricultural land.

For the other organic fertilizers applied to agricultural soils, the quantity and nitrogen content of potato cell sap is obtained from Statistical Services of the Natural Resources Institute Finland (Luke). The meat and bone meal manufactured for agricultural fertiliser use is derived from manufacture declarations for the Finnish Food Authority (formerly Finnish Food Safety Authority).

Crop yields taken from Luke’s statistical services are converted to biomass as described in Appendix 6j and further to nitrogen content of plant residues using the coefficients from the 2006 IPCC Guidelines. The cultivated areas of each crop plant on organic and mineral soils are obtained by combining the data from the Finnish Food Authority (Table 5.4-6) with the Finnish Soil Database (Lilja et al. 2009). The data for cultivated areas are available from 1995 onwards, and except for the fallows, the cultivated areas from 1990 to 1994 were assumed to be the same as in 1995. For fallows, the areas for 1990–1994 were assumed to be twice as high as in 1995. The data described above are used to determine the share of organic soils under perennial and annual plants. Overall areas of organic soils are obtained from the National Forest Inventory (see Section 6.3. and Appendix 6a). The cultivated area of cover crops is taken from the database of the Finnish Food Authority and the above- and belowground biomasses of cover crops are assumed to be constant, i.e. 800 and 1200 kg DM/ha, respectively, based on the average yields of cover crops cultivated in Finland (Känkänen 2019). Mostly used cover crop species are graminoids (70%) but clovers are also used and therefore, the biomass is converted into N content using IPCC 2006 Guideline values for grass-clover mixture. The data for cover crop areas are available from 2015 and presented in Appendix 6j.

The distribution of fertiliser types is used in the Nitrogen flow model when calculating indirect (deposition) N_2O emissions from synthetic fertilisers. Data for the years 1990 to 1999 were obtained from the reports of Kemira (Kekäläinen, A., annual, 1990 to 1999), now Yara, the years 2000 to 2007 are based on data from Yara (email, M. Toimela 2007), 2008 to 2014 are interpolated and the years 2015 and 2016 data are from Yara (email, M. Toimela 2016 and 2017) and from import declarations collected by the Finnish Food Safety Authority Evira (now: Finnish Food Authority). From the year 2017 onwards the distribution of fertilizer types is based on the manufacture and import declarations collected by the Finnish Food Safety Authority Evira/Finnish Food Authority. The necessary calculations are performed by P. Mattila in Luke Statistical Services.

Table 5.4-3 Activity data sources for calculating nitrous oxide emissions from agricultural soils

Activity data	Data source
Synthetic fertilisers applied to agricultural soils	Statistical Services of the Natural Resources Institute Finland (Luke), Yearbook of Farm Statistics
Number of cattle, sheep, goats, poultry, reindeer	Natural Resources Institute Finland (Luke) Statistics database, Yearbook of Farm Statistics
Number of horses	Finnish Trotting and Breeding Association
Number of fur animals	Finnish Fur Breeders Association
Nitrogen excretion by animal type	Natural Resources Institute Finland
Distribution of manure management systems	Grönroos et al. 2009, Grönroos 2014
Sewage sludge applied to agricultural soils	Total amount of sewage sludge: YLVA database (see section 1.4, Annex 6). Share of sludge used on agricultural lands: 1990-2000 Lapinlampi & Raassina 2002, 2001-2005 estimated based on usage trends (Lundström 2020), 2006-2014 interpolated, 2015-2020 Vilpanen & Toivikko 2017 (value from 2016 used for the years 2017–2021)
Other organic fertilisers applied to agricultural soils	Statistical Services of the Natural Resources Institute Finland (Luke), Finnish Food Authority
Ammonia emission estimates	Nitrogen mass flow model, Grönroos et al. 2009
Crop statistics, including cover crops	Natural Resources Institute Finland (Statistics database, Yearbook of Farm Statistics), Finnish Food Authority (Cover crop area), Land Parcel Identification System (EU 1992), Palosuo et al. 2015 and Känkänen 2019 (national parameters)
Area of cultivated organic soils	Natural Resources Institute Finland
Net carbon stock change in mineral soils	Yasso07 soil carbon model

Table 5.4-4 Nitrogen input to soils via synthetic fertilisers, manure, bedding and sewage sludge application (t N a^{-1}) (the fraction lost as NH_3 and NO_x during application has not been subtracted)

Year	Synthetic fertilisers[1]	Manure[2]	Bedding	Sewage Sludge[3]	Other organic fertilisers[4]
1990	228 470	86 478	8 253	1 586	422
1995	195 460	79 175	7 297	1 345	441
2000	167 276	79 214	6 468	741	439
2005	149 562	80 603	5 378	695	439
2010	156 523	80 537	5 237	1 260	793
2013	138 136	81 142	5 076	1 826	570
2014	147 373	82 419	5 018	1 978	567
2015	143 479	83 684	4 963	2 066	607
2016	138 128	81 855	4 883	2 547	355
2017	138 948	81 110	4 776	2 731	411
2018	138 385	80 373	4 681	2 420	828
2019	146 798	80 145	4 532	2 729	579
2020	139 316	79 859	4 436	2 545	619
2021	145 807	78 561	4 445	2 674	420
2022	101 831	75 552	4 383	2 722	518

[1] Sales of fertilisers to farms. Sources: Statistics service of Natural Resources Institute Finland, Yearbook of Farm Statistics.

[2] Includes manure applied to agricultural soils (not bedding) as well as manure deposited on pastures.

[3] Source: see Table 5.4-3

[4] Includes N input from potato cell sap and meat and bone meal

Table 5.4-5 Distribution of synthetic N-fertilisers used in Finland by fertiliser type. The share of each fertiliser depends on the year (Sources: Kemira / Yara Finland and Finnish Food Safety Authority Evira / Finnish Food Authority)

	% of applied N												
Fertiliser type	**1990**	**1995**	**2000**	**2005**	**2010**	**2015**	**2016**	**2017**	**2018**	**2019**	**2020**	**2021**	**2022**
Ammonium sulphate	0.004	0	0	0	0.2	0.4	0	0.7	0.4	0.5	0.6	0.2	0.2
Ammonium nitrate	0	0	0	0	0	0	0	0	0	0.0	0.0	0.0	0.0
Calcium ammonium nitrate	10.8	9.3	15.3	15.2	23.8	30.9	30.5	27.1	19.9	24.4	24.6	25.3	29.2
Anhydrous ammonia	0	0	0	0	0	0	0	0	0	0	0.0	0.0	0.0
Urea	1.3	0.1	0.2	0.4	0.5	0.8	1.2	0.7	0.7	0.9	0.7	0.5	3.7
Nitrogen solutions	0.003	0	0	0.02	0.02	0	0	0.09	0.06	0.07	0.2	0.1	0.0
Ammonium phosphates	0.1	0.1	0.1	0.2	0.2	0.2	0.1	0.4	0.0	0.0	0.0	0.0	0.2
Other NK and NPK	87.5	90.3	84.3	84.2	75.3	67.6	68.1	70.7	79.0	74.1	74.0	73.8	66.6
Nitrate only	0.3	0.09	0.08	0.06	0.06	0.07	0.10	0.29	0	0	0.0	0.0	0.0

Table 5.4-6 Parameters for calculating crop residue emissions

	1990		2022		Parameters		
	yield (kg DM/ha)	area, ha	yield (kg DM/ha)	area, ha	res/yield	*above N	*below N
Winter wheat	3 289	12 548	3 334	35 575	1.84	0.006	0.009
Spring wheat	2 873	88 152	3 255	197 162	1.84	0.006	0.009
Rye	2 534	20 801	2 898	19 995	1.99	0.005	0.011
Barley	3 059	516 317	3 271	428 979	1.25	0.007	0.014
Oats	3 137	329 437	2 148	337 318	1.59	0.007	0.008
Turnip rape	1 607	37 240	1 140	33 572	2.47	0.006	0.009
Rape	1 787	9 514	1 621	8 401	2.47	0.006	0.009
Peas, beans, vegetables	2 462	15 038	2 583	99 860	1.43	0.008	0.008
Potato	4 852	35 438	6 167	19 648	1.00	0.019	0.014
Sugar beet	6 995	35 969	9 022	8 877	0.63	0.016	0.014
Silage	6780	769989	5383	869413	0.43	0.015	0.012
Cover crops	-	-	800	144930	-	0.025	0.016

DM = dry matter; yield = average crop yield; res/yield = above ground plant residues/crop yield, above N & below N = nitrogen content of above-ground and below-ground residues

*2006 IPCC GL, grass-clover mixture values used for cover crops

Table 5.4-7 Areas of cultivated organic soils in Finland (ha) and their nitrous oxide emissions (kt N_2O)

	Areas, ha				Emissions, kt N_2O		
Year	Total	Cropland, annual	Cropland, perennial	Grassland	Cropland, annual	Cropland, perennial	Grassland
1990	302 101	76 300	140 228	85 573	1.6	2.1	0.8
1995	286 018	75 150	137 909	72 959	1.5	2.1	0.7
2000	285 889	91 733	124 744	69 412	1.9	1.9	0.6
2005	305 989	100 873	136 276	68 840	2.1	2.0	0.6
2009	314 746	107 322	139 022	68 402	2.2	2.1	0.6
2010	316 685	97 301	151 478	67 906	2.0	2.3	0.6
2013	323 098	103 626	152 337	67 135	2.1	2.3	0.6
2014	325 139	105 613	152 906	66 620	2.2	2.3	0.6
2015	327 064	105 476	155 756	65 832	2.2	2.3	0.6
2016	329 701	103 955	160 719	65 027	2.1	2.4	0.6
2017	332 029	101 012	166 709	64 308	2.1	2.5	0.6
2018	335 114	98 267	173 066	63 781	2.0	2.6	0.6
2019	338 117	100 550	173 865	63 702	2.1	2.6	0.6
2020	341 031	105 236	171 646	64 149	2.1	2.6	0.6
2021	344 021	106 082	173 191	64 748	2.2	2.6	0.6
2022	346 866	109 471	172 026	65 369	2.2	2.6	0.6

5.4.2.3 Emission factors and other parameters

Country-specific emission factors have been used for calculating nitrous oxide emissions from agricultural soils (Table 5.4-8). As a country-specific emission factor for organic soils cultivated with annual plants, the default value in the IPCC Wetlands Supplement for drained organic croplands in boreal and temperate climate/vegetation zones is used (IPCC 2014, Chapter 2, Table 2.5).

Emissions from actively cultivated fields on organic soil with perennial plants are calculated using the default for boreal drained grassland from the same table in the IPCC Wetlands Supplement. In Finland, perennial crops are mainly grasses in crop rotation. Emissions from organic grassland soils that are mostly abandoned fields in Finland, are calculated using a country-specific EF (Maljanen et al. 2010b).

The direct emissions have been calculated with the modified Equation 11.1 (2006 IPCC Guidelines page 11.7):

$N_2O - N_{OS} = F_{OS,perennial} * EF1 + F_{OS,annual} * EF2 + F_{GL} * EF3$ (Eq. 11.1 modified)

N_2O-N_{OS} = nitrous oxide N from managed/drained organic soils
F_{OS} = annual area of managed/drained organic soils, ha
EF1 = EF for Cropland remaining and converted, perennials, 9.5 kg N_2O-N/ha/year (IPCC Wetlands Supplement 2013)
EF2 = EF for Cropland remaining and converted, annual crops 13.0 kg N_2O-N/ha/year (IPCC Wetlands Supplement 2013)
EF3 = EF for Grassland, 5.7 kg N_2O-N/ha/year (Maljanen et al. 2010b)

The cultivated areas on organic soils are determined by utilizing the Finnish Soil Database (Lilja et al., 2009), where areas with soil type classified under classes 410, 510, and 610-630 are identified as organic soils. The applicable areas of cultivated organic soils were calculated as a part of the production of land use data for the LULUCF sector (Section 6.3).

The EFs for boreal cropland (annual and perennial crops) from the IPCC Wetlands Supplement were considered suitable for estimating the emissions of N_2O from organic agricultural soils in active use since many of the measurements behind the EFs were carried out in Finland and EFs are based on a larger dataset than the former country-specific EFs. However, the EF for grasslands was taken from Maljanen et al. 2010b since the EF based on measurements on abandoned Nordic, mostly Finnish organic fields was found to represent these areas better. The great majority of the organic grasslands in Finland are abandoned fields.

Indirect N_2O emissions caused by atmospheric deposition have been calculated with the modified Equation 11.9 (2006 IPCC Guidelines page 11.21). FracGasm1,2,3 and FracGasf are country-specific:

$$N_2O_{AD} - N = \left[\left(F_{SN} * Frac_{Gasf}\right) + (F_{MN} * Frac_{Gasm1} + F_{SW} * Frac_{Gasm2} + F_{OF} * Frac_{Gasm2} + F_{PRP} * Frac_{Gasm3})\right] * \mathrm{EF}$$

F_{SN} = annual amount of synthetic fertiliser N applied to soils (=sold annually), kg N/a
$Frac_{Gasf}$ = c. 0.015 kg N volatilised/kg of N applied (from Nitrogen mass flow model, country-specific)
F_{MN} = annual amount of animal manure applied to soils, kg N/a
$Frac_{Gasm1}$ = c. 0.08-0.1 kg N volatilised /kg of N applied (not including dry lot & pasture)
F_{SW} = annual amount of sewage applied to soils, kg N/a
F_{OF} = annual amount of other organic fertilizers applied to soils, kg N/a
$Frac_{Gasm2}$ = c. 0.08-0.09 kg N volatilised /kg of N applied or deposited (not including dry lot, including pasture)
F_{PRP} = annual amount of urine & dung N deposited by grazing animals on pasture, kg N/a
$Frac_{Gasm3}$ = c. 0.044 kg N volatilised /kg of N deposited
$Frac_{Gasm}$ and $Frac_{Gasf}$ are calculated from the data acquired from the N mass flow model.
EF = 0.01 kg N_2O-N/kg N volatilised (default)

Emission factors for the volatilization of ammonia and the reduction effects of different abatement measures on ammonia emissions are documented in Grönroos et al. (2009), see also Section 5.4.2.1 *Nitrous oxide from manure and synthetic fertilisers*. Emission factors for the volatilization of nitric oxide and dinitrogen from manure are derived from the EMEP/EEA Guidebook 2016 (EMEP/EEA 2016).

For crop residues including cover crops, plant biomasses and crop residues are estimated on the basis of group-specific dry matter contents, harvest indices (harvest index) and shoot to root ratios. Country-specific parameters are used (Palosuo et al. 2015, Känkänen 2019 (see Appendix_6j)). Nitrogen contents are taken from the 2006 IPCC Guidelines (Table 5.4-8).

Table 5.4-8 Emission factors used for calculating direct and indirect nitrous oxide emissions from agricultural soils

Emission source	Emission factor	Reference
Direct soil emissions		
Synthetic fertilisers	0.01 kg N_2O-N/kg N	2006 IPCC GLs, table 11.1
Animal wastes, sewage sludge and other organic fertilizers applied to soils	0.01 kg N_2O-N/kg N	2006 IPCC GLs, table 11.1
N excretion on pasture, range and paddock	0.02 and 0.01 kg N_2O-N/kg N	2006 IPCC GLs, table 11.1
Crop residue	0.01 kg N_2O-N/kg N input	2006 IPCC GLs, table 11.1
Mineralisation on mineral soils	0.01 kg N2O-N/kg N mineralised	2006 IPCC GLs, table 11.1
Cultivation of organic soils on cereals (cropland)	13.0 kg N_2O-N/ha/a	IPCC Wetlands Supplement (2013; table 2.5): Augustin et al., 1998; Drösler et al., 2013; Elsgaard et al., 2012; Flessa et al., 1998; Kasimir-Klemedtsson et al., 2009; Maljanen et al., 2003a,b, 2004, 2007; Petersen et al., 2012; Regina et al., 2004; Taft et al., 2013
Cultivation of organic soils on perennials (cropland)	9.5 kg N_2O-N/ha/a	IPCC Wetlands Supplement (2013; table 2.5): Grønlund et al., 2006; Hyvönen et al., 2009; Jaakkola, 1985; Maljanen et al., 2001, 2003a, 2004, 2009, 2010a; Nykänen et al., 1995; Regina et al., 1996, 2004
Cultivation of organic soils (grassland)	5.7 kg N_2O-N/ha/a	Maljanen et al. 2010b
Atmospheric deposition	0.01 kg N_2O-N/kg NH_3-N & NO_x-N deposited	2006 IPCC GLs, table 11.3
Nitrogen leaching and run-off*	0.011 kg N_2O-N/kg N/a	2019 Refinement to the 2006 IPCC GLs, table 11.3

*note IPCC 2019 default

Table 5.4-9 Fraction of N lost through leaching and run-off and volatilisation from synthetic fertilisers, manure and sewage sludge and other organic fertilizers

Parameter	Abbreviation	Value	Reference
Fraction of N input that is lost through leaching or run-off	$Frac_{LEACH}$	0.144	Huttunen et al. 2023
Fraction of N input that volatilises as NH_3 and NO_x from synthetic fertilisers	$Frac_{GASF}$	0.015	EMEP/CORINAIR Emission Inventory Guidebook 2007
Fraction of manure N input* that volatilises as NH_3 and NO_x	$Frac_{GASM}$	0.08-0.09	EMEP/EEA Guidebook 2016

*pasture&manure&bedding application, same FracGasm is used for sewage sludge and other organic fertilizers

5.4.3 Uncertainty assessment and time series' consistency

Quantitative estimates of uncertainty are provided in Annex 2. A description of the uncertainty analysis is included in Section 1.6.

The uncertainties in N_2O emissions from agricultural soils are estimated by applying the Tier 2 Monte Carlo simulation directly to the emission calculation models (LUKEAgri calculation sheet and Nitrogen mass flow model).

The uncertainty in the direct nitrous oxide emission factor for agricultural soils is based on the uncertainty range given in the 2006 IPCC Guidelines (-70…+200%). Uncertainties in the national emission factors for nitrous oxide from organic soils are estimated at -37…+38% (cereals) and -52…+47% for perennials (lognormally distributed) based on the IPCC Wetlands Supplement 2013. For grassland, the uncertainty is estimated to be ±64% (Maljanen 2010b). The uncertainty in the indirect nitrous oxide emission factor from atmospheric deposition is estimated at -80…+400% based on the uncertainty range in the 2006 IPCC Guidelines and the uncertainty in indirect nitrous oxide emission, the factor for leaching is -66…+167%. Uncertainty of the emission factors is due to both lack of knowledge of the emission generating processes and high natural variability, which make estimation of the average annual emission factor difficult.

Activity data and related uncertainties used for calculating nitrous oxide emissions from manure input to agricultural soils were the same as in the calculation of nitrous oxide emissions from manure management (CRF 3.B). Uncertainty estimate of the area of cover crops is -5…+5%, based on expert judgement (Heikkinen & Känkänen 2021). The cover crop area is obtained from the Finnish Food Authority database; it is the area declared for the cover crop subsidy. A limited area per farm is eligible for the subsidy, and some farmers may declare only that, which causes underestimation of the area. On the other hand, the cover crop establishment does not always succeed, which causes overestimation of the area. Uncertainty estimates of other activity data were based on expert judgement (Monni et al. 2007).

As the same calculation methods are used for the whole time series 1990 to 2021, the time series can be considered consistent (see also Sections 5.2.3 and 5.3.3 for animal numbers and manure management data).

5.4.4 Category-specific QA/QC and verification

The quality objectives and the QA/QC plan for the Finnish greenhouse gas inventory at the national inventory level are presented in Section 1.5. The QC procedures are performed according to the QA/QC plan in order to attain these quality objectives. A bilateral quality meeting is held annually between the inventory unit and the sectoral expert. In the 2024 quality meeting we discussed the possibilities for updating manure management data and national N excretion calculations for swine and poultry in forthcoming submissions.

Quality Control (QC) procedures applied to the category Agricultural soils (CRF 3.D):

The QA/QC plan for the agricultural sector includes the QC measures presented in the 2006 IPCC Guidelines (Vol 1, Chapter 6, Table 6.1). These measures are implemented every year during preparation of the agricultural inventory. If errors or inconsistencies are found, they are documented and corrected. The QC checklist (LUKEagri check) is used during the inventory. The check includes, for example, checking of formulas, links between sheets and evaluating correctness of parameters used with cross-checks to previous years. The results from the Nitrogen mass flow model are compared with a simpler calculation built in LUKEagri calculation sheets to examine possible problems with the model.

A checklist (LUKEagri check) is used for ensuring consistency of the activity data in different sections of the agricultural inventory. The checklist is a list of the activity data with a column for marking the result of the check. Graphs are used to compare N input with previous years.

Country-specific EFs are used for organic soils. See Section 5.4.2.3 about the selection of EFs. Areas are coherent with the LULUCF sector.

Quality assurance and verification:

Every year we check the availability of new data for updating the emission factors. When new research results are published, the current emission factors are reconsidered. For 2022 inventory (2024 submission) the calculations for GE (gross energy), DE (digestible energy) and volatile solids in cattle were renewed for the entire time series 1990-2022. This revision was prompted by the adoption of a new country-specific method for national cattle excretion (Nousiainen et al., 2023). These revisions had an effect on emissions related to N mineralization, the application of organic fertilizers, and the deposition of urine and dung on pasture, as outlined in Section 5.4.5.

Formulas and cell references used in Lukeagri calculation sheets have been regularly reviewed, compared with the 2006 IPCC Guidelines and updated by the researchers working in the inventory as necessary. The 2021 submissions calculations have been made by new researchers in the inventory, T. Silfver and X. Tarpio.

The agricultural inventory is reviewed by the UNFCCC Expert Review teams and the EU Technical Expert Review teams, and improvements to the inventory are made according to the recommendations.

5.4.5 Category- specific recalculations

Due to the adoption of a new country-specific method for national cattle excretion (Nousiainen et. al. 2023), the calculations for gross energy (GE), digestible energy (DE), volatile solids (VS), and excreted nitrogen (N) in cattle were updated for the entire time series 1990-2022. These revisions influenced emissions from agricultural soil, particularly by increasing emissions related to the application of organic fertilizer, the deposition of urine and dung on pasture, and nitrogen mineralization at the beginning of the time series but decreased them towards the end of the time series. Additionally, new area estimates for cropland and grassland that were calculated due to the updating of NFI data (see Section 6.2) affected the emissions from nitrogen mineralisation in mineral soils and the emissions from the cultivation of organic soils. The effect of these updates on total emissions from agricultural soils ranged from -29 kt CO_2 eq. (in 2014) to +41 kt CO_2 eq. (in 1990) during 1990-2021, resulting in an average increase of 0.3 %. The emissions of 2021 increased 2 kt CO_2 eq.

5.4.6 Category-specific planned improvements

The adoption of the revised Nitrogen flow model (Grönroos et al., 2017), which will particularly influence volatilization calculations, is scheduled for the 2025 submission.

5.5 Field Burning of Agricultural Residues (CRF 3.F)

5.5.1 Category description

Field burning of crop residues (CRF 3.F) has generally been a minor emission source in Finland, comprising less than 0.05% of the emissions in the Agriculture Sector. Since the beginning of 2021, field burning of crop residues is not allowed according to the Ministry of Agriculture and Forestry, and the compliance of this rule is now a condition for being able to apply full subsidies. The decision was adopted, as it was estimated that in Finland the field burning of crop residues is not necessary in order to succeed in sowing or to prevent weeds, diseases and pets. Therefore, from 2021 onwards the emissions are estimated as not occurring. The methodology, activity data and all other information concerning the calculations of the emission in this category for the earlier years (1990-2020) are presented in NIR 2020 (submission 2022).

5.6 Liming (CRF 3.G)

5.6.1 Category description

Liming is used to reduce soil acidity and improve plant growth but adding carbonates to soils in the form of limestone (for example, calcic limestone ($CaCO_3$), or dolomite ($CaMg(CO_3)_2$) leads to CO_2 emissions as the carbonate limes dissolve and release bicarbonate, which evolves into CO_2 and water. Emissions from all liming are reported under Agriculture. Most of the limestone use is assumed to take place on cropland, a minor part is used on grasslands or for landscape development in settlements. Forest lands are not limed in Finland (Ala-Mantila 2021).

The annual reports for all fertilizer manufacturers for the year 2022 were not received on time by the statistical services at the Natural Resources Institute Finland (Luke) for the inventory. The delay is attributed to a change in the schedule, particularly the adoption of a new submission system for the annual reports at the Finnish Food Authority, which has proven to be more demanding than expected. As a result, estimates for lime quantities for the year 2022 are calculated based on the change between 2021 and 2022 in the lime quantities of those companies for which the data has already been obtained for 2022. The assumption is that the change in lime quantities between 2021 and 2022 for the companies with the missing data for 2022 is equal to that of the companies included in the data. The estimated share of lime quantity for missing companies in the total lime quantity is 21%.

Emissions were 0.25 Mt in 2022, which is 61% less than in 1990. In general, emissions from liming have decreased as the usage of lime has declined, most likely because the liming demand is nowadays increasingly better based on soil fertility and pH sampling reducing excess liming. However, emissions were 25% higher (0.05 Mt CO_2) in 2022 compared to 2021. This increase is likely due to the high prices and limited availability of fertilizers. As a result, the shortage of fertilizers has been addressed by increasing lime application, as lime facilitates nutrient uptakes and thus reduces the need for fertilizers.

5.6.2 Methodological issues

5.6.2.1 Methods

The emissions from liming have been calculated using the IPCC method (Tier 1) described in the 2006 IPCC Guidelines (Eq. 11.12). Limestone ($CaCO_3$), dolomite ($MgCa(CO_3)_2$) and briquette lime are included. The amount of lime sold annually is multiplied by the specific emission factor for each lime type in order to estimate the amount of carbon in each compound. The highwater content (37.5%) of briquette lime (waste material from sugar factories) is taken into account in the calculations. Carbon is converted to CO_2 by multiplying it by 44/12.

5.6.2.2 Activity data

Activity data comprises the annually manufactured and imported lime (Table 5.6-1). Data for the years from 1990 to 2012 is based on the amount of manufactured lime from the Liming Association and import data from the Finnish Food Safety Authority Evira. Import data from Evira are available from the year 2005 onwards. Imports during 1990 to 2004 were estimated to be the average of the years 2005 to 2014 because no clear trend was found in the values during this period. The imports were assumed to consist solely of limestone, as the share of dolomite and different side products of the total imports was small.

When Liming Association ceased its activities, the amounts of both the manufactured and imported lime were obtained (from the year 2013 onwards) from the Finnish Food Safety Authority Evira, now Finnish Food Authority. Evira/Finnish Food Authority compiles statistics of liming materials that are manufactured in

Finland or imported based on the reports of operators (Fertiliser Product Act 539/2006) grouped by type designation.

The liming activity data includes several liming product type designations other than limestone, dolomite and briquette lime. The carbonate content of each type of designation is estimated based on the national type designation list of fertiliser products (Finnish Food Authority 2019), as well as data available from the operators (Table 5.6-2). The liming product's carbonate content was estimated to be 80% if it was reported to contain primarily carbonate lime. The carbonate content of some type of designations was reported to be uncertain, and these were estimated to contain 50% carbonate lime. The share of dolomite from the manufactured lime is estimated to be 30% (Yli-Savola 2005) until 2013, and thereafter the amount of dolomite is available in the data received from Finnish Food Authority. For the years 2013-2014 the amount of dolomite in the data from the Finnish Food Authority was exceptionally low however, and therefore these years were interpolated to maintain consistent time series. Also, minor amounts of eggshell lime have been manufactured but these are excluded from the calculation as they are not of fossil origin.

There are also minor amounts of carbonate lime included in other fertiliser products than liming products (Evira 2011), but these were excluded from the calculation, as sufficient data on the composition of these products are unavailable. Also, most of this carbonate lime is already included in the calculation as the operators have reported to Evira that approximately 0.98% of the produced liming products were used in further processing in the time period 2005 to 2014.

Table 5.6-1 The amount of annual lime used in the estimation of the emissions (calculated as $CaCO_3$) (1,000 t/year).

Year	Cropland		
	Limestone + briquette lime	Dolomite	Total
1990	686	714	1 400
1995	665	246	911
2000	571	207	778
2005	478	167	645
2009	548	204	752
2010	458	159	617
2013	612	95	706
2014	482	63	545
2015	334	32	366
2016	518	50	568
2017	379	40	418
2018	354	82	436
2019	367	41	408
2020	379	39	417
2021	408	15	423
2022	548	18	566

Table 5.6-2 Liming products manufactured in Finland and their carbonate contents

Liming materials total	Share of $CaCO_3$	Reference
Limestone and other liming materials		
Limestone, $CaCO_3$	1	Finnish Food Authority 2019
Dolomite, $CaMg(CO_3)_2$	1	Finnish Food Authority 2019
Cinereous lime granules	0.5	Apila Group Oy Ab 2013
Mixture of liming materials and side products used as liming materials as such	0.5	Finnish Food Authority 2019
Biotite	0	Mälkki 1998

Side products used as liming materials as such		
Briquette lime	1	Suominen 2007
Precipitation residue of PCC lime	1	Finnish Food Authority 2019
Lime sludge	0.8	Apila Group Oy Ab 2013
Calciferous stone	0.8	Finnish Food Authority 2019
Mixture of limestone or dolomite and calcium oxide	0.5	Finnish Food Authority 2019
Mixture of side products used as liming materials as such	0.5	Finnish Food Authority 2019
Blast furnace slag	0	Finnish Food Authority 2019
Steel slag	0	Finnish Food Authority 2019
Lime kiln filter dust	0	SMA Mineral Oy 2013
Lime slaking residue	0	SMA Mineral Oy 2013
Lime tailings	0	Omya Oy 2011, Mälkki 1998
Carbide lime	0	Finnish Food Authority 2019

For the dry matter content of briquette lime, a value reported by the producing company, 62.5% (Suominen 2007) is used for the whole time series.

5.6.2.3 Emission factors and other parameters

The IPCC default emission factors are used for calculating CO_2 emissions from agricultural lime application. The emission factors are 0.12 for limestone, 0.13 for dolomite and 0.12 for briquette lime (2006 IPCC Guidelines). The emissions from limestone and briquette lime have been combined in the CRF table for limestone since they have the same emission factor. For the other lime types, the share of $CaCO_2$ (see Table 5.6-2 above) is taken into account in the estimation of the CO_2 emissions.

5.6.3 Uncertainty assessment and time series' consistency

Quantitative estimates of uncertainty are provided in Annex 2. A description of the uncertainty analysis is included in Section 1.6.

The estimation of the amount of lime applied annually is based on manufacturing statistics and imported lime, and not on the actual applied amounts which causes some uncertainty in the actual annual emissions in this source category. This bias should, however, be negligible over long term. The uncertainty in activity data for liming is estimated at ±20% based on expert judgement. The uncertainty estimate for the emission factor is -50%. This includes the uncertainty in the carbonate content of other lime products than limestone, dolomite and briquette lime.

As two different activity data sets (see Section 5.6.2.2) are used in the calculation, the time series' consistency was checked by calculating the emissions from 2005 to 2012 with both data sets (import excluded). The use of data received from Finnish Food Safety Authority Evira provides on average 5% smaller values for the total annual lime emissions for the years 2005 to 2012 compared with Liming Association data see Figure 5.6-1. The difference in the data in the two sets is considered sufficiently low, taking into account the estimated activity data uncertainty and data availability, to assume that the times series can be considered consistent.

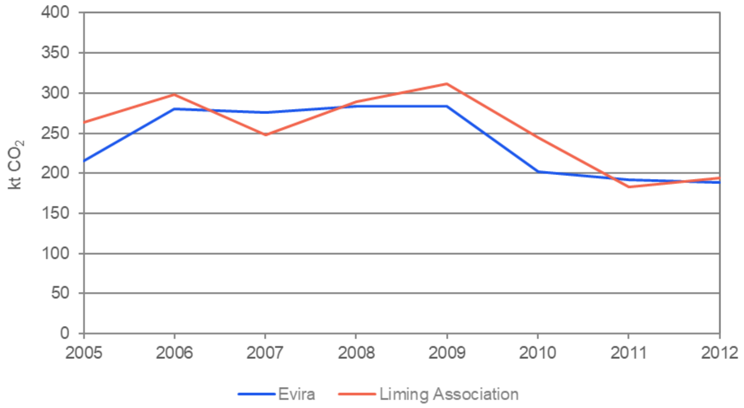


Figure 5.6-1 Comparison of emissions between Liming association and Evira, import excluded

5.6.4 Category-specific QA/QC and verification

The quality objectives and the QA/QC plan for the Finnish greenhouse gas inventory at the national inventory level are presented in Section 1.5. The QC procedures are performed according to the QA/QC plan in order to attain these quality objectives. A bilateral quality meeting is held annually between the inventory unit and the sectoral expert.

Quality Control (QC) procedures applied to the category Liming (CRF 3.G):

The QA/QC plan for the agricultural sector includes the QC measures presented in the 2006 IPCC Guidelines (Vol 1, Chapter 6, Table 6.1). These measures are implemented every year during the preparation of the agricultural inventory. If errors or inconsistencies are found, they are documented and corrected. The QC checklist (LUKEagri check) is used during the inventory. The check includes, for example, checking of formulas, links between sheets and evaluating correctness of parameters used with cross-checks to previous years. A checklist (LUKEagri check) is used for ensuring consistency of the activity data in different sections of the agricultural inventory. The checklist is a list of the activity data with a column for marking the result of the check.

Quality assurance and verification:

We check periodically if new scientific articles for updating emission factors have been published. Results of the articles will be taken into account in evaluating emission factors.

The agricultural inventory is reviewed by the UNFCCC Expert Review teams and the EU Technical Expert Review teams, and improvements to the inventory are made according to the recommendations, where possible.

5.6.5 Category-specific recalculations

There were no category-specific recalculations done.

5.6.6 Category-specific planned improvements

No planned improvements.

5.7 Urea application (CRF 3.H)

5.7.1 Category description

Urea fertilisation to soils leads to a loss of CO_2. Urea is converted into ammonium, hydroxyl ion, and bicarbonate in the presence of water and urease enzymes. Bicarbonate evolves into CO_2 and water. Under this category, CO_2 emissions from urea application emissions to all soils, not only agriculture, should be reported. Finland has a short growing season and acid soils, which are not well suited for urea fertilising, but urea has nevertheless been applied to agricultural and forest soils in a small scale.

The emissions from urea are small, and they have decreased by 44% since 1990. This decrease can be attributed to the nitrates directive (91/676/EEC) through which the emission arising from fertilization have been more strictly regulated since late 1990s. Data of urea are also used in the N flow model for indirect N_2O emission calculation of synthetic fertilisers (deposition). The annual reports for all fertilizer manufacturers for the year 2022 were not received on time by the statistical services at the Natural Resources Institute Finland (Luke) for the inventory. The delay is attributed to a change in the schedule, particularly the adoption of a new submission system for the annual reports at the Finnish Food Authority, which has proven to be more demanding than expected. As a result, estimates for urea quantities for the year 2022 are calculated based on the change between 2021 and 2022 in the urea quantities of those companies for which data has already been obtained for 2022. The assumption is that the change in urea quantities between 2021 and 2022 for the companies with the missing data for 2022 is equal to that of the companies included in the data. The CO_2 emission of agricultural urea was 7.8 kt for 2022 which is approximately six times bigger than in 2021. The increased usage of urea in both forestry and agriculture may be attributed to more favourable pricing of urea compared to other nitrogen fertilizers. However, in agriculture, urea's share of the total nitrogen amount in fertilizers remains relatively small.

Small amounts of urea are used as a fertiliser in forest land. Annual CO_2 emissions from urea application to forest lands were estimated to be 2 kt for 2022 in official statistics.

5.7.2 Methodological issues

5.7.2.1 Methods

Urea fertilisation CO_2 emissions are calculated following the 2006 IPCC Guidelines (Eq. 11.13, Tier 1). Carbon is converted to CO_2 by multiplying it by 44/12.

5.7.2.2 Activity data

The amount of urea used in agriculture was obtained from Kemira Agro Oy (Kekäläinen A., annual) for the years 1990 to 1999, and from the records of imported fertilisers collected by the Finnish Food Safety Authority Evira from 2010 onwards. The years from 2000 to 2009 were interpolated. An inquiry to the Information Centre of the Ministry of Agriculture and Forestry, now part of Luke, has revealed that no survey has been carried out on the use of urea on agricultural fields. The amount of urea fertiliser applied to forest soils was obtained from Yara for the years 1995 to 2016. From the year 2018 onwards, both the amount of urea used in agriculture and the amount of urea applied to forest soils are obtained from the records of manufactured and imported fertilisers, collected by the Finnish Food Safety Authority Evira/Finnish Food Authority. For the years 2018 and 2021, forestry use of urea was zero in the records. For such zero cases, we had earlier used - previous year’s value but decided to change them to zero as in official statistics.

5.7.2.3 Emission factors and other parameters

Default EF of 0.2 was applied to estimate CO_2 emissions, based on the 2006 IPCC Guidelines.

5.7.3 Uncertainty assessment and time series' consistency

Quantitative estimates of uncertainty are provided in Annex 2. The annex also documents assumptions made for the analysis. A description of the uncertainty analysis is included in Section 1.6.

Uncertainty estimates are based on the 2006 IPCC Guidelines. The time series of forest urea has been checked for consistency. From the year 2000 onwards, sales data of agricultural urea are no longer available to the inventory, so we are forced to use other, less direct data sources. In the records of the manufactured and imported fertilisers, the end use of each product (agriculture/forest/home garden) was not registered before the year 2018, and even for 2018 the information is not complete. Expert evaluation based on product name, fertiliser type and package size is needed to determine the end use. Linear interpolation is used to fill in the time series gaps resulting from the years of missing data in agricultural urea.

5.7.4 Category-specific QA/QC and verification

The quality objectives and the QA/QC plan for the Finnish greenhouse gas inventory at the national inventory level are presented in Section 1.5. The QC procedures are performed according to the QA/QC plan in order to attain these quality objectives. In the 2024 quality meeting, we discussed the difficulties in achieving the latest statistics for urea use in time.

5.7.5 Category-specific recalculations

There were no category-specific recalculations done.

5.7.6 Category-specific planned improvements

No improvements are currently planned.

Appendix_5a

Activity data for the Agricultural sector

Table 1_App_5a. Animal numbers in Finland (x 1,000)

Year	Cattle					Swine				
	Dairy cows	Suckler cows	Heifers >1 yr	Bulls >1 yr	Calves <1 yr	Sows (w. piglets)	Piglets	Fattening pigs	Boars	Weaned pigs
1990	489.90	14.20	218.80	148.90	487.90	178.76	394.04	476.39	5.93	283.49
1991	445.60	21.20	213.50	144.10	485.50	173.96	383.46	463.59	5.77	275.87
1992	428.20	27.90	211.10	143.30	462.70	167.96	370.22	447.59	5.57	266.35
1993	426.40	33.10	216.70	139.20	436.90	164.69	363.03	438.90	5.47	261.18
1994	416.70	32.60	214.80	143.50	425.40	168.01	370.33	447.73	5.58	266.43
1995	398.50	29.20	188.90	109.30	422.00	161.10	420.54	490.63	6.50	276.99
1996	392.20	31.10	201.10	114.70	406.50	179.80	402.69	483.99	6.60	279.44
1997	390.90	32.40	196.80	120.50	401.80	185.20	386.86	511.96	7.10	331.83
1998	383.05	30.58	190.35	114.75	398.35	186.50	378.99	457.76	7.80	323.42
1999	372.40	29.60	187.50	118.10	379.20	180.20	386.60	469.19	5.80	268.67
2000	364.12	27.83	185.00	114.89	364.76	184.30	363.96	440.67	6.00	261.70
2001	354.83	27.18	181.73	111.34	362.34	163.60	361.49	425.76	5.40	263.87
2002	347.78	28.13	179.98	115.28	354.21	172.20	386.07	440.56	5.30	267.86
2003	333.87	28.15	178.54	115.46	344.15	178.10	398.44	483.23	5.00	268.85
2004	324.38	30.83	173.09	110.45	330.39	175.00	399.95	480.18	4.70	263.60
2005	318.76	34.61	168.78	107.81	328.97	176.70	398.71	500.31	4.40	279.89
2006	309.42	38.91	170.83	112.47	317.66	170.89	422.13	497.83	4.04	295.55
2007	296.07	43.28	166.47	109.78	311.10	177.30	391.80	524.60	4.40	328.70
2008	289.28	48.22	164.74	108.52	304.58	167.10	383.30	532.90	3.90	312.30
2009	290.04	51.82	162.55	109.51	304.35	155.90	355.50	535.20	3.50	303.20
2010	289.34	55.37	163.77	114.22	303.11	146.40	360.90	525.60	3.10	303.90
2011	285.53	57.26	161.92	110.78	298.56	134.20	333.50	530.60	3.00	288.40
2012	283.62	57.95	159.66	108.59	302.95	130.00	327.40	534.30	2.30	276.50
2013	283.12	57.33	161.80	109.63	299.97	121.50	328.40	533.60	2.00	272.70
2014	285.25	57.79	158.11	109.91	303.38	117.80	327.50	506.80	2.00	268.50
2015	285.15	58.71	154.61	109.35	306.90	115.80	345.30	501.10	2.10	274.70
2016	282.44	58.98	150.16	107.79	309.65	108.10	342.30	489.20	1.60	255.50
2017	274.95	59.85	150.27	110.77	297.33	99.10	312.40	446.90	1.40	248.50
2018	271.43	60.10	146.10	105.77	298.88	95.20	273.30	425.00	1.40	246.20
2019	262.29	60.35	142.43	104.49	288.07	92.20	272.40	438.60	1.30	257.70
2020	259.58	61.98	136.45	98.19	290.20	88.70	299.70	450.60	1.10	263.70
2021	253.53	63.70	136.47	101.47	288.87	93.00	338.50	405.40	1.00	255.90
2022	248.01	65.15	137.28	102.22	281.34	85.00	301.78	379.84	0.81	230.30

N.B. Fattening pigs = 50+ kg and weaned pigs = 20-50 kg

Year	Poultry							Sheep	Goats	Horses	Ponies	Minks & fitches	Foxes & raccoon dogs	Reindeer
	Laying hens	Broilers	Chickens	Cockerels	Broiler hens	Turkeys	Other poultry							
1990	4 844.80	2 993.00	1 632.50	49.70	61.83	59.90	20.77	103.30	5.90	39.40	6.00	1 838.00	1 508.23	239.07
1991	4 138.00	3 249.68	1 303.50	44.80	97.20	63.92	31.80	106.70	5.35	41.73	6.39	1 604.00	1 124.48	259.61
1992	3 968.90	3 506.36	1 597.50	39.90	132.57	67.94	42.93	108.40	4.80	42.72	6.40	1 683.00	1 366.00	231.64
1993	4 024.90	3 763.04	1 522.30	35.00	167.94	71.96	54.06	120.40	4.80	42.65	6.33	1 584.00	1 525.00	215.36
1994	4 089.80	4 019.72	1 421.60	30.10	203.31	75.98	65.19	121.10	5.70	42.13	6.16	1 870.00	1 938.76	214.27
1995	4 178.80	4 276.40	1 482.30	25.20	239.80	80.00	75.20	158.60	6.00	43.71	6.23	1 939.00	2 042.00	208.14
1996	4 183.50	4 052.40	1 245.60	24.60	278.60	95.80	54.30	149.50	6.50	45.62	6.41	2 041.00	2 622.00	212.85
1997	4 151.50	4 911.10	1 287.80	32.00	299.20	111.60	33.40	150.10	8.00	47.87	6.75	2 117.00	2 587.83	202.62
1998	3 801.80	5 507.20	1 184.70	29.50	347.10	144.80	34.50	128.29	8.11	49.24	6.90	2 112.00	2 866.00	196.14
1999	3 361.30	5 998.20	1 025.30	17.20	382.40	210.00	39.20	106.60	7.90	49.60	6.60	1 802.50	1 762.00	195.44
2000	3 110.00	7 917.90	914.40	17.60	363.50	214.50	31.60	99.60	8.60	50.70	6.70	1 900.80	1 905.00	203.42
2001	3 201.70	5 412.10	1 043.00	12.40	393.90	455.40	35.10	96.00	7.45	51.90	6.70	2 000.70	2 104.00	185.73
2002	3 212.50	5 766.30	772.30	9.40	401.60	530.50	41.40	95.88	6.61	52.10	7.00	2 000.66	2 268.00	199.71
2003	3 016.20	6 050.30	930.90	10.10	346.00	603.40	40.20	98.41	6.76	52.90	7.29	2 000.86	2 670.00	196.73
2004	3 069.20	5 573.20	911.60	10.40	287.40	535.30	18.10	108.89	7.27	53.76	7.30	1 701.40	2 601.00	201.06
2005	3 127.60	5 472.30	953.60	12.30	456.99	495.40	19.95	89.74	6.94	56.11	7.66	1 901.30	2 207.00	207.16
2006	3 103.33	5 366.14	844.01	13.40	404.54	492.64	14.95	116.65	6.67	58.05	8.00	2 001.00	2 346.00	197.80
2007	3 134.43	5 074.09	763.87	12.90	350.94	430.51	24.33	119.25	6.18	59.50	8.50	2 100.50	2 073.00	193.34
2008	3 190.25	5 674.55	865.46	18.51	338.86	414.77	19.26	122.22	5.92	60.55	8.80	1 801.00	1 947.00	195.42
2009	2 926.09	4 918.45	858.92	15.50	328.58	306.11	15.80	117.67	5.92	63.00	9.30	1 900.04	1 636.00	192.92
2010	3 393.77	4 616.21	837.85	14.24	432.64	279.67	12.43	125.67	4.89	64.60	9.70	1 900.05	1 697.00	193.65
2011	3 304.31	5 421.35	745.35	21.73	420.61	308.14	14.19	129.09	4.90	65.30	10.20	1 700.00	1 883.00	196.37
2012	3 172.60	6 038.34	743.44	27.09	470.63	294.64	13.84	130.01	4.89	65.00	10.40	1 800.00	2 164.00	191.92
2013	3 432.19	6 861.15	857.56	22.45	520.14	274.34	12.73	135.55	4.51	64.60	10.40	2 000.00	2 186.00	191.60
2014	3 645.32	7 341.22	714.07	24.62	544.41	291.95	15.26	137.87	4.36	64.20	10.40	2 100.00	2 437.00	186.78
2015	3 594.54	7 827.34	662.23	25.50	548.18	245.91	23.25	155.24	4.55	63.80	10.40	1 900.00	2 796.00	191.10
2016	3 598.94	8 271.56	747.63	26.27	523.22	260.31	16.93	156.50	4.80	63.80	10.40	1 620.00	2 168.00	191.47
2017	3 745.94	8 046.70	508.87	22.34	472.98	291.58	47.21	155.93	5.28	64.00	10.40	1 448.00	2 282.00	193.14
2018	3 984.82	8 780.90	607.63	17.43	424.30	299.09	26.14	155.00	5.44	64.00	10.40	1 368.00	2 092.00	184.96
2019	3 900.39	9 111.74	647.26	16.41	394.72	262.65	26.76	144.88	5.93	63.90	10.40	1 042.00	2 060.00	188.19
2020	3 811.55	8 507.33	566.33	17.96	396.10	267.99	9.64	140.17	6.03	64.00	10.00	768.00	1 413.00	194.97
2021	3 729.00	8 499.27	796.12	21.55	478.78	296.02	11.19	131.09	5.93	64.00	10.00	778.00	1 266.00	182.45
2022	3 865.83	8 900.74	664.53	24.18	597.65	294.21	8.70	132.08	6.30	59.00	13.00	538.00	773.00	185.36

Table 2_App_5a. Cattle live weights and mature weights, kg (Source: Natural Resources Institute Finland Luke)

Year	Dairy cow		Suckler cow		Bull (>1 year)		Heifer		Calf (<1 year)	
	Live weight	Mature weight	Live weight	Mature weight	Live weight	Mature weight	Live weight	Mature weight	Live weight	Mature weight
1990	546.4	577.9	558.8	584.9	448.1	804.6	403.6	568.6	196.1	692.6
1991	544.3	576.8	557.1	583.3	459.5	803.4	404.2	567.0	196.4	691.8
1992	537.9	570.6	550.7	576.6	457.5	795.6	401.3	561.2	195.5	685.1
1993	550.6	584.6	563.9	590.3	456.0	815.5	411.0	577.3	197.7	702.8
1994	557.4	591.8	570.9	597.5	464.6	826.2	416.1	584.5	199.2	712.1
1995	555.2	590.1	568.8	595.3	461.5	823.7	415.6	583.7	198.9	710.2
1996	566.0	601.5	579.6	606.6	466.9	832.5	423.8	595.1	200.6	719.7
1997	572.3	608.3	585.4	612.7	461.7	844.4	428.3	603.0	201.7	729.7
1998	570.7	607.1	581.8	608.9	459.0	845.0	428.9	602.5	201.8	729.8
1999	573.9	610.6	583.8	611.0	462.7	851.5	431.2	606.1	202.6	735.0
2000	577.9	614.2	567.2	595.9	471.8	839.5	433.9	605.8	202.6	729.5
2001	583.2	619.8	575.2	603.5	483.7	860.5	438.5	613.4	205.0	743.9
2002	591.8	629.0	594.1	621.0	503.9	894.3	445.3	624.4	209.0	766.2
2003	596.5	634.1	600.8	628.2	519.3	918.4	448.1	630.1	211.8	781.1
2004	600.7	638.3	616.2	643.2	530.3	937.2	453.3	635.4	214.4	793.9
2005	602.8	640.5	609.0	636.0	531.1	936.1	455.1	636.9	214.4	794.0
2006	597.7	635.2	613.6	641.5	539.3	940.3	453.9	632.8	214.7	794.0
2007	609.5	647.5	627.6	656.1	551.8	960.3	461.9	645.0	218.0	810.6
2008	614.8	653.0	632.8	661.5	554.7	965.2	466.7	651.4	219.0	816.3
2009	616.1	654.3	637.2	666.1	556.0	964.6	468.2	652.5	219.0	816.6
2010	623.0	661.3	647.7	676.8	566.4	973.9	473.2	659.3	221.1	824.6
2011	628.7	667.3	660.1	689.3	561.7	967.9	476.5	665.3	221.0	825.1
2012	633.7	672.7	656.0	684.2	552.1	954.1	477.3	667.5	219.8	819.1
2013	642.8	682.2	663.8	692.1	547.7	947.8	480.5	674.1	219.6	818.6
2014	648.4	688.3	670.7	698.4	555.6	960.2	483.4	680.2	221.6	827.9
2015	654.8	695.1	675.1	702.7	564.0	982.9	485.3	686.9	224.5	843.1
2016	656.3	697.1	685.1	711.7	564.2	988.3	483.7	689.3	225.1	846.7
2017	662.6	703.4	681.4	707.5	568.8	996.1	487.2	694.2	226.9	855.3
2018	663.3	704.0	680.7	706.9	576.7	1006.9	486.6	694.5	228.3	861.7
2019	684.0	725.8	695.0	722.7	587.4	1030.7	499.7	715.8	233.2	884.0
2020	705.7	748.4	727.5	755.5	598.2	1053.0	513.7	739.5	238.3	906.9
2021	723.1	766.6	729.5	757.6	596.9	1059.6	522.8	755.7	240.7	919.7
2022	719.3	762.5	728.8	757.4	590.6	1054.5	520.5	753.2	238.8	912.9

Table 3_App_5a. Annual average N excretion per animal (kg N/animal/year). Cockerels 1.0, broiler hens 1.0, goats 10.7 and reindeer 10.7 kg N/animal/year are for whole time series (Nousiainen, J. Natural Resources Institute Finland (Luke))

Year	Dairy cow	Suckler cow	Bulls	Heifers	Calves	Fattening pigs (50- kg)	Weaned pigs (20-50 kg)	Boars	Sows (including piglets)[1]	Piglets[1]
1990	97.8	57.6	55.9	48.6	30.0	18.3	8.8	19.6	27.8	IE
1995	101.9	58.7	56.9	50.0	30.5	17.4	8.5	19.1	26.5	IE
2000	110.6	59.1	58.3	52.5	31.3	17.5	8.6	17.8	26.8	IE
2005	119.5	62.1	65.2	55.4	33.8	17.5	8.9	20.1	28.4	IE
2010	125.7	65.0	68.5	56.6	35.1	17.6	9.0	20.5	29.9	IE
2013	127.6	65.9	65.8	57.5	34.7	17.4	9.1	20.4	30.7	IE
2014	130.5	66.3	66.6	57.5	35.1	17.3	9.1	20.7	31.2	IE
2015	131.0	66.6	67.9	57.9	35.7	17.4	9.1	20.6	31.4	IE
2016	131.3	67.1	67.9	58.1	35.7	17.3	9.1	20.6	32.1	IE
2017	134.9	66.9	68.6	58.3	36.1	17.2	9.1	20.8	32.0	IE
2018	136.4	66.9	69.4	58.3	36.3	17.2	9.2	21.0	32.9	IE
2019	140.1	67.8	70.7	59.9	37.3	17.2	9.2	20.9	32.3	IE
2020	144.6	69.7	72.1	61.7	38.4	17.1	9.2	20.7	33.8	IE
2021	145.0	69.8	71.4	62.8	38.8	17.0	9.2	20.6	33.5	IE
2022	143.4	69.8	70.4	62.3	38.2	16.9	9.2	20.2	33.2	IE

[1] The N excretion value for sows includes N excretion of piglets.

Year	Laying hens	Broilers	Chickens	Turkeys	Other poultry	Horses	Ponies	Sheep	Minks & fiches	Foxes & raccoon dogs
1990	0.6	0.4	0.4	1.1	0.6	59.4	43.4	7.5	1.2	2.1
1995	0.6	0.4	0.4	1.3	0.6	60.5	44.4	7.5	1.3	2.2
2000	0.6	0.4	0.4	1.4	0.7	60.1	44.1	7.6	1.3	2.3
2005	0.6	0.4	0.4	1.5	0.7	61.0	43.6	7.4	1.3	2.8
2010	0.6	0.5	0.4	1.6	0.6	61.1	43.5	7.4	1.3	3.0
2013	0.6	0.5	0.4	1.7	0.6	61.6	43.7	7.4	1.3	3.0
2014	0.6	0.5	0.4	1.6	0.6	61.7	44.0	7.4	1.3	3.0
2015	0.6	0.5	0.4	1.6	0.6	61.9	44.3	7.5	1.3	3.0
2016	0.6	0.5	0.4	1.6	0.6	62.0	44.5	7.5	1.3	3.0
2017	0.6	0.5	0.4	1.7	0.6	62.0	44.5	7.7	1.3	3.0
2018	0.6	0.5	0.4	1.6	0.6	61.9	44.6	7.8	1.3	3.0
2019	0.6	0.5	0.4	1.7	0.6	61.8	44.7	8.0	1.3	3.0
2020	0.6	0.5	0.4	1.7	0.6	61.7	44.7	7.9	1.3	3.0
2021	0.6	0.5	0.4	1.7	0.6	61.6	44.6	7.8	1.3	3.0
2022	0.5	0.5	0.4	1.7	0.6	63.9	44.6	7.9	1.3	3.0

Table 4_App_5a Fraction of manure managed in each manure management system (Sources: Grönroos et al. 2009, Grönroos 2014 (results of a 2013 farm survey conducted by J. Grönroos and S. Luostarinen))

	1990	**1995**	**2000**	**2005**	**2010**	**2013**	**2014**	**2015**	**2016**	**2017**	**2018**	**2019**	**2020**	**2021**	**2022**
Dairy cows															
Pasture	0.22	0.19	0.17	0.15	0.13	0.12	0.12	0.12	0.11	0.11	0.11	0.11	0.11	0.11	0.11
Slurry	0.24	0.28	0.37	0.53	0.57	0.60	0.61	0.62	0.63	0.64	0.65	0.66	0.67	0.67	0.67
Slurry with natural cover	0.09	0.11	0.15	0.21	0.38	0.47	0.48	0.48	0.49	0.50	0.51	0.51	0.52	0.52	0.52
Slurry with no cover	0.14	0.17	0.22	0.32	0.19	0.13	0.13	0.14	0.14	0.14	0.14	0.15	0.15	0.15	0.15
Solid storage	0.53	0.52	0.45	0.30	0.29	0.27	0.26	0.25	0.24	0.22	0.21	0.20	0.18	0.18	0.18
Deep litter	0.008	0.004	0.004	0.004	0.003	0.005	0.007	0.009	0.011	0.013	0.015	0.017	0.019	0.019	0.019
Dry lot	0.008	0.004	0.004	0.004	0.003	0.005	0.007	0.009	0.011	0.013	0.015	0.017	0.019	0.019	0.019
Suckler cows															
Pasture	0.35	0.36	0.36	0.36	0.41	0.42	0.41	0.41	0.41	0.41	0.41	0.41	0.40	0.40	0.40
Slurry	0.03	0.03	0.16	0.19	0.07	0.03	0.03	0.03	0.03	0.04	0.04	0.04	0.04	0.04	0.04
Slurry with natural cover	0.01	0.01	0.06	0.08	0.05	0.02	0.02	0.03	0.03	0.03	0.03	0.03	0.03	0.03	0.03
Slurry with no cover	0.02	0.02	0.10	0.11	0.02	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01
Solid storage	0.27	0.27	0.17	0.15	0.24	0.28	0.28	0.29	0.29	0.29	0.29	0.29	0.29	0.29	0.29
Deep litter	0.13	0.12	0.12	0.12	0.10	0.09	0.09	0.09	0.09	0.08	0.08	0.08	0.08	0.08	0.08
Dry lot	0.22	0.21	0.18	0.17	0.18	0.18	0.18	0.18	0.18	0.18	0.18	0.18	0.18	0.18	0.18
Bulls (<1 year)															
Pasture	0	0	0	0	0.02	0.04	0.04	0.04	0.04	0.04	0.04	0.04	0.04	0.04	0.04
Slurry	0.30	0.40	0.40	0.40	0.50	0.54	0.54	0.55	0.56	0.56	0.57	0.57	0.58	0.58	0.58
Slurry with natural cover	0.12	0.16	0.16	0.16	0.34	0.42	0.42	0.43	0.43	0.44	0.44	0.45	0.45	0.45	0.45
Slurry with no cover	0.18	0.24	0.24	0.24	0.16	0.12	0.12	0.12	0.12	0.12	0.12	0.13	0.13	0.13	0.13
Solid storage	0.64	0.54	0.54	0.54	0.39	0.32	0.31	0.31	0.31	0.30	0.30	0.29	0.29	0.29	0.29
Deep litter	0.06	0.06	0.06	0.06	0.09	0.10	0.10	0.10	0.10	0.10	0.10	0.10	0.10	0.10	0.10
Dry lot	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0.00
Heifers															
Pasture	0.36	0.35	0.35	0.35	0.28	0.24	0.24	0.24	0.23	0.23	0.23	0.23	0.22	0.22	0.22
Slurry	0.19	0.24	0.24	0.24	0.34	0.39	0.40	0.41	0.42	0.43	0.44	0.45	0.47	0.47	0.47
Slurry with natural cover	0.08	0.09	0.09	0.09	0.23	0.31	0.31	0.32	0.33	0.34	0.35	0.35	0.36	0.36	0.36
Slurry with no cover	0.11	0.14	0.14	0.14	0.11	0.09	0.09	0.09	0.09	0.10	0.10	0.10	0.10	0.10	0.10
Solid storage	0.43	0.40	0.40	0.40	0.33	0.30	0.29	0.29	0.28	0.27	0.27	0.26	0.26	0.26	0.26
Deep litter	0.01	0.01	0.01	0.01	0.03	0.03	0.03	0.03	0.03	0.03	0.03	0.03	0.03	0.03	0.03
Dry lot	0.01	0.01	0.01	0.01	0.03	0.03	0.03	0.03	0.03	0.03	0.03	0.03	0.03	0.03	0.03
Calves (<1 year)															
Pasture	0.08	0.07	0.07	0.07	0.09	0.10	0.10	0.10	0.10	0.10	0.10	0.10	0.10	0.10	0.10
Slurry	0.28	0.35	0.35	0.35	0.34	0.34	0.35	0.36	0.37	0.38	0.39	0.40	0.41	0.41	0.41
Slurry with natural cover	0.11	0.14	0.14	0.14	0.23	0.27	0.27	0.28	0.29	0.30	0.30	0.31	0.32	0.32	0.32
Slurry with no cover	0.17	0.21	0.21	0.21	0.11	0.08	0.08	0.08	0.08	0.08	0.09	0.09	0.09	0.09	0.09
Solid storage	0.55	0.55	0.55	0.55	0.45	0.40	0.40	0.39	0.39	0.38	0.37	0.37	0.36	0.36	0.36
Deep litter	0.05	0.01	0.01	0.01	0.06	0.08	0.07	0.07	0.07	0.07	0.07	0.07	0.07	0.07	0.07
Dry lot	0.05	0.01	0.01	0.01	0.06	0.08	0.07	0.07	0.07	0.07	0.07	0.07	0.07	0.07	0.07
Swine															
Pasture	0.003	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Slurry	0.37	0.53	0.53	0.59	0.80	0.89	0.90	0.90	0.91	0.92	0.93	0.93	0.93	0.94	0.94
Slurry with natural cover	0.04	0.05	0.05	0.06	0.16	0.22	0.24	0.25	0.26	0.27	0.28	0.30	0.30	0.31	0.31
Slurry with no cover	0.33	0.48	0.48	0.53	0.64	0.67	0.66	0.66	0.65	0.65	0.64	0.64	0.64	0.64	0.64
Solid storage	0.58	0.42	0.42	0.36	0.17	0.10	0.09	0.09	0.08	0.07	0.06	0.06	0.06	0.06	0.06
Deep litter	0.05	0.05	0.05	0.05	0.02	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01
Sheep															
Pasture	0.36	0.32	0.32	0.32	0.35	0.35	0.35	0.35	0.35	0.35	0.35	0.35	0.35	0.35	0.35
Slurry	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0.00
Solid storage	0.06	0.07	0.07	0.07	0.25	0.33	0.33	0.33	0.33	0.33	0.33	0.33	0.33	0.33	0.33
Deep litter	0.57	0.61	0.61	0.61	0.40	0.33	0.33	0.33	0.33	0.33	0.33	0.33	0.33	0.33	0.33

	1990	1995	2000	2005	2010	2013	2014	2015	2016	2017	2018	2019	2020	2021	2022
Goats															
Pasture	0.36	0.32	0.32	0.32	0.35	0.35	0.35	0.35	0.35	0.35	0.35	0.35	0.35	0.35	0.35
Slurry	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Solid storage	0.06	0.07	0.07	0.07	0.25	0.33	0.33	0.33	0.33	0.33	0.33	0.33	0.33	0.33	0.33
Deep litter	0.57	0.61	0.61	0.61	0.40	0.33	0.33	0.33	0.33	0.33	0.33	0.33	0.33	0.33	0.33
Horses															
Pasture	0.36	0.36	0.36	0.36	0.39	0.36	0.36	0.36	0.36	0.36	0.36	0.36	0.36	0.36	0.36
Slurry	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Solid storage	0.42	0.25	0.25	0.42	0.37	0.37	0.37	0.37	0.37	0.37	0.37	0.37	0.37	0.37	0.37
Deep litter	0.00	0.17	0.17	0.00	0.04	0.06	0.06	0.06	0.06	0.06	0.06	0.06	0.06	0.06	0.06
Dry lot	0.21	0.21	0.21	0.21	0.20	0.21	0.21	0.21	0.21	0.21	0.21	0.21	0.21	0.21	0.21
Reindeer															
Pasture	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
Slurry	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Solid storage	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Deep litter	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Laying hens															
Pasture	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Slurry	0	0.02	0.02	0.02	0.07	0.09	0.09	0.09	0.09	0.09	0.09	0.09	0.09	0.09	0.09
Slurry with natural cover	0	0.002	0.002	0.002	0.01	0.02	0.02	0.02	0.03	0.03	0.03	0.03	0.03	0.03	0.03
Slurry with no cover	0	0.02	0.02	0.02	0.06	0.07	0.07	0.07	0.06	0.06	0.06	0.06	0.06	0.06	0.06
Solid storage	0.95	0.93	0.93	0.93	0.76	0.69	0.69	0.69	0.69	0.69	0.69	0.69	0.69	0.69	0.69
Deep litter	0.05	0.05	0.05	0.05	0.17	0.22	0.22	0.22	0.22	0.22	0.22	0.22	0.22	0.22	0.22
Chickens															
Pasture	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Slurry	0	0.02	0.02	0	0	0	0	0	0	0	0	0	0	0	0
Slurry with natural cover	0	0.002	0.002	0	0	0	0	0	0	0	0	0	0	0	0
Slurry with no cover	0	0.02	0.02	0	0	0	0	0	0	0	0	0	0	0	0
Solid storage	0.95	0.93	0.93	0.95	0.70	0.60	0.60	0.60	0.60	0.60	0.60	0.60	0.60	0.60	0.60
Deep litter	0.05	0.05	0.05	0.05	0.30	0.40	0.40	0.40	0.40	0.40	0.40	0.40	0.40	0.40	0.40
Cockerels															
Pasture	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Slurry	0	0.01	0.01	0	0	0	0	0	0	0	0	0	0	0	0
Slurry with natural cover	0	0.001	0.001	0	0	0	0	0	0	0	0	0	0	0	0
Slurry with no cover	0	0.01	0.01	0	0	0	0	0	0	0	0	0	0	0	0
Solid storage	0.95	0.94	0.94	0.95	0.63	0.50	0.50	0.50	0.50	0.50	0.50	0.50	0.50	0.50	0.50
Deep litter	0.05	0.05	0.05	0.05	0.37	0.50	0.50	0.50	0.50	0.50	0.50	0.50	0.50	0.50	0.50
Broiler hens															
Pasture	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Slurry	0	0.01	0.01	0	0	0	0	0	0	0	0	0	0	0	0
Slurry with natural cover	0	0.001	0.001	0	0	0	0	0	0	0	0	0	0	0	0
Slurry with no cover	0	0.01	0.01	0	0	0	0	0	0	0	0	0	0	0	0
Solid storage	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Deep litter	1.00	0.99	0.99	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
Broilers															
Pasture	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Slurry	0	0.01	0.01	0	0	0	0	0	0	0	0	0	0	0	0
Slurry with natural cover	0	0.001	0.001	0	0	0	0	0	0	0	0	0	0	0	0
Slurry with no cover	0	0.009	0.009	0	0	0	0	0	0	0	0	0	0	0	0
Solid storage	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Deep litter	1.00	0.99	0.99	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00

Appendix_5b

A description of Nitrogen flow concerning year 2022

Table 1_App_5b Nitrogen flow in storage phase and amount spread to fields. Dry lot N is subtracted from Storage phase N resulting in N applied to fields (bedding added)

Manure management, N kg		**dry lot, N kg** *(manure is left to dry lot)*		**difference, N kg**	
83 286 009	N excretion (pasture excluded)	3 371 258	Nex	79 914 751	Nex
14 917 202	NH_3-N+NO-N volatilised	147 155	NH_3-N volatilised	14 770 047	NH_3-N+NO-N volatilised
485 461	leaching N (only dry lot)	485 461	leaching N	0	leaching N
382 999	direct emission N_2O-N	67 425	direct emission N_2O-N	315 574	direct emission N_2O-N
2 102 541	N_2-N	0	N_2-N	2 102 541	N_2-N
data for CRF 3.D.2.a, N kg					
79 914 751	Nex manure management minus Nex left to dry lot				
14 770 047	NH_3-N+NO-N volatilised in manure management minus dry lot volatilisation				
2 102 541	N_2-N volatilised in manure management				
315 574	direct N_2O-N emission from manure management minus dry lot emission				
4 382 771	bedding added to fields				
67 109 361	**N kg spread to fields (no dry lot manure)** Nex + Bedding – (NH_3&NO+leach+direct emission from storage)				

6 LAND USE, LAND-USE CHANGE AND FORESTRY (CRF 4)

6.1 Overview of the sector

In 2022, the Land Use, Land-Use Change and Forestry (LULUCF) sector as a whole acted as a CO_2 source of 4.4 million tonnes of CO_2 equivalent (Mt CO_2 eq.) because the total removals resulting from the sector were smaller than the total emissions (Figure 6.1-1, Table 6.1-2). The net emissions in 2022 were 10% of the total national emissions, which did not include the LULUCF sector. The change to the 2022 net emissions from the 1990 net removals was 119% and from the 2021 net emissions 28%.

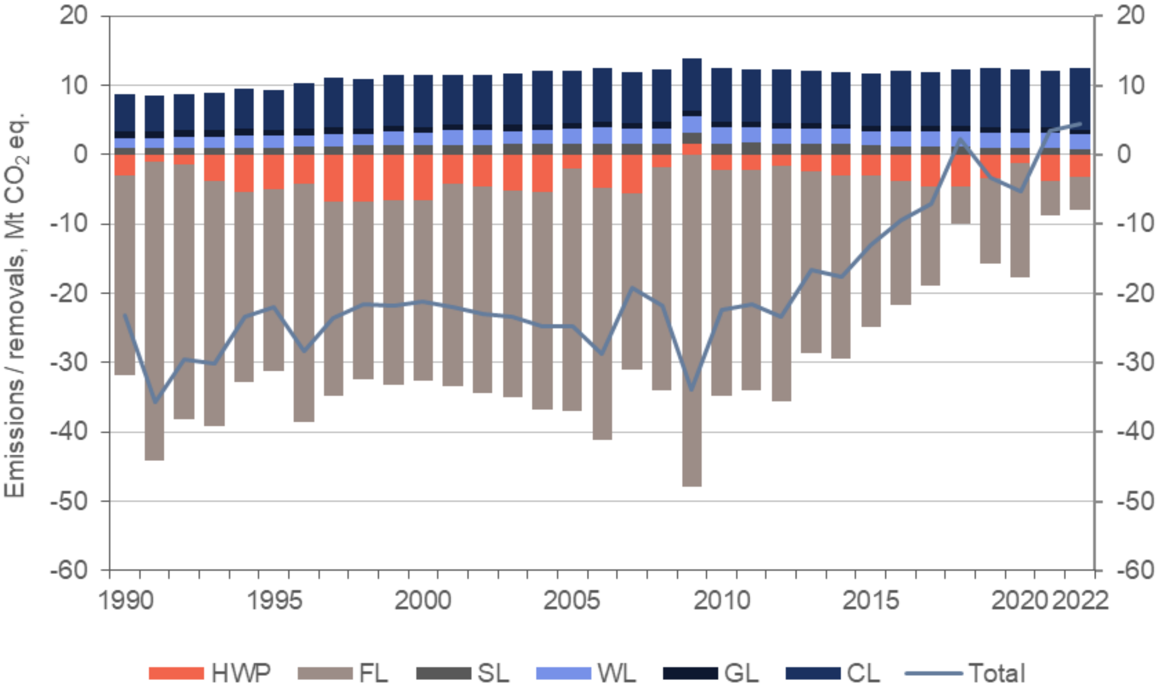


Figure 6.1-1 Net emissions and removals in the LULUCF sector by land-use category and harvested wood products, Mt CO_2 eq.

The LULUCF sector has been a net sink during the whole time series from 1990 to 2017. Starting from 2018, the sector has been either a net sink or a net source of emissions. The decreasing trend in the net sink of Forest Land has continued for about ten years, being so low in recent years that it does not cover the emissions from other land use. Forest Land has been a net sink, whereas the other land-use categories have comprised net sources. Harvested Wood Products have totalled a net sink except for the year 2009. The level, trend and the inter-annual variability in the sink or source for the whole LULUCF sector are determined by the Forest Land sink (Figure 6.1-1). The low levels of roundwood fellings at the beginning of the 1990s and mid-2000`s and again after the financial crisis in 2008/2009 are the cause of the high removals of the LULUCF sector during those periods of time. There are several reasons for why the sector has turned from a net sink into a net source. The main reasons are that commercial fellings have increased, and same time the tree volume increment has decreased according to the NFI. (Luke 2023b, Luke 2023c). Also, the emissions from organic soils have increased considerably, but carbon sink of mineral soils has decreased. This meant that the Forest Land net sink has decreased so that the sum of emissions from the other land categories is larger than the Forest Land net sink.

Living biomass comprises most of the Forest Land sink. The combined pools of soil organic matter (SOM) and the dead organic matter (DOM) in mineral forest soils are also a sink. By contrast, organic soils act as a source because of CO_2, CH_4 and N_2O emissions from drained soils. Other, minor emission sources of the Forest land category are N mineralisation, N fertilisation and biomass burning (Table 6.1-2).

The Forest Land net sink has decreased by 84% from 1990 to 2022. The high fluctuation in net biomass removals in the Forest Land category during the period 1990 to 2022 is mainly caused by the changes in the international market of forest industry products, which affect the amount of domestic commercial roundwood fellings. The unstable global situation has had its effects on international markets, resulting in roundwood imports almost ceasing in 2022. In 2018, the total roundwood removals reached 78 million m^3 being the highest ever in the history of the statistics (Luke 2023b). Since then, the roundwood removals have dropped, but still remaining at a high level compared to the historical levels (Luke 2023b). In the year 2022 roundwood removals reached 75 million m^3. The other significant factor affecting the trend in the Forest Land sink are the changes in the annual volume increment. The annual increment of growing stock was 77.7 million m^3, based on the 8th National Forest Inventory (NFI) (measured 1986 to 1994), 107.8 million m^3 based on the NFI12 (2014 to 2018) and 103.7 million m^3 based on the NFI13 (2019 to 2022) (Luke 2023c). The rapid increase in the increment in the 1980’s and 1990’s has leveled out and according to the last inventory measurements the increment has diminished by 4.1 million m^3 compared to the highest level, measured in NFI12.

The Cropland category is a source. The emissions have increased by 64% from 1990 to 2022. This is due to the increase in total cropland area, and a slightly increased proportion of organic soils. Only mineral soils at the beginning of the 1990s have been a minor sink of CO_2. The Grassland category is also a source. The emissions from organic soils exceed the small removals by mineral soils and living biomass (Table 6.1-2, Figure 6.1-2).

In the Wetlands category, a diverse group of lands are included. Characteristics of the group are that they are organic soils without biomass cover or with low biomass cover, and hence constitute a source of CO_2, CH_4 and N_2O emissions. Total emission has increased from 1.4 Mt CO_2 eq. in 1990 to 2.1 Mt CO_2 eq. in 2022. The peat extraction sites cover the most of the emissions from Wetlands. A slight decline in emissions can be seen as the area of peat production sites is currently decreasing.

In the Settlements category, the emissions consist of biomass and dead wood losses due to LUC and emissions from litter and soil organic matter pools after the conversion. The N_2O emissions are due to N mineralisation in the soil organic matter after the conversion. At the highest, the emissions were 1.7 Mt CO_2 eq. in 2011, but at present they are halved being at the same level as in 1990.

The Harvested Wood Products (HWP) category has been a net sink except for the year 2009. The most important component of the HWP carbon stock change is sawn wood. The net sink of harvested wood products decreased by 13% from 2021 to 2022 mainly due to decreased production of sawn wood compared to the previous year.

Further descriptions on the trends can be found under the section describing each land-use category.

Emissions and removals from the LULUCF sector were calculated according to the 2006 IPCC Guidelines. The land area is divided into six land-use categories and into the subcategories “lands remaining in the same land-use category for the last 20 years” and ”lands converted to present land use during the past 20 years”. The land-use categories are Forest Land, Cropland, Grassland, Wetlands, Settlements and Other Land (2006 IPCC Guidelines). The carbon stock changes and greenhouse gas emissions reported under the LULUCF sector are listed in Table 6.1-1.

Emissions and removals are not reported under Other land as the category is considered unmanaged land, or in the case of land-use changes to Other land, the carbon stock changes and other emissions have been judged to be zero. Emissions and removals from harvested wood products (HWP) are included in the LULUCF sector estimates as a separate category 4.G.

Land-use areas are calculated from National Forest Inventory (NFI) data. In detection of land-use changes the NFI data is supported by spatial data, e.g., aerial photographs and satellite images.

The areas have been estimated consistently for all land-use classes before and after 1990. The 20 years before 1990 have also been taken into account in carbon stock change and emission estimation to obtain a complete time series since 1990. For biomass gains, the time since conversion has been taken into account. For mineral soils, the carbon stock changes have been estimated mainly with the dynamic soil carbon model Yasso07. For organic soils, emission factors are used. For land-use changes since 1971, there are 20-year emission factors that have been applied according to the conversion year.

The amount of carbon accumulated or released is converted to CO_2 by multiplying it by -44/12.

A general assessment of the completeness can be found in Section 1.7 and a more detailed assessment is included in Annex 5.

Table 6.1-1 Reported emissions / removals, calculation methods and types of emission factors for the LULUCF sector (DOM = dead organic matter, SOM= soil organic matter, CS = country-specific, D = IPCC default)

CRF	Source	Stock change reported	Emissions reported	Methods	Emission factors
4.A	Forest land *(remaining, converted)*				
	- living biomass	carbon/ CO_2		Tier 3	CS
	- DOM, SOM (mineral and organic soils)	carbon/ CO_2		Tier 3, Tier 2	CS
4.B	Cropland *(remaining, converted)*				
	- living biomass	carbon/ CO_2		Tier 3, Tier 2	CS, D
	- DOM, SOM (mineral and organic soils)	carbon/ CO_2		Tier 3, Tier 2, Tier 1	CS, D
4.C	Grassland *(remaining, converted)*				
	- living biomass	carbon/ CO_2		Tier 3, Tier 2	CS, D
	- DOM, SOM (mineral and organic soils)	carbon/ CO_2		Tier 3, Tier 2, Tier 1	CS, D
4.D	Wetlands *(remaining, converted)*				
	- peat extraction areas: living biomass	carbon/ CO_2		Tier 3	CS
	- peat extraction areas: DOM, SOM	carbon/ CO_2		Tier 2	CS
	- flooded land: living biomass	carbon/ CO_2		Tier 3	CS
	- flooded land: DOM, SOM	carbon/ CO_2		Tier 1	CS, D
	- other wetlands: SOM	carbon/ CO_2		Tier 2	CS
4.E	Settlements *(converted)*				
	- living biomass	carbon/ CO_2		Tier 3	CS
	- DOM, SOM	carbon/ CO_2		Tier 2	CS
4.F	Other land *(converted)*				
	- living biomass	carbon/ CO_2		Tier 1	D
	- DOM, SOM	carbon/ CO_2		Tier 1	D
4.G	Harvested Wood Products	carbon/ CO_2		Tier 2	CS, D
4(I)	Direct N_2O emissions from fertilisation				
	-Forest land		N_2O	Tier 1	D
4(II)	Non-CO_2 emissions from drainage and rewetting and other management of organic and mineral soils[1]				
	-Wetlands: Peat extraction areas		CH_4, N_2O	Tier 2	CS
	-Wetlands: Flooded land		CH_4	Tier 1	D
	-Other Wetlands		CH_4, N_2O	Tier 2	CS
	-Forest land: Drained organic forest soils		CH_4, N_2O	Tier 1, Tier 2	CS, D
4(III)	Direct non-CO_2 emissions from N mineralisation/immobilisation				
	-Forest land, Settlements, Cropland, Grassland		N_2O	Tier 1	CS, D

CRF	Source	Stock change reported	Emissions reported	Methods	Emission factors
4(IV)	N_2O emissions from N leaching and runoff		N_2O	Tier 1, Tier 2	CS, D
4(V)	Biomass burning -Forest land, Cropland, Grassland		CO_2, CH_4, N_2O, NOx, CO	Tier 2	D

[1] N_2O emissions from the management of agricultural soils are reported under the Agriculture sector.

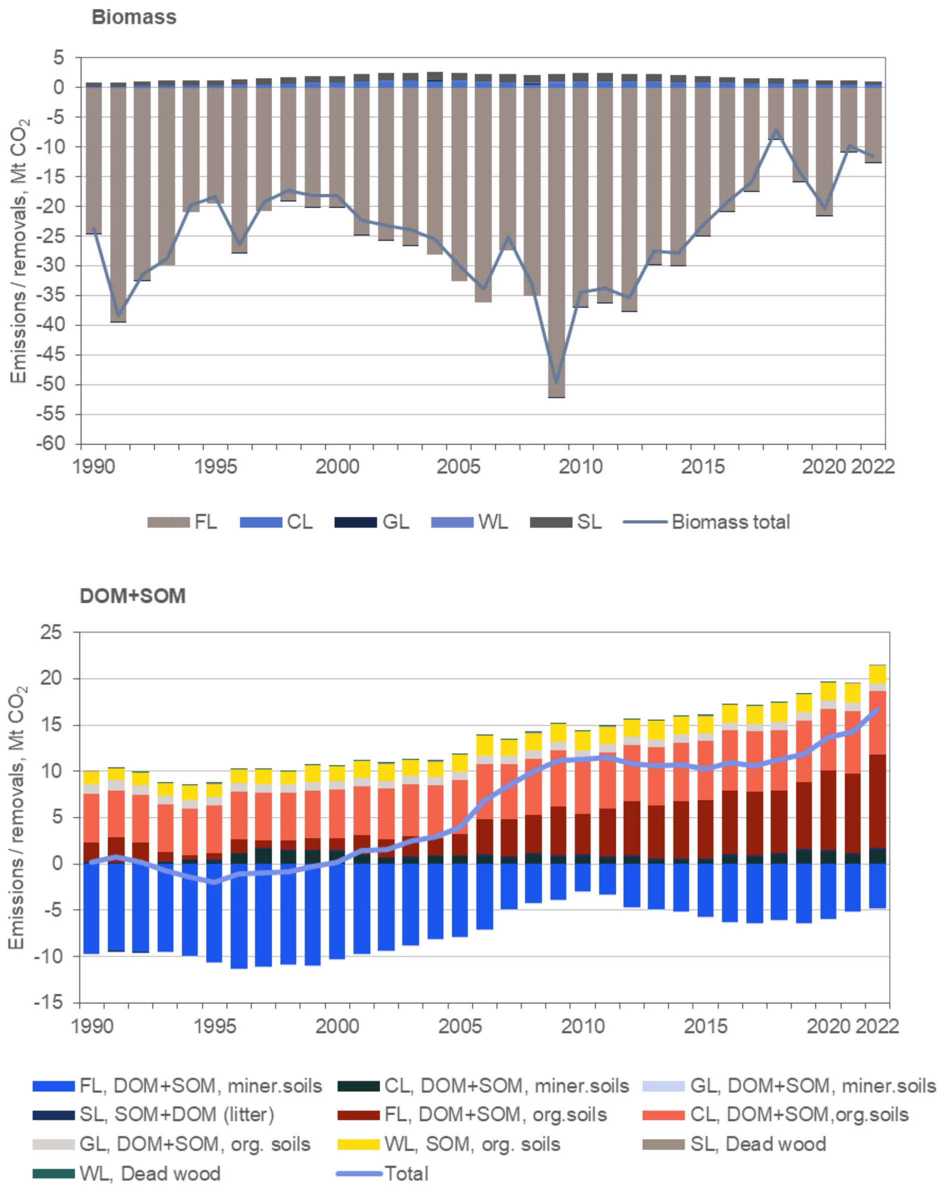


Figure 6.1-2 Emissions (positive sign) and removals (negative sign) from biomass (upper) and from soils (soil and dead organic matter) (lower) in different land use classes, Mt CO_2. (FL = Forest Land, CL = Cropland, GL = Grassland, SL = Settlements, WL = Wetlands)

Table 6.1-2 Greenhouse gas emissions and removals from the LULUCF sector (Mt CO_2 eq.) (positive figures indicate emissions, negative removals)

	Mt CO2 eq.	1990	1995	2000	2005	2010	2011	2012	2013	2014	2015	2016	2017	2018	2019	2020	2021	2022
4.A	**Forest land**	**-28.95**	**-26.37**	**-26.05**	**-35.07**	**-32.66**	**-31.77**	**-33.89**	**-26.21**	**-26.37**	**-21.86**	**-17.76**	**-14.41**	**-5.47**	**-12.39**	**-16.42**	**-4.98**	**-4.77**
	Biomass, mineral soils	-13.9	-7.7	-6.5	-17.0	-22.9	-22.9	-24.3	-18.1	-18.5	-14.0	-10.0	-6.9	0.5	-5.5	-10.3	-1.4	-2.8
	Biomass, organic soils	-10.6	-11.9	-13.6	-15.5	-13.9	-13.4	-13.3	-11.6	-11.4	-10.9	-10.8	-10.4	-9.1	-10.2	-11.2	-9.5	-9.8
	DOM^1+SOM, mineral soils	-9.7	-10.7	-10.3	-7.9	-3.0	-3.3	-4.7	-4.8	-5.2	-5.7	-6.2	-6.4	-6.1	-6.4	-5.9	-5.2	-4.8
	DOM^1+SOM, organic soils	2.1	0.8	1.3	2.3	4.4	5.1	5.8	5.8	6.2	6.3	6.9	6.9	6.8	7.3	8.5	8.6	10.1
4(I)	N fertilisation	0.018	0.005	0.007	0.007	0.015	0.015	0.010	0.012	0.012	0.011	0.015	0.026	0.029	0.031	0.034	0.027	0.005
4(V)	Biomass burning	0.005	0.002	0.001	0.002	0.001	0.002	0.001	0.001	0.002	0.001	0.001	0.001	0.002	0.001	0.003	0.002	0.001
4(III)	N mineralisation	0.007	0.008	0.005	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.002	0.002	0.002	0.001	0.001	0.001	0.000
4(II)	CH4 and N2O emissions from drained forest land	3.03	3.07	3.12	3.03	2.76	2.68	2.63	2.58	2.53	2.48	2.43	2.43	2.42	2.42	2.42	2.42	2.43
4.B	**Cropland**	**5.39**	**5.66**	**7.48**	**7.56**	**7.70**	**7.59**	**7.76**	**7.43**	**7.42**	**7.45**	**7.99**	**7.82**	**8.21**	**8.63**	**8.53**	**8.27**	**8.83**
	Biomass	0.15	0.31	0.86	0.98	0.86	0.85	0.89	0.85	0.74	0.75	0.73	0.68	0.74	0.64	0.49	0.53	0.48
	Dead wood	4.4E-04	0.001	0.004	0.005	0.003	0.002	0.003	0.003	0.003	0.004	0.005	0.004	0.005	0.004	0.003	0.003	0.002
	DOM^1+SOM, mineral soils	0.067	0.268	1.331	0.773	0.807	0.628	0.697	0.337	0.379	0.326	0.819	0.652	0.915	1.359	1.322	0.974	1.516
	DOM^2+SOM, organic soils	5.16	5.08	5.27	5.80	6.03	6.10	6.16	6.23	6.30	6.36	6.43	6.48	6.54	6.62	6.70	6.76	6.83
4(III)	N mineralisation	0.006	0.005	0.005	0.007	0.007	0.007	0.008	0.008	0.008	0.008	0.008	0.008	0.008	0.007	0.007	0.007	0.007
4.C	**Grassland**	**1.02**	**0.91**	**0.84**	**0.91**	**0.81**	**0.76**	**0.76**	**0.76**	**0.75**	**0.76**	**0.78**	**0.77**	**0.78**	**0.78**	**0.77**	**0.76**	**0.77**
	Biomass	-0.029	0.004	-0.024	0.047	-0.042	-0.082	-0.084	-0.079	-0.086	-0.064	-0.030	-0.031	-0.017	-0.009	-0.031	-0.043	-0.044
	Dead wood	NA	0.00016	0.00014	0.00077	NA	NA	NA	0.0001	0.0001	0.0002	0.0002	0.0003	NA	NA	NA	NA	NA
	DOM^1+SOM, mineral soils	-0.050	-0.033	-0.028	-0.020	-0.019	-0.020	-0.021	-0.022	-0.024	-0.025	-0.025	-0.026	-0.025	-0.025	-0.025	-0.026	-0.028
	DOM^2+SOM, organic soils	1.10	0.94	0.89	0.88	0.87	0.87	0.87	0.86	0.85	0.84	0.83	0.83	0.82	0.82	0.82	0.83	0.84
4(III)	N mineralisation	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001
4(V)	Biomass burning	0.0001	0.0001	0.0000	0.0001	0.0001	0.0001	0.0000	0.0001	0.0001	0.0000	0.0001	0.0001	0.0001	0.0000	0.0001	0.0000	0.0000
4.D	**Wetlands**	**1.45**	**1.65**	**1.79**	**2.10**	**2.31**	**2.24**	**2.10**	**2.31**	**2.19**	**2.12**	**2.14**	**2.14**	**2.26**	**2.15**	**2.15**	**2.27**	**2.09**
	Biomass	0.002	0.080	0.072	0.111	0.187	0.183	0.138	0.145	0.106	0.078	0.071	0.054	0.020	0.008	0.008	NA	NA
	Dead wood	NA	0.002	0.001	0.002	0.003	0.003	0.002	0.002	0.002	0.002	0.002	0.001	0.001	0.000	0.000	NA	NA
	SOM	1.33	1.44	1.58	1.84	1.96	1.89	1.80	2.00	1.92	1.88	1.90	1.92	2.07	1.97	1.98	2.11	1.94
4(II)	CH4 and N2O emissions	0.11	0.13	0.14	0.15	0.16	0.16	0.16	0.16	0.17	0.17	0.17	0.17	0.16	0.16	0.16	0.16	0.15
4.E	**Settlements**	**0.87**	**1.06**	**1.29**	**1.61**	**1.65**	**1.73**	**1.60**	**1.51**	**1.49**	**1.31**	**1.18**	**1.15**	**1.13**	**0.98**	**0.91**	**0.87**	**0.78**
	Biomass	0.68	0.87	1.09	1.38	1.40	1.46	1.33	1.24	1.21	1.02	0.90	0.87	0.86	0.71	0.65	0.62	0.54
	Dead wood	0.013	0.017	0.024	0.033	0.030	0.030	0.028	0.026	0.024	0.021	0.019	0.017	0.016	0.014	0.015	0.013	0.013
	DOM^2 +SOM	0.16	0.16	0.16	0.18	0.21	0.22	0.23	0.23	0.24	0.24	0.24	0.24	0.24	0.23	0.23	0.22	0.21
4(III)	N mineralisation	0.012	0.012	0.012	0.014	0.016	0.017	0.017	0.017	0.018	0.018	0.018	0.018	0.018	0.017	0.017	0.017	0.016
4.G	**Harvested wood products**	**-2.95**	**-4.90**	**-6.61**	**-1.97**	**-2.20**	**-2.17**	**-1.67**	**-2.37**	**-3.03**	**-2.91**	**-3.82**	**-4.50**	**-4.58**	**-3.38**	**-1.29**	**-3.72**	**-3.25**
4(IV)	**Indirect N2O emissions**	**0.001**	**0.001**	**0.001**	**0.001**	**0.001**	**0.001**	**0.001**	**0.001**	**0.001**	**0.001**	**0.001**	**0.001**	**0.001**	**0.001**	**0.001**	**0.001**	**0.001**
4	**Total CO2 eq.**	**-23.17**	**-22.00**	**-21.26**	**-24.85**	**-22.38**	**-21.62**	**-23.34**	**-16.56**	**-17.54**	**-13.13**	**-9.49**	**-7.03**	**2.32**	**-3.23**	**-5.35**	**3.47**	**4.44**

[1] Dead organic matter in dead wood and litter

[2] Dead organic matter in litter

6.1.1 Key Categories

The key categories in the LULUCF sector are summarised in Table 6.1-3.

Table 6.1-3 Key categories in the LULUCF sector (CRF 4) in 1990 and 2022 (Approach 1 and Approach 2). Identification criteria L=level, T=trend.

IPCC category	Gas	Identification criteria	Tier
4.A.1. Forest Land remaining Forest Land	CO_2	L, T	Tier 3, Tier 2
4.A.2. Land converted to Forest Land	CO_2	L	Tier 3, Tier 2
4.B.1. Cropland remaining Cropland	CO_2	L, T	Tier 3, Tier 2
4.B.2. Land converted to Cropland	CO_2	L, T	Tier 3, Tier 2, Tier 1
4.C.1 Grassland remaining Grassland	CO_2	L, T	Tier 3, Tier 2
4.D.1. Wetlands remaining Wetlands	CO_2	L, T	Tier 3, Tier 2
4.E.2. Land converted to Settlements	CO_2	L	Tier 3, Tier 2
4.G Harvested Wood Products	CO_2	L, T	Tier 2
4.(II). Drainage and Rewetting and Other Management of Soils	CH_4	L, T	Tier 2, Tier 1
4.(II). Drainage and Rewetting and Other Management of Soils	N_2O	L	Tier 2

6.2 Land use definitions and the classification systems used and their correspondence to the LULUCF

For the GHG inventory, Finland’s land area and inland water bodies are classified according to the 2006 IPCC Guidelines. The data source for activity data of land use, that is the areas of land-use categories and sub-categories, is the National Forest Inventory (NFI). The land and site-class classification scheme of the NFI is employed to re-classify lands into the IPCC land-use categories (Tomppo et al. 2011, Table 6.2-1). The recommendation given by a working group on a follow-up system for land use and land-use changes in Finland was mainly followed (MMM 2005). It describes data sources, compares different land-use classification systems, and also presents which data are available for the whole country with quality assessment and uncertainty estimates. It includes recommendations on what should be included under each land-use category.

In Figure 6.2-1 the boundaries for Southern and Northern Finland are given.

National application of IPCC land-use categories in the Finnish inventory

Forest Land. Definition: Trees are higher than five metres and a canopy cover is more than 10%, or trees able to reach these thresholds *in situ*, and minimum area is 0.25 hectares. Lands predominantly under agricultural or urban land use are excluded. Young natural and planted stands established for forestry purposes that have yet to reach a crown density of 10% or a tree height of 5 metres are included in forest, as are the areas normally forming a part of the forest area that are temporarily unstocked as a result of human intervention or natural causes, but which are expected to revert to forest land. For linear formations, a minimum width of 20 m is applied but for the part of continuous forest area in which forestry can be practised, the 20 m minimum width is not required. Parks and yards are excluded, regardless of whether they would meet the forest definition or not. All forest land is considered managed land.

The definition is the same apart from the 0.5 ha minimum area, which Finland applies for the FAO’s Forest Resource Assessments (FRA 2020). In the 2023 GHGI submission, Finland harmonized the use of minimum area of forest land to 0.25 ha to correspond to Regulation (EU) 2023/839 of the European Parliament and of the Council amending Regulation (EU) 2018/841 and Regulation (EU) 2018/1999.

Cropland. The area of cropland comprises the area defined as arable crops, rotational grass, set-aside, permanent horticultural crops, greenhouses and kitchen gardens. All croplands are considered managed land.

Grassland. Grassland includes areas of extensive grass, ditches associated with agricultural land, areas of bioenergy plants and abandoned arable land. In this context, abandoned arable land refers to fields that are no longer used for agricultural production and where natural reforestation is possible or is already taking place. All grasslands are considered managed land.

Wetlands. Wetlands include peat extraction areas and peatlands that do not fulfil the definition of Forest Land, Cropland, Grassland or Settlements. Inland waters, which comprise reservoirs and natural lakes and rivers, are included in Wetlands. Peat extraction areas, lands converted from other land use to Wetlands as well as Wetlands that have undergone a change in land management are considered managed lands.

Settlements. Settlements comprise built-up land, power supply lines and roads, which include roads and railroads with ditches and open side areas close to these. This category also includes airports, parks, yards, farm roads and barns. Settlements are considered managed land.

Other Land. Other Land includes bare soil and rock and vegetated lands on mineral soils, which do not fulfil the threshold values of Forest Land or are not included in the other land-use categories. Typical sites are rocky lands and treeless mountain areas. Other Land is managed if it has been converted from other land use, otherwise it is considered unmanaged land.

Table 6.2-1 Comparison between the IPCC land-use categories and national land classification according to the NFI

National land classes
Forest land is land used or available for growing trees. The mean annual increment under favourable growing conditions and with recommended rotation length is at least 1 m^3/ha including bark or 0.85 m^3/ha excluding bark. Forest land includes afforested (planted or seeded) stands.
Poorly productive forest land is land used or available for tree growing. The mean annual increment is 0.10–0.99 m^3/ha/year including bark.
Unproductive land is forestry land where potential growth is less than 0.10 m^3/ha/year. Single, poorly growing trees and shrubs may occur on unproductive land.
Other forestry land includes forestry roads, seed production stands, permanent depots and built-up land related to forestry. It also includes gravel pits, and game feeding areas, etc. within forests.
Arable land includes fields, pastures, and waste land inside these land use classes, small roads and buildings (other than houses) used for agriculture. It also includes *abandoned arable lands, without or with tree cover but which cannot yet be considered as forest land.*
Built-up land is land used for buildings, houses, and factories and land in the immediate vicinity of these. This class includes peat production areas, where peat harvesting has been started and the site has not been reforested. Also mechanised gravel production sites are included in this class. It also includes some wooded areas like parks, graveyards, and corresponding areas.
Roads include roads and railroads, including ditches and side areas related to these. It also includes airports. Roads inside built-up areas (cities, etc.) are classified as built-up land.
Power supply lines include electricity lines, water tube lines and gas tube lines. The width of the line must be at least 5 meters. If the line is inside other land uses classes than forestry land (1-4) it is included in the surrounding land-use class no matter the width.
Inland water. Water basins (rivers, etc.) less than 5 meters in width are included in the surrounding land-use class.
Seawater areas.

IPCC	***National land classification according to the NFI***
Forest Land	*All national forest land* *Poorly productive forest land which is Forest Land according to the FAO/FRA definition* *Other forestry land e.g. forest roads, excluding built-up land, gravel and sand production sites*
Cropland	*Arable land excluding natural pastures, small roads and buildings, ditches more than 3 m wide, lands for bioenergy plant production* *Part of built-up land including greenhouses and home gardens*
Grassland	*Arable land not included in Croplands e.g. natural pastures, ditches more than 3 m wide, lands for bioenergy plant production, abandoned arable lands*
Wetlands	*Poorly productive forest land which is not Forest Land according to the FAO/FRA definition and is on organic soils* *Unproductive land on organic soils* *Peat production areas of built-up land* *Inland waters*
Settlements	*Built-up land excluding peat production areas, greenhouses and home gardens* *Roads* *Power supply lines* *Part of other forestry land including built-up land for forestry purposes, gravel and sand production sites* *Part of arable land including small roads and buildings used for agriculture*
Other Land	*Poorly productive forest land which is not Forest Land according to the FAO/FRA definition and is on mineral soils* *Unproductive land on mineral soils*

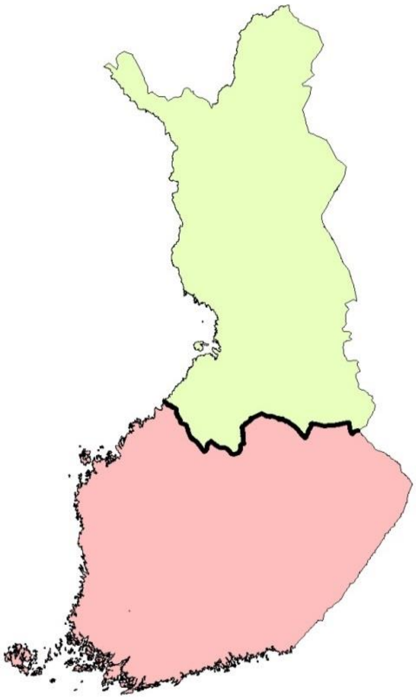
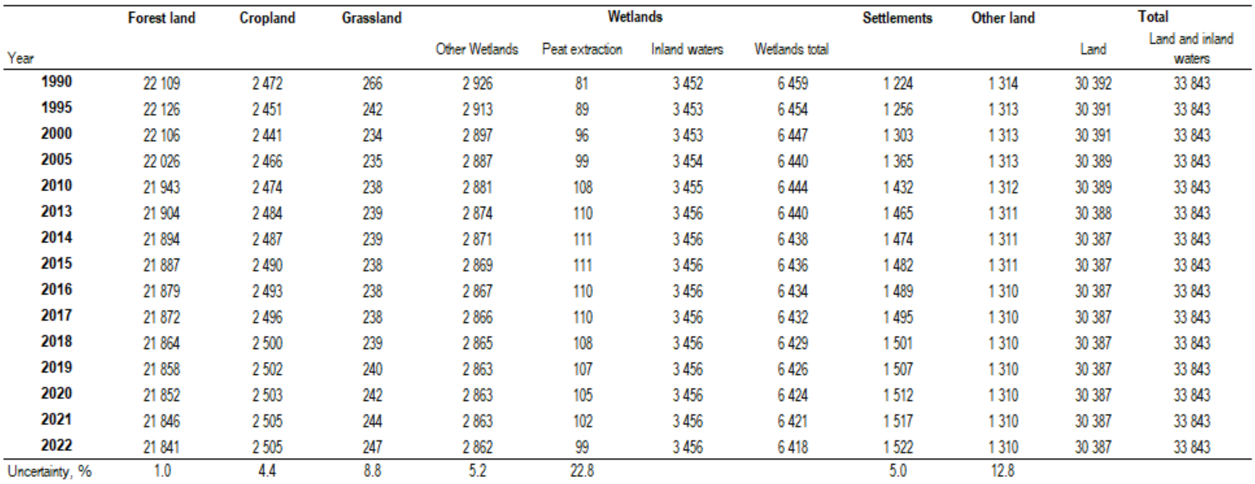


Figure 6.2-1 The partitioning of the country into Southern Finland (red) and Northern Finland (green)

The areas of IPCC land-use categories are given in Table 6.2-2 where the total land area refers to Finland's official land area on 1 January 2014. The total area is the official area of Finland including inland waters.

Table 6.2-2 The areas of IPCC land-use categories (1,000 ha). The last row shows the uncertainties, which are twice the relative standard errors, in area estimates due to sampling



	Forest land	Cropland	Grassland	Wetlands				Settlements	Other land	Total	
Year				Other Wetlands	Peat extraction	Inland waters	Wetlands total			Land	Land and inland waters
1990	22 109	2 472	266	2 926	81	3 452	6 459	1 224	1 314	30 392	33 843
1995	22 126	2 451	242	2 913	89	3 453	6 454	1 256	1 313	30 391	33 843
2000	22 106	2 441	234	2 897	96	3 453	6 447	1 303	1 313	30 391	33 843
2005	22 026	2 466	235	2 887	99	3 454	6 440	1 365	1 313	30 389	33 843
2010	21 943	2 474	238	2 881	108	3 455	6 444	1 432	1 312	30 389	33 843
2013	21 904	2 484	239	2 874	110	3 456	6 440	1 465	1 311	30 388	33 843
2014	21 894	2 487	239	2 871	111	3 456	6 438	1 474	1 311	30 387	33 843
2015	21 887	2 490	238	2 869	111	3 456	6 436	1 482	1 311	30 387	33 843
2016	21 879	2 493	238	2 867	110	3 456	6 434	1 489	1 310	30 387	33 843
2017	21 872	2 496	238	2 866	110	3 456	6 432	1 495	1 310	30 387	33 843
2018	21 864	2 500	239	2 865	108	3 456	6 429	1 501	1 310	30 387	33 843
2019	21 858	2 502	240	2 863	107	3 456	6 426	1 507	1 310	30 387	33 843
2020	21 852	2 503	242	2 863	105	3 456	6 424	1 512	1 310	30 387	33 843
2021	21 846	2 505	244	2 863	102	3 456	6 421	1 517	1 310	30 387	33 843
2022	21 841	2 505	247	2 862	99	3 456	6 418	1 522	1 310	30 387	33 843
Uncertainty, %	1.0	4.4	8.8	5.2	22.8			5.0	12.8		

The land-use conversion matrix between all land-use categories has been calculated based on the NFI sample plots (Table 6.2-3). Uncertainties presented in the matrix are based on the standard approach of the Finnish NFI (Tomppo et al. 2011). Land-use changes were assessed in the field and completed with auxiliary information on land-use changes. Remote sensing (RS) data and digital maps were used to check any undetected and post-measurements land-use changes on sample plots. The RS and other spatial data included satellite images, digital maps, thematic maps and shape files of the EU Land Parcel Identification System (LPIS) for monitoring of the agricultural land parcels (EU 1992). In the first stage of the image interpretation, RS data were supported by the NFI parameters, for example, with stand age to encompass all sample plots with potential land-use changes. Aerial images were utilised in the final stage of the interpretation to confirm each individual land-use change. The findings were used to complement the land-use change observations and the land-use changes that were identified in this process were updated to the NFI data.

Table 6.2-3 The land-use change matrix for IPCC land-use categories from 31 December 2002 to 31 December 2022 (1,000 ha) together with an uncertainty per cent twice the relative sampling error

	Initial							
Final	**Forest land**	**Cropland**	**Grassland**	**Wetlands**	**Settlements**	**Other land**	**Inland waters**	**Total (Final)**
Forest land	21 735 (1%)	12 (40.4%)	39 (20.5%)	32 (25.8%)	23 (26.4%)	0	0	21 841
Cropland	101 (13.2%)	2 370 (4.4%)	7 (48%)	25 (36%)	2 (146.7%)	0	0	2 505
Grassland	15 (36.1%)	51 (20.6%)	176 (10.4%)	5 (74%)	1 (122.8%)	0	0	247
Wetlands	37 (27.8%)	1 (141.4%)	1 (142%)	2 919 (5.2%)	0	0	3 (0%)	2 962
Settlements	191 (12%)	16 (35.4%)	8 (47.4%)	5 (97.2%)	1 299 (5.1%)	3 (69.8%)	0	1 522
Other land	0	0	0	0	1 (152.2%)	1 309 (12.8%)	0	1 310
Inland waters	0	0	0	4 (70%)	1 (141.6%)	0	3 451 (0%)	3 456
Total (initial)	22 079	2 449	233	2 991	1 326	1 313	3 453	33 843
NET change	**-238**	**56**	**15**	**-29**	**196**	**-3**	**3**	**0**

Recalculation of areas for the land-use categories

The land-use areas were recalculated due to new NFI data (Section 6.3 and Appendix 6b), updated land-related data on sample plots and corrections to the data. Due to recalculations the areas have slightly changed. The effect of the changes is shown in Table 6.2-4.

Table 6.2-4 The difference due to recalculations in the areas of the land-use categories between the 2023 and 2024 submissions (1,000 ha)

	Areas in Submission 2023		Areas in Submission 2024		Diffrences in areas between two submissions	
	1990	2021	1990	2021	1990	2021
Forest land	22 109	21 846	22 109	21 846	0	1
Cropland	2 472	2 508	2 472	2 505	0	-3
Grassland	266	240	266	244	0	4
Wetlands	3007	2966	3007	2965	0	-1
Settlements	1 224	1 517	1 224	1 517	0	0
Other land	1 314	1 310	1 314	1 310	0	0
Inland waters	3 452	3 457	3 452	3 456	0	0

6.3 Country-specific approaches

6.3.1 Information on the approaches used for representing land areas and on the land-use data used for inventory preparation

The data source on which the areas of land-use categories are based is the National Forest Inventory (NFI). The NFI is a sampling-based forest inventory system. Sample plots are located in systematic clusters and the proportions of temporary and permanent clusters are 20% and 80%, respectively. Since 2014 part of the temporary clusters are established as new permanent clusters, which are planned to be measured twice. After this change in sampling proportions of cluster types are 2/5 for temporary clusters, 2/5 for new permanent clusters which are measured in two consecutive rounds of NFI and 1/5 for permanent clusters. Further, since 2019 the proportions of temporary, permanent and new permanent clusters are 1/5, 1/5 and 3/5. The field measurements are carried out in five-year cycles and each year 20% of the plots are measured. Time series of the areas since 1990 are computed from data in the national forest inventories: NFI10 (2004 to 2008), NFI11 (2009 to 2013), NFI12 (2014 to 2018) and NFI13 (2019 to 2022) of which measurement years 2005 to 2022 are used and have appropriate classification parameters for GHGI AD purposes. NFI7–NFI9 (1977 to 2003) data have been used to compute estimates for land-use changes before 1990. This information is needed to divide land-use categories into sub-categories Lands Remaining and Lands Converted, and also for the modelling of carbon stock changes in mineral soils. More information on the NFI is provided in Appendix_6a.

The reasons for using NFI data for area estimations in the GHG inventory are: i) NFI data cover the whole country regardless of land ownership and all land use types, ii) NFI data cover the whole time span needed for the GHG inventory's time series, iii) NFI definitions and measurements of important variables relative to the GHG inventory have not changed, iv) NFI provides data on land use, land-use changes, soils and trees under different land use, and v) NFI is a continuous system, which also provides data for recent years.

The area estimation method is based on the methodology used in the NFI (Tomppo et al. 2011, Korhonen et al. 2021). Each sample plot, or strictly speaking the centre point of a sample plot, represents a particular area depending on the sample density region to which the sample plot belongs (see Appendix_6a, Figure 1_App_6a). Finland's official total land area is used to compute the representativeness of the sample plots. Official areas of municipalities are published annually by the National Land Survey of Finland (NLS) based on the NLS Topographic database. The method of how official areas were employed for area estimation is described by Tomppo et al. (2011) and briefly in Appendix_6a. Since some changes occur between the years in the surface area of municipalities due to improvements in the mapping precision and changes in water and land areas, a fixed total area is used in the GHG inventory. In this submission, the reference date for official area data is 1 January 2014 (National Land Survey of Finland 2014). If significant changes occur, the new official land area will be used. Luke's steering group and the advisory board for the greenhouse gas inventory appointed by Statistics Finland assesses significant changes before they are implemented in the inventory.

Areas for each land-use category are calculated by multiplying the number of the sample plot centres belonging to a particular land-use category with the area representativeness of a sampling density region. Areas are calculated separately for Southern and Northern Finland by sampling density regions (Figure 1_App_6a), as well as separately for land areas and inland waters. The sum of all different land-use categories, remaining and converted, is the total area of Finland.

The steps in land representation and area estimation are, firstly defining the six IPCC land-use categories according to Finnish circumstances. This is described in Section 6.2. In the second step, the employed NFI sample plot and stand level data are reclassified into the six IPCC land-use categories. The area estimates for land-use categories are computed separately for Southern and Northern Finland. The final results are reported at country level (Figure 6.2-1). A 20-year period is used for converted lands, except for peat extraction where a five-year conversion period is used (2006 IPCC Guidelines' default). The areas of land-use categories and subcategories are subdivided into mineral and organic soils, and organic forest soils further into drained and undrained lands.

The reported annual areas of land-use changes in 1990 to 2022 are based on a five-year moving average method. As the time series are produced from NFI data, the five-year moving averages were computed to decrease the effect of sampling error. Full sets of NFI data cover five years of field measurements and NFI provide new data every year. Therefore, the area estimates for the latest years, where the new data are applied, are recalculated in every submission. For a more detailed description of the area computations and the estimation of the annual land-use changes, see Appendix_6b.

Information on land-use changes before 1990 is needed, for example, for the estimation of carbon stock changes in mineral soil. Therefore, the areas of land-use changes have been estimated also for 1971 to 1989 by employing NFI7 to NFI9 data. For the pre-1990 time series, the average annual land-use changes areas were estimated for NFI mean years, and interpolated between the mid-years. For example, the mean years of the NFI7, NFI8 and NFI9 in Northern Finland are 1977, 1988 and 1996 respectively. The mid-year data are utilised to interpolate and extrapolate land-use change areas for years from 1971 to 1989. The value from the latest year available is used in extrapolation. For other land-use classes than Forest land the oldest available data are from NFI9.

The information on areas of the mineral and organic soils is needed for the estimation of carbon stock changes and non-CO_2 emissions from soils. Organic soils are identified in the field during the NFI measurements for Forest land and Wetlands and partly for other land-use classes in case of land-use change. The Finnish georeferenced soil database was applied for those NFI sample plots where soil type was not assessed in the field, e.g., for Cropland and natural pastures and ditches in the Grasslands category. The Finnish soil database includes a soil map at a scale of 1:250,000 and properties of the soils (Lilja et al. 2006, 2009). Polygons that are smaller than 6.25 ha are merged with adjacent larger polygons in the database. The soil database was published in 2009 and produced by Agrifood Research Finland (MTT)[21], the Finnish Forest Research Institute (Metla) and the Geological Survey of Finland (GTK).

Any further subdivisions of areas used in the emission calculations are described under the sections of each land-use category. The needed subdivisions also depend on reported gasses and soil type, i.e., different types of stratification for the different land-use categories and pools are used. For example, in estimating carbon stock changes in soil organic matter under the CRF 4.A category, the organic soils are divided into undrained and drained soils and the drained soils further into five site fertility types (Table 6.3-1 and Section 6.4.2.1). The stratification is slightly modified when estimating CH_4 and N_2O emissions (Table 6.3-1, **Virhe. Viitteen lähdettä ei löytynyt.** and Section 6.10.2.2).

Table 6.3-1 Stratification of forest soils on drained organic lands. Different subcategories are used for CSCs, N_2O and CH_4 estimation

CO_2	N_2O	CH_4
Site fertility type	**Peatland site type**	**Drainage situation**
Herb-rich type	Herb-rich type (Rhtkg)	Poor
Vaccinium myrtillus type	*Vaccinium myrtillus* type I (MtkgI)	Good
Vaccinium vitis-idaea type	*Vaccinium myrtillus* type II (MtkgII)	
Dwarf shrub type	*Vaccinium vitis-idaea* type I (PtkgI)	
Cladina type	*Vaccinium vitis-idaea* type II (PtkgII)	
	Dwarf shrub type (Vatkg)	
	Cladina type (Jätkg)	

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[21] Since 2015 Agrifood Research Finland and Finnish Forest Research Institute are parts of the Natural Resources Institute Finland.

6.3.2 Information on approaches used for natural disturbances, if applicable

Not applicable for Finland.

6.3.3 Information on approaches used for reporting harvested wood products

The Production Approach as described in the 2006 IPCC Guidelines, Vol. 4, Annex 12.A.1 is used to estimate the carbon stock change in HWP. The approach and the reporting scheme encompass domestically produced HWP originating from domestic harvests separately for domestically consumed and exported products using as detailed country-specific classification for HWP categories as possible (Hamberg et al. 2016). Further description of the method can be found under Section 6.11.2.

6.4 Forest Land (CRF 4.A)

6.4.1 Category description

Forest Land was a net sink in 2022 as it has been since 1990. The net removals due to changes in carbon stocks were 7.2 Mt CO_2 in 2022, whereas they were 32.0 Mt CO_2 in 1990 and 7.4 Mt CO_2 in 2021. The net removals due to carbon stock changes have decreased by 77% since 1990 and 3% since 2021. The CRF 4.A category includes emissions and removals resulting from carbon stock changes in living biomass, dead organic matter (DOM) including litter and dead wood, and soil organic matter (SOM). The category is subdivided into CRF 4.A.1 Forest Land Remaining Forest land, and 4.A.2 Land Converted to Forest Land.

Forest Land is defined as a land with a tree crown cover of more than 10%. The trees should be able to reach a minimum height of five metres. According to the national forest land definition, a minimum area for forest is not exactly set, but a guideline of 0.25 ha for a forest stand in Southern Finland and 0.5 ha in Northern Finland is given in NFI11 and before that. Since NFI12, a minimum stand area of 0.25 ha is given as guidance for the whole country. When comparing NFI11 and NFI12 permanent plots on national forest land there is no difference in forest area caused by the guidance change in Northern Finland. The definition does not comply strictly with the FAO definition, but to include all nationally defined forest lands in the GHG inventory under the Forest Land category, the minimum forest area is adjusted to 0.25 ha in the Convention reporting (See Section 6.2).

Living biomass was a net sink of 12.6 Mt CO_2 in 2022. Living biomass and combined pools of DOM and SOM have been a net sink during the whole time series, whereas the organic soils have been a net source. In 2022, the sink of mineral soils was 4.8 Mt CO_2 and the emissions of organic soils 10.1 Mt CO_2. In recent years, the sink of Forest Land has been declining. The reason for the declining sink has been the increasing volume of roundwood removals. The main proportion of the sink was from Forest Land Remaining Forest Land, while Land Converted to Forest Land played a minor role (about 2 %).

The most important components of the forest sink are the tree biomass growth and biomass removed from forest due to fellings. The annual increment of growing stock was 77.7 million m^3, based on the 8th National Forest Inventory (NFI) (measured in 1986 to 1994), 107.8 million m^3 based on the NFI12 (2014 to 2018) and 103.7 million m^3 based on NFI13 (2019 to 2022) (Luke 2023c). The rapid increase in increment in the 1980's and 1990's has leveled out and the increment has decreased according to the last inventory measurements. In the NFI based increments, there is less fluctuation between years in contrast to the harvest rates. In 2022, the total drain (incl. roundwood removals, stemwood of natural and logging residues) was 89.5 million m^3 (Luke 2023b) (Figure 6.4-1).

Increase in the volume of roundwood removals increases the litter input to the soil, thus increasing the carbon storage of combined pools of DOM and SOM. In the organic soils (peat soils), there are two main factors for the variations in emissions and removals since 1990: 1) due to drainage, previously poorly productive sites have been converted to Forest Land; and 2) the increase in mean May-October air temperature. The first factor has slightly increased the total emissions caused by peat decomposition. The second factor has significantly increased the emissions in drained peatlands by increasing the decomposition of litter and SOM.

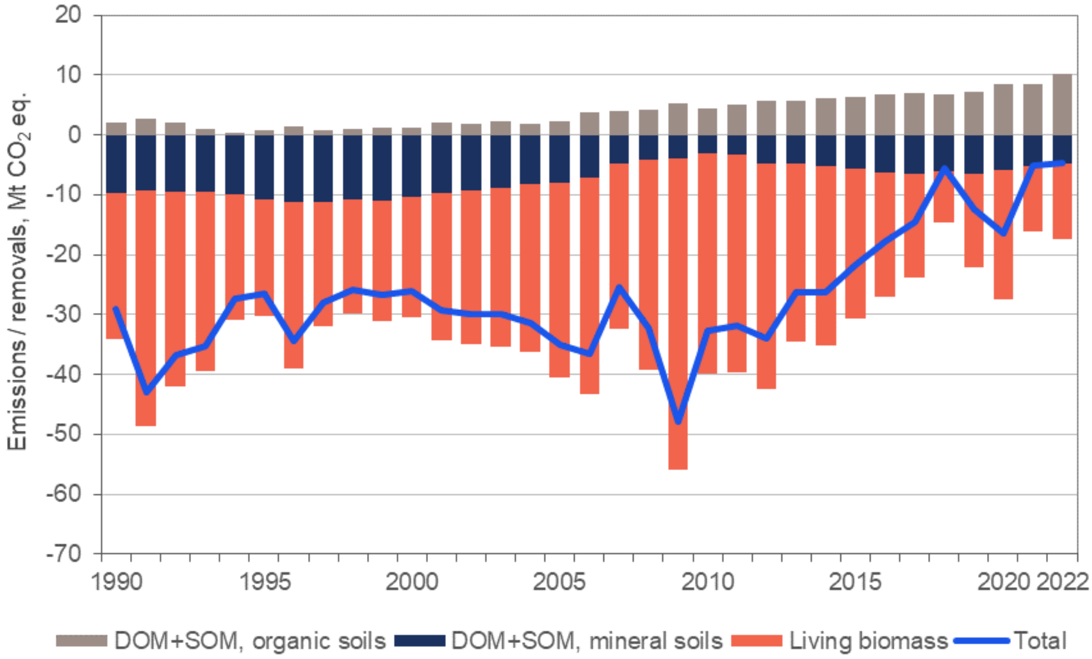


Figure 6.4-1 Emissions (positive sign) and removals (negative sign) in Forest Land

Forest Land Remaining Forest land is a key category.

Definitions of carbon pools

Living biomass. Tree biomass is the dry weight of living trees with a height of at least 1.35 m, i.e. those trees that are measured in NFIs. Tree biomass includes stem wood, stem bark, living and dead branches, needles/foliage, stumps, and roots down to a minimum diameter of one cm (Repola 2008, Repola 2009). Stumps and roots are considered below-ground biomass and the rest is above-ground biomass. The biomass of other vegetation includes the biomass of ground vegetation, which consists of moss, lichen, shrub and dwarf shrub vegetation. This biomass is not included in carbon stock changes in living biomass, but it is included when the litter input to the soil is estimated.

Dead wood. This carbon pool includes tree stems that are left in the forest to decay. This pool originates from the natural mortality of the trees and from waste wood from logging. The minimum diameter is 10 cm. Due to modelling framework, this carbon pool is reported on mineral soils as a combined estimate for dead wood, litter and soil organic matter pools. On drained organic forest soils, the pools are also reported as an aggregated estimate.

Litter. This carbon pool includes both above-ground and below-ground litter, which originates from trees and ground vegetation. Litter consists of dead foliage, leaves, branches, bark coarse roots, stumps and fine roots. Due to modelling framework, this carbon pool is reported on mineral soils as a combined estimate for dead wood, litter and soil organic matter pools. On drained organic forest soils, the below-ground litter is input to the estimation of carbon stock changes in soil organic matter and therefore not reported separately (see below the definition for soil organic matter). On drained organic forest soils, the above-ground litter pool is assumed to be in a steady state (i.e. no change).

Soil organic matter. Soil organic matter is built up by the decomposed litter that has accumulated in soils. The soil carbon model Yasso07 estimates soil carbon stocks and their changes to a depth of one metre (Appendix_6e). Due to the modelling framework, this carbon pool is reported on mineral soils as a combined estimate for dead wood, litter and soil organic matter pools. On drained organic forest soils, the carbon stock change of SOM is estimated based on the below-ground litter input and peat decomposition.

Soil is considered organic if the soil type is peat. Finland is a relatively flat and humid country, where the conditions have been favourable for peat accumulation. Peatlands are defined in the same way as in the NFI;

a site is classified as peatland if the organic layer is peat or if more than 75% of the ground vegetation consists of peatland vegetation. Otherwise, the soil is considered mineral. The applied definition gives a slightly larger area for organic soil than the IPCC definition.

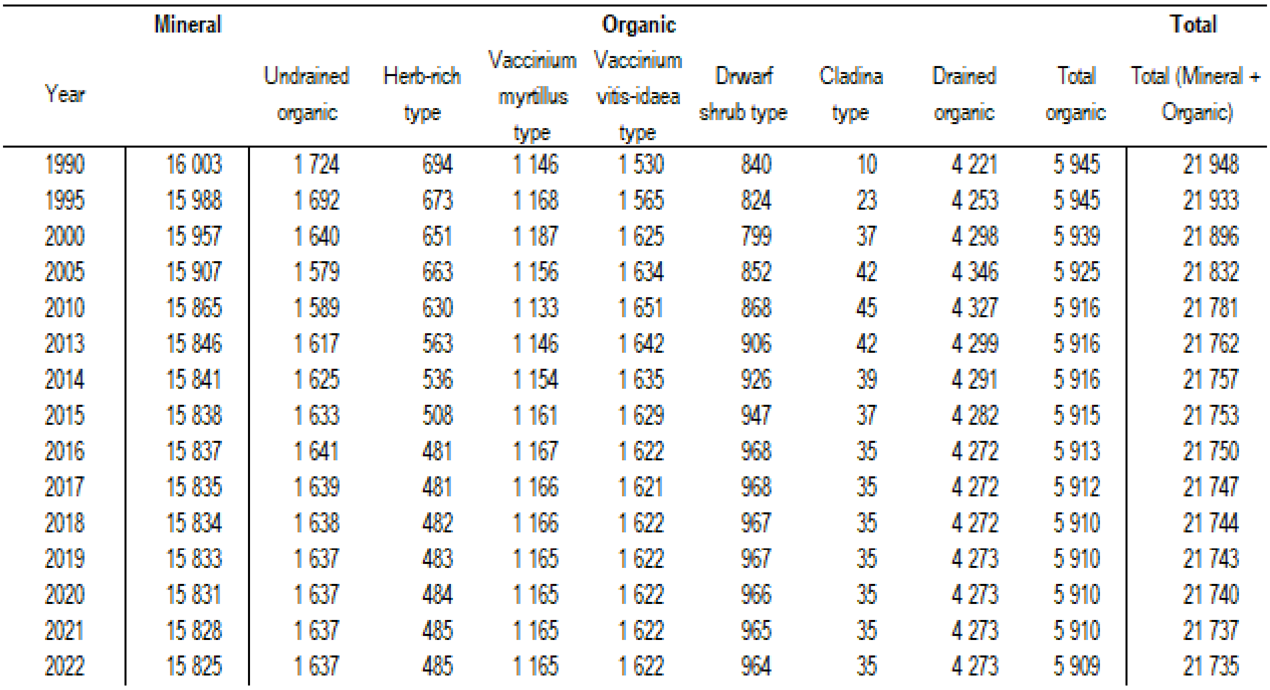
6.4.2 Methodological issues

6.4.2.1 Forest Land Remaining Forest Land (CRF 4.A.1)

Activity data

Land use area calculations are described in detail in Section 6.3. The activity data for Forest Land Remaining Forest Land are the difference between total Forest Land area and the area of Land converted to Forest Land. Organic soils were divided into undrained and drained soils and the drained soils further into five site types based on the fertility of the soil (Table 6.4-1, Laine 1989). NFI7-NFI12 data were used to estimate the proportional distribution of site types. Areas of site types were interpolated between different NFIs (Section 6.3). The definition for Forest Land is given in Section 6.2.

Table 6.4-1 Areas of mineral and organic soils on Forest Land Remaining Forest Land (1,000 ha). Emissions from organic soils are only estimated for drained land



Year	Mineral	Organic								Total
		Undrained organic	Herb-rich type	Vaccinium myrtillus type	Vaccinium vitis-idaea type	Drwarf shrub type	Cladina type	Drained organic	Total organic	Total (Mineral + Organic)
1990	16 003	1 724	694	1 146	1 530	840	10	4 221	5 945	21 948
1995	15 988	1 692	673	1 168	1 565	824	23	4 253	5 945	21 933
2000	15 957	1 640	651	1 187	1 625	799	37	4 298	5 939	21 896
2005	15 907	1 579	663	1 156	1 634	852	42	4 346	5 925	21 832
2010	15 865	1 589	630	1 133	1 651	868	45	4 327	5 916	21 781
2013	15 846	1 617	563	1 146	1 642	906	42	4 299	5 916	21 762
2014	15 841	1 625	536	1 154	1 635	926	39	4 291	5 916	21 757
2015	15 838	1 633	508	1 161	1 629	947	37	4 282	5 915	21 753
2016	15 837	1 641	481	1 167	1 622	968	35	4 272	5 913	21 750
2017	15 835	1 639	481	1 166	1 621	968	35	4 272	5 912	21 747
2018	15 834	1 638	482	1 166	1 622	967	35	4 272	5 910	21 744
2019	15 833	1 637	483	1 165	1 622	967	35	4 273	5 910	21 743
2020	15 831	1 637	484	1 165	1 622	966	35	4 273	5 910	21 740
2021	15 828	1 637	485	1 165	1 622	965	35	4 273	5 910	21 737
2022	15 825	1 637	485	1 165	1 622	964	35	4 273	5 909	21 735

Carbon stock change in living biomass

Carbon stock changes in living tree biomass are reported as an aggregated estimate for above-ground and below-ground biomass for the whole of Finland. The biomass of other plants was assumed not to change; hence the change is not estimated for the category Forest Land Remaining Forest Land. The stratification used in the biomass estimation is more detailed than reported and is described in Appendix_6c.

The employed method is a Tier 3 Biomass Gain-Loss method (2006 IPCC Guidelines, Vol. 4, Equation 2.7). The National Forest Inventory (NFI) provides measured tree-level data of tree characteristics to employ tree species-specific biomass functions for direct estimation of biomass (Repola 2008, Repola 2009, Repola et al. 2007), as well as estimates of the total increment of growing stock in stem volume. Biomass conversion and expansion factors (BCEF) for the increment were developed separately for each NFI rotation and stratum to convert volume increments into biomass increments.

Trees measured in the NFI can be defined as tally trees and sample trees; the latter ones are measured in greater detail (see Appendix_6 a). Stem volume, as well as above-ground and below-ground biomass were predicted for sample trees of permanent sample plots, and tree-level predictions of annual increment were obtained as the differences between the two most recent measurements divided by the length of the time interval between the two measurements. The BCEFs were derived as ratios between the stratum-level sums of annual biomass and volume increments of the sample trees on permanent plots. Biomass conversion and expansion factors (BCEF) for cutting removals and natural losses are also estimated from the NFI data, and then, applied to convert the statistical drain volume to biomass losses. (See Appendix_6c for a more detailed description).

The annual gain (growth) in living tree biomass was first estimated for the total forest land and then for lands converted to forest land. The difference between these two estimates is the biomass growth for Forest Land Remaining Forest Land. The method is described in Appendix_6c. Employed biomass models are given in Appendix_6d.

The biomass loss in living trees in Forest Land Remaining Forest Land was estimated as the difference between the total biomass loss and the biomass losses due to forest land being converted to other land uses and biomass losses on Land converted to Forest land. The total biomass loss estimate is based on the statistics on the total drain of growing stock. The official drain and harvest statistics were published until 2014 in the Yearbook of Forestry by the Finnish Forest Research Institute and from 2015 onwards in the Statistical Database by Natural Resources Institute Finland (Luke). The biomass losses from forest are connected with the land-use changes based on the NFI data. The method is described in Appendix_6c.

To convert biomass to carbon, the default conversion factor 0.5 was used.

Carbon stock changes in dead wood, litter and soil organic matter

Mineral soils

The methodology for estimating carbon stock changes in soil, litter and dead wood in mineral soils is a Tier 3 approach and builds on the research by Liski et al. (2006). This method combines forest inventory data, biomass models, litter turnover rates and the dynamic soil carbon model. For Forest Land Remaining Forest Land, the Yasso07 model (Tuomi et al. 2011b) was applied. For a more detailed description of the Yasso07 model, see Appendix_6e. The advantage of Yasso07 is the model's ability to produce uncertainty estimates for carbon stock changes. The model has been verified and reported in several scientific articles (Tuomi et al. 2008, 2009, 2011a, 2011b).

An aggregated estimate of the litter, dead wood and soil organic matter (DOM+SOM) is provided in the reporting because the Yasso07 soil carbon model estimates carbon stock change for the total of the above-mentioned components. The Yasso07 model has been defined to estimate carbon stock change to a depth of one metre. The division of the model estimates into soil carbon pools (SOM and DOM) would be artificial, and, therefore, an aggregated estimate has been provided.

The aggregated estimate of carbon stock changes in DOM+SOM is driven by tree and ground vegetation litter production and was estimated using the Yasso07 soil model, which has been developed for applications concerning the decomposition of various types of litter and different SOM types. The Yasso07 simulations were made separately for the mineral soils of Southern and Northern Finland.

Prior to soil carbon stock change simulations, preliminary data preparation involved three steps:

i) Estimating the litter input data, including dead wood, from the standing tree stock, ground vegetation and drain and dividing them into three different decomposition compartments
  - Non-woody litter (e.g. fine roots, foliage and ground vegetation)
  - Fine woody litter (e.g. branches and woody roots)
  - Coarse woody litter (e.g. dead wood, stumps and cutting waste)

ii) Estimating weather parameters for Southern and Northern Finland

iii) Estimating the initial values of the model state variables based on NFI6 data (1971–1976) (so-called spin-up runs to obtain a steady state for the model)

The annual litter input of the model originated from the living trees, ground vegetation, harvesting residues and unrecovered natural losses. Litter production from living trees was estimated using the biomass compartments of living trees and litter production rate coefficients. Biomass compartments were calculated from NFI data using Finnish tree-level biomass models (Appendix_6d). The method for estimating carbon stocks of living tree biomass is described in Appendix_6c. Fine root biomass was estimated using coefficients that describe the relation between root and leaf biomass (Helmisaari et al. 2007).

The litter input has been estimated since the 6th National Forest Inventory (NFI6). Harvesting and other drain statistics were also used to estimate the litter input of these components. Harvesting residues consist of foliage, branches, waste wood and stumps, while litter from living trees and from natural mortality consists of all the biomass components of trees. The use of energy wood was also taken into account by deducting the amounts of harvesting residues used for energy production (Finnish Statistical Yearbook of Forestry 2014, Luke 2021b). The volumes of the harvesting residues and unrecovered natural losses were converted to biomass using the expansion factors computed from NFI data; their derivation is explained in Appendix_6c, subsection Losses in living biomass. For the ground vegetation of the mineral soils, the biomass was estimated with the use of 3,000 permanent sample plots described by Mäkipää and Heikkinen (2003). The models of Muukkonen et al. (2006) were applied to estimate the biomass of shrubs, herbs and grasses and mosses separately for mineral soils in Southern and Northern Finland. The litter input of the ground vegetation was estimated using litter turnover rates presented by Liski et al. (2006).

The litter production from each tree biomass compartment was calculated using litter production rate coefficients (Table 6.4-2) as follows:

$litter_i = r_i * W_i$,

where r_i is the litter production rate of compartment i and W_i is the biomass of compartment i (kg). In mineral soils, litter production from ground vegetation was assessed based on the vegetation coverage measurements of the NFI and biomass models (Muukkonen et al. 2006) (Table 6.4-3).

Table 6.4-2 Litter production rates of the biomass compartments of trees (Lehtonen et al. 2004, Muukkonen and Lehtonen 2004, Starr et al. 2005, Liski et al. 2006). The litter production rate for pine needles in drained organic soils is based on data presented in Table 1 of Ojanen et al. (2014)

Tree species/type	Needles/ Leaves	Branches	Bark of stems	Bark of stumps	Roots >2mm	Fine roots
pine, south	0.245	0.02	0.0052	0.0029	0.0184	0.85
pine, north	0.154	0.02	0.0052	0.0029	0.0184	0.85
pine, drained peatlands	0.33	0.02	0.0052	0.0029	0.0184	0.85
spruce, south	0.1	0.0125	0.0027	0	0.0125	0.85
spruce, north	0.05	0.0125	0.0027	0	0.0125	0.85
deciduous, south	0.79	0.0135	0.0029	0.0001	0.0135	0.85
deciduous, north	0.79	0.0135	0.0029	0.0001	0.0135	0.85

Table 6.4-3 Litter production of ground vegetation on mineral soils (g C m^{-2} a^{-1}) Muukkonen et al. 2006)

Species group	Above ground	Below ground	Area	Soil
Total, South Finland	50.6	-	Southern Finland	Mineral
Total, North Finland	66.6	-	Northern Finland	Mineral

The weather data applied in the model runs were obtained from the Finnish Meteorological Institute (FMI). The data consist of monthly mean temperatures and rainfall since 1960 with a 1x1 km grid covering all of Finland. A subset grid of 10x10 km was selected to reduce the need of computing power. Based on the gridded data the mean annual weather data (mean annual temperature, temperature amplitude and annual rainfall) used with the Yasso07 model were estimated separately for Southern and Northern Finland for the period 1960 to 2022. Annual weather was calculated as an arithmetic mean of grid points locating within Southern and Northern Finland. Thereafter, weather parameters used in the modelling were calculated as 30 years moving averages (e.g. 1988 to 2017 for 2017, 1987 to 2016 for 2016).

The model initialisation was done using NFI6 data from 1971 to 1974 in Southern Finland and from 1975 to 1976 in Northern Finland. The average annual litter input of trees, ground vegetation, loggings and natural mortality from those periods were given to the Yasso07 model. The model used the given litter and mean weather data for 1960 to 1990 as the steady state. Earlier research has shown that approximately ten years of simulation since spin-up is enough to cancel out the effect of the spin-up level (Peltoniemi et al. 2006). Stock changes in forest soil carbon are reported as five-year moving averages. Model simulations provide the aggregated carbon stock change of dead wood, litter and soil organic matter.

The soil carbon stock change for the mineral soils of Forest Land Remaining Forest Land were simulated with the Yasso07 model using litter input, litter quality and weather as an input data (see Appendix_6f).

Organic soils

Organic forest soils (peatlands) are defined according to the NFI: a site is classified as peatland, if the organic layer is peat or if more than 75% of the ground vegetation consists of peatland vegetation. CO_2 emissions are estimated from drained peatlands, while the carbon stock changes of soils on undrained peatlands were assumed to be in a steady state.

The estimation of the emissions and removals on drained organic soils is a Tier 3 approach. The applied method is based on the CO_2 balance of the released CO_2 from decomposing soil organic matter and the carbon entering the soil through plant litter input (Alm et al. 2023, Appendix_6k).

Below-ground and above-ground litter input from living trees, dead trees and logging residues are estimated from the tree data measured by the NFI and statistics on roundwood removals. The litter input from living trees is estimated by tree biomass components multiplied by the litter turnover rates, and it follows the same principles as the litter modelling for mineral soils. Litter input from ground vegetation is estimated using regressions models from Ojanen et al. 2014 (see Appendix_6k). The litter input from arboreal fine roots is estimated using regression models from Ojanen et al. 2014 and measured root turnover rates (Alm et al. 2023). The decomposition of peat and litter, except for harvesting residues, was estimated using regression models from Ojanen et al. 2014. The explanatory variables of the regression models for each drained peatland forest site type are the mean basal area of the trees (m^2 ha^{-1}) by the tree species groups and mean May-October air temperature (°C). The mean basal areas were estimated using the NFI8 to NFI13 data and the mean temperatures were derived from the weather data provided by the Finnish Meteorological Institute. The decomposition of harvesting residues and litter from natural mortality of trees was estimated using Yasso07 soil model.

The annual estimated carbon stock changes in soils are presented for Forest Land Remaining Forest Land, separately for Southern and Northern Finland and by fertility type in Appendix_6f.

6.4.2.2 Land Converted to Forest Land (CRF 4.A.2)

Activity data

Land use area calculations are described in detail in Sections 6.2 and 6.3 and in Appendix_6b. Land Converted to Forest Land is the cumulative sum of the converted areas over a 20-year period. There were land use conversions from all LU categories to Forest Land. Former Wetlands could have previously been either peat extraction areas or wetlands drained for forestry purposes. Former Settlements are a diverse group of lands. Areas belonging to this group include, for example, large forested gravel pits, former power supply lines, forested roads and abandoned dwelling places (Section 6.3).

Carbon stock change in living biomass

Emissions and removals are reported from carbon stock changes in living tree biomass including above-ground and below-ground biomass. The carbon stock change in living biomass of trees was estimated according to the Tier 3 method in the 2006 IPCC Guidelines (Vol. 4, Eq. 2.15). The annual mean increment per hectare was estimated separately for Forest Land converted from five other land-use categories. The annual increment per hectare and age-class was estimated separately for Forest Land converted from agricultural areas and other land areas, separately for Southern Finland and Northern Finland. The trees measured on the permanent NFI sample plots were used to estimate the biomass losses. The methodology is described in Appendix_6c.

In the sub-category Cropland converted to Forest Land, agricultural biomass of 4 t C ha^{-1} was removed as a loss in the carbon stock of living biomass in the conversion. The value is a country-specific mean crop biomass based on yield (see also Section 6.5.2.2 Land converted to cropland). In the sub-category of Grassland converted to Forest Land the areas are abandoned fields that are slowly gaining tree biomass and turning into forest land. When this type of grassland finally converts to forest, no biomass is removed but the grass is left growing on the site together with the trees. As trees grow slowly, it can be considered that the grass keeps growing throughout the whole conversion period of 20 years. Thus no biomass loss is reported during the conversion.

Carbon stock changes in dead wood, litter and soil organic matter

Mineral soils

The Yasso07 soil carbon model (Tuomi et al. 2011b) was applied for the Land Converted to Forest Land (see Appendix_6e). The method is a Tier 3 approach according to the 2006 IPCC Guidelines. The Yasso07 model was developed and tested against soil carbon measurements on afforestation and reforestation sites in a HILPE project and it was found that the model worked well against the measurements (Karhu et al. 2011).

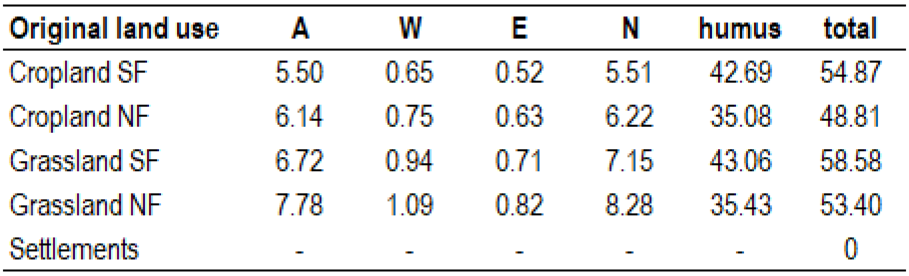
For mineral soils, an aggregated estimate of the litter, dead wood and soil organic matter (SOM) was provided due to the fact that the Yasso07 soil carbon model estimates carbon stock change for the total of the above-mentioned components (DOM+SOM). The division of soil carbon pools from those models into SOM and DOM would be artificial.

Before the simulations, preliminary preparations were made using three steps:

i) Estimating the litter input data from trees and ground vegetation and dividing them into two different decomposition compartments
  - Non-woody litter
  - Fine woody litter (mean size two cm)
ii) Estimating the chemical properties of the litter (acid-, water-, ethanol- and non-soluble compounds) and weather data (mean temperature, amplitude and precipitation)
iii) Estimating the initial values of the model state variables (Table 6.4-4).

The carbon stock estimates of the previous land use before the conversion were estimated by applying the Yasso07 model with typical agricultural litter input. For both the Cropland and Grassland model, runs with Yasso07 were made with typical cultivation practices to estimate carbon stocks (Table 6.4-4). The carbon input from agricultural crops was estimated based on mean crop yields from agricultural statistics and harvest indices from the existing Nordic literature. The chemical quality of the wheat and barley litter was measured by fractionating it into compounds soluble in ethanol (E), water (W), hydrolysable with acid (A) and a non-soluble non-hydrolysable residue (N) (Berg et al. 1991). For rye and oats, an average of wheat and barley values (AWEN) was used because all these cereals have a rather similar chemical quality. The quality of grass litter was estimated based on Van Soest extractions (Jensen et al. 2005) that were transformed to correspond to the proximate carbon fractions (AWEN) with the regression models of Ryan et al. (1990). The mean annual temperature, precipitation and temperature amplitudes (0.5*(minimum monthly mean - maximum monthly mean)) were estimated for Southern and Northern Finland. The Yasso07 soil model was driven using mean weather data between 1981 and 2010 corresponding to the period used in the climatological standard normal. For unvegetated settlements, the starting value of soil carbon was assumed to be equal to zero.

Table 6.4-4 The carbon stocks of mineral agricultural soils and settlements (tonnes of carbon per ha) before land-use change for Southern Finland (SF) and Northern Finland (NF) divided into acid (A), water (W), ethanol (E), non-solubles (N) and humus compartments (tonnes C per ha)



Original land use	A	W	E	N	humus	total
Cropland SF	5.50	0.65	0.52	5.51	42.69	54.87
Cropland NF	6.14	0.75	0.63	6.22	35.08	48.81
Grassland SF	6.72	0.94	0.71	7.15	43.06	58.58
Grassland NF	7.78	1.09	0.82	8.28	35.43	53.40
Settlements	-	-	-	-	-	0

For Land Converted to Forest Land, the litter input given in the model consisted of tree and ground vegetation litter. The tree litter was estimated based on the age class specific mean tree biomasses of corresponding NFI12 plots. The tree biomass estimation is described in Section 6.4.2.1. This estimation was done separately for forested Croplands, Grasslands and Settlements. The same biomass turnover rates were applied here as for Forest Land Remaining Forest Land. The average ground vegetation litter was also applied as an input during the simulations. The Yasso07 model runs were made for 20 years to estimate the response of the soil carbon to the land-use change. For Settlements converted to Forest Land, only unvegetated settlements were simulated using the Yasso07 model. The soils of vegetated Settlements (gardens, greenhouses, etc.) were assumed to be in a steady state during conversion to Forest Land.

Annual estimates for carbon stock changes in soils are presented for Land Converted to Forest Land and separately for Southern and Northern Finland in Appendix_6f.

Organic soils

The emission estimation of organic lands converted to Forest Land were calculated as a difference between emissions of the previous land use before the conversion (Table 6.4-5) and the C entering the soil through below-ground litter input from living trees and ground vegetation. The method corresponds to the Tier 2 method of the IPCC (2006 IPCC Guidelines). The below-ground litter input of the trees was derived from the biomass estimates of the corresponding NFI data; for ground vegetation, average estimates of below-ground litter from ground vegetation were used. The biomass estimation is described in the Section 6.4.2.1.

The difference between below-ground litter input and emissions was estimated for the period of 20 years after the conversion and the annual average was used in the calculation.

Table 6.4-5 The emissions of the original land use on organic soils converted to forests (tonnes C per ha)

Original land use	Assumed previous emissions of CO_2 (tonnes C per ha)	Source
Cropland	6.8	(IPCC Wetlands Supplement, Table 2.1)
Grassland	3.5	(Maljanen et al. 2010)
Peat extraction sites	2.6	(Alm et al. 2007)
Wetlands	Depending on the fertility	(Minkkinen et al. 2007)
Settlements	Fertility of *Vaccinium vitis-idaea* type	(Minkkinen et al. 2007)

The emission factor for organic Cropland converted to Forest Land is the average of the emission factors for annual crops (7.9 tonnes C per ha) and perennial crops (5.7 tonnes C per ha) (Table 6.4-5). The emission factor for organic Grassland converted to Forest Land was estimated applying the same emission factor as for organic Grassland. Annually estimated carbon stock changes in soils are presented for Land Converted to Forest Land and separately for Southern and Northern Finland in Appendix_6f.

6.4.3 Uncertainty assessment and time series’ consistency

Quantitative estimates of uncertainty are provided in Annex 2. The annex also documents assumptions made for the analysis. A description of the uncertainty analysis is included in Section 1.6.

6.4.3.1 Uncertainty of carbon stock changes in living biomass

The uncertainty (UC) for carbon stock change in living biomass for Forest Land Remaining Forest Land is a combined uncertainty of NFI sampling, uncertainty of statistics on total drain, model and biomass conversion and expansion factor uncertainties.

Gains in living tree biomass

The UC due to NFI sampling in the estimates of volume increment, I_V, was assessed on the basis of ’our years' data from NFI13 (2019 to 2022) and that in the estimates of biomass conversion and expansion factors for biomass increment, $BCEF_G$, on the basis of five years’ data from NFI12 (2014 to 2018). The standard approach of the Finnish NFI (Tomppo et al. 2011) was applied. The total biomass increment was estimated as a sum of stratum-specific increments

$$I_{B,sp,soil,region} = I_{V,sp,soil,region} \bullet BCEF_{G,sp,soil,region},$$

where I_V is the stem volume increment and $BCEF_G$ the biomass conversion and expansion factor for growth. Their sampling uncertainties and the propagation of these uncertainties for the total biomass increment are reported in Table 6.4-6 .

Table 6.4-6 Sampling uncertainties, twice the relative standard errors, for NFI13 estimates of biomass increment in living trees using NFI12 biomass conversion and expansion factors, $\boldsymbol{U(I_B) = \sqrt{U(I_V)^2 + U(BCEF_G)^2}}$

Region	Soil	Tree species	Volume inc., I_V million m^3/a	U(I_V), %	$BCEF_G$	U($BCEF_G$), %	Biomass inc., I_B Tg/a	U(I_B), %
south	mineral	pine	20.604	3.1	0.576	1.3	11.878	3.3
		spruce	23.785	3.5	0.704	2.5	16.734	4.3
		deciduous	13.742	4.0	0.762	2.1	10.471	4.5
	organic	pine	6.118	5.5	0.570	1.9	3.487	5.8
		spruce	5.808	7.7	0.729	5.0	4.231	9.2
		deciduous	3.764	7.7	0.766	2.2	2.885	8.0
north	mineral	pine	13.529	4.8	0.604	1.5	8.172	5.0
		spruce	3.824	8.1	0.901	10.4	3.444	13.2
		deciduous	3.279	8.0	0.833	3.0	2.732	8.6
	organic	pine	4.583	6.0	0.597	2.2	2.734	6.4
		spruce	2.095	10.5	0.819	5.5	1.716	11.8
		deciduous	2.278	8.9	0.822	4.6	1.872	10.0
Total, using Equation 3.2 in Volume 1 of the 2006 IPCC Guidelines							70.355	1.8

Losses in living tree biomass

The uncertainties in the biomass conversion and expansion factors for fellings and natural mortality due to NFI sampling was similarly assessed by region, soil and species, and propagated into the uncertainty in the total biomass of fellings (2.0%) and natural mortality (14.7%). In addition to sampling uncertainty in the expansion factors, the biomass estimate of fellings is influenced by the uncertainty in the felling volume. An assumed 5% uncertainty in the annual statistics on commercial removals yields 5.4% total sampling uncertainty for fellings. Propagation of sampling uncertainty for the net change in living biomass is reported in Table 6.4-7 .

Table 6.4-7 Sampling uncertainties, twice the relative standard errors, for the net change in living biomass in 2015

Source	Biomass change, Tg	Uncertainty, %
Increment	70.355	1.8
Fellings	-59.041	5.4
Natural losses	-4.380	14.7
Net change (IPCC 2006, Vol. 1, Eq. 3.2)	6.934	15.8

Biomass conversion and expansion factors (BCEF) are also influenced by uncertainty due to uncertain parameter values of the biomass models, which were assessed with methods presented by Ståhl et al. (2014) on the basis of the simplest model versions with only tree species, diameter and height as explanatory variables (Appendix_6g). The resulting estimate of model uncertainty is 4.12%.

The total uncertainty in biomass change (gains and losses) assessed as described above is 16.3%.

6.4.3.2 Uncertainty for Carbon stock changes in dead wood, litter and soil organic matter

Quantitative estimates of uncertainty are provided in Annex 2. The annex also documents assumptions made for the analysis. A description of the uncertainty analysis is included in Section 1.6.

The uncertainty estimation for mineral soils is described in Appendix 6h and by Lehtonen and Heikkinen (2015), yielding a 31.5% uncertainty. For organic soils, in this case drained peat soils, the uncertainty of the new method is estimated to be 76.0%, which is much lower than the UC of the old method. The uncertainty assessment method for the new method for drained forest peatland soils is given in Alm. et al. 2023.

6.4.3.3 Combined uncertainty for carbon stock changes in Forest Land Remaining Forest Land

The uncertainty estimates reported for tree biomass change and for soil carbon change are combined in Table 6.4-8.

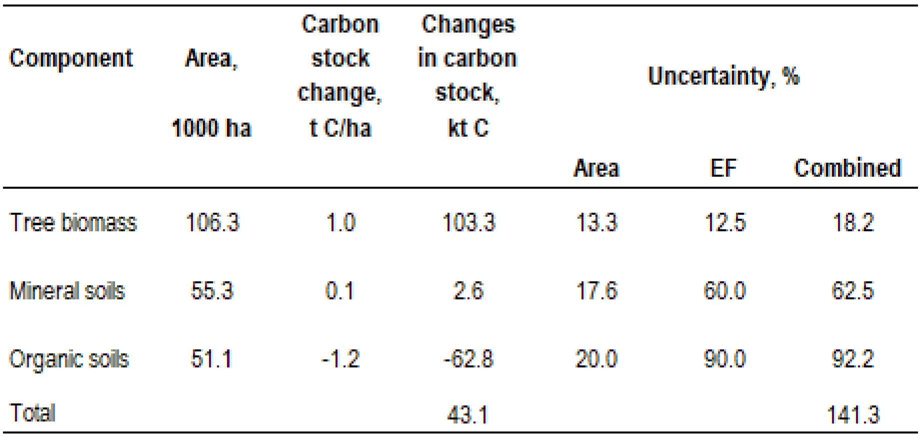
Table 6.4-8 Uncertainties, twice the relative standard errors, for carbon stock changes in Forest Land Remaining Forest Land in 2022 (2006 IPCC Guidelines, Vol. 1, Ch. 3, Eq. 3.2)

Component	Change, Mt C	Uncertainty, %
Tree biomass	3.3	16.3
Mineral soils	1.3	31.5
Organic soils	-2.7	76.0
Total	1.9	83.9

6.4.3.4 Uncertainty of carbon stock changes in Land Converted to Forest Land

The propagation of uncertainty for 2022 carbon stock changes on lands converted to forest land is reported in Table 6.4-9. The uncertainty due to sampling in the area estimates was estimated by the standard NFI methods. Assessments of uncertainty in the carbon stock change (gains and losses) in living tree biomass was estimated by the standard NFI methods. The assessment of uncertainty in the soil carbon stock changes are reported as an expert judgement based on the known uncertainty in the area converted to forest land and uncertainties of the carbon stock changes for soils on forest land remaining forest land.

Table 6.4-9 Uncertainties, twice the relative standard errors, for carbon stock changes in land converted to forest land in 2022



Component	Area, 1000 ha	Carbon stock change, t C/ha	Changes in carbon stock, kt C	Uncertainty, %		
				Area	EF	Combined
Tree biomass	106.3	1.0	103.3	13.3	12.5	18.2
Mineral soils	55.3	0.1	2.6	17.6	60.0	62.5
Organic soils	51.1	-1.2	-62.8	20.0	90.0	92.2
Total			43.1			141.3

6.4.3.5 Time series' consistency

The main data source for land area estimation and for carbon stocks and carbon stock changes in forest land is NFI. The assessment methods, definitions and classification of variables have mainly remained unchanged from 1990 onwards, which ensures consistent activity data and tree biomass data. Until the NFI12, the method to estimate tree stem volume increment was based on increment core samples collected on the temporary plots. Then the method was changed to be based on trees measured on permanent plots. The NFI12 was the turning point, at which the increment was possible to estimate employing both methods. NFI reported 2 million cubic meters lower increment calculated from permanent plots than from temporary plot data (Korhonen et al. 2021). Volume increment is possible to estimate from the NFI13 data only using the data from permanent plots. Thus, a consistency problem was obvious, which led to a need to develop a method for the GHG inventory. The issue was resolved by a correction factor calculated by region, soil type and tree species from the biomass growths estimated with two different methods. The correction factor was applied to timeseries from 1990 to 2013 in Southern Finland and to 2012/ 2013 in Northern Finland. This method was used first time in the GHG inventory in the 2023 submission.

6.4.4 Category-specific QA/QC and verification

The quality objectives and the QA/QC and verification plan for the Finnish greenhouse gas inventory at the national inventory level are presented in Section 1.5. The QC procedures are performed according to the QA/QC plan in order to attain these quality objectives. A bilateral quality meeting or a quality desk review is held annually between the inventory unit and the sectoral expert. In the 2023 quality meeting, the short-term and long-term development plans and QC procedures were discussed.

An AFOLU steering group supervises the reporting of emissions and removals for the LULUCF sector. The members, working at Luke, have a broad expertise in using the measurements and methodology to estimate carbon stock changes and greenhouse gases. All changes in methods, activity data and emissions or other

factors and parameters are discussed and approved by the steering group before they are introduced to the advisory board (see Section 1.2.1). The steering group meets two to four times per year.

The area of forest land presented in Table 6.2-2 are at the same level as areas calculated by the NFI (national classification) in Table 1_App_6a. Comparison between the IPCC land-use categories and national land classification are explained in Table 6.2-1. Areas of land-use categories against the areas presented in the previous submission are given in Table 6.2-4. The classification and areas of all IPCC land-use categories were compared to that of Corine Land Cover 2012 in a separate project (Haakana et al. 2015). The comparison showed a close consistency for forest land and wetlands, whereas the other categories differed more because Corine refers to land cover and the IPCC categories to land use. Especially grassland and settlement areas with tree cover were largely classified as forest land in Corine.

NFI data are employed for area and biomass estimation and to compute biomass conversion and expansion factors, which ensure the fit between different estimates. The data have gone through the NFI's quality checks and control according to the QA/QC procedures developed for the Finnish NFI. The methods applied in the GHG inventory are based on the NFI's methods, which have been published in reviewed scientific articles and books (Tomppo et al. 2011, Korhonen et al. 2013). The biomass models have also been published in scientific articles (Repola 2008, Repola 2009).

The quality assurance system of the NFI data collection is described in the publication by Tomppo et al. (2011). NFI also has its internal quality handbook, where each part of the NFI data collection and data processing are described, as well as responsibilities; instructions for field work, data handling, correctness of data, training of field workers, measurement of increment cores in laboratory, estimation of results, etc.

The increment of the growing stock was first calculated for the national forest land and compared to estimates presented by the NFI to ensure that all trees and sample plots are included in the biomass estimation. The total volume and increment of growing stock were computed separately for the categories Forest land remaining Forest land and lands converted to Forest land and then aggregated to confirm that the total was the same as in the NFI results. After that, the biomass stocks and biomass growth of living trees were computed and the time series constructed.

The soil carbon model Yasso07 has been tested against empirical data by Rantakari et al. (2012), Ortiz et al. (2013) and Heikkinen et al. (2014). Rantakari et al. (2012) and Ortiz et al. (2013) compared the Yasso07 modelling results with national inventory data. Study by Ortiz et al. (2013) was conducted in Sweden, which is similar to Finnish conditions with respect of climate and forest management. Both studies showed that Yasso07 predicts the soil carbon stocks and changes with reasonable accuracy at national level. In the study by Heikkinen et al. (2014) Yasso07 model was tested against measured soil carbon stocks obtained from long term land use change experiment. In that study Yasso07 slightly underestimated the soil carbon accumulation after cropland conversion to grassland, but there was high variation also in measured soil carbon stocks.

Luke's statistical service, as one of the Finland's statistics authorities, complies and publishes statistics on roundwood removals and drain of the growing stock. A description of the statistics is given on Luke's website including the content of the statistics and data collection and sources (https://www.luke.fi/en/statistics). The statistical service is responsible for the QA/QC of the statistics. Statistics on the drain of growing stock were compared with the drain estimated from NFI permanent sample plots. The average annual drain between NFI10 (measured 2004–2008) and NFI11 (2009–2013) was 69.5 mill. m^3. The statistical average annual drain in 2009–2013 was 69.54 mill. m^3. For the years 2009–2014, the NFI-based drain is 1% higher than the statistical drain. The result indicates that the statistics are a reliable data source for the GHG inventory use.

Comparison of stock-change and gain-loss methods for estimating net change in tree biomass

A comparison of stock-change and gain-loss methods for estimating net change in tree biomass was carried out in 2018. The stock-change method was applied to the permanent NFI sample plot data to estimate an average annual biomass change of living trees on forest land. The result was compared to the annual biomass changes, which were computed by applying the gain-loss method and both the permanent and temporary NFI sample plot data. The biomass stocks were estimated from the NFI10 and NFI11 data.

First, the volume and biomass of individual sample trees and the volume of all measured trees were estimated. The biomass was expanded to all measured trees with the biomass: volume ratios of sample trees, and then to the sampling regions by multiplying with the area of forest land (see Appendix_6a). The computations were carried out by sampling regions excluding the northernmost region of Lapland. The sampling design is quite different in northernmost Lapland compared to the other regions, and the sample plot representatives were not recalculated in this exercise due to the additional effort required.

The change in biomass is the difference between the stocks of two NFIs. Since the interval of measurements is not always exactly five years, the mid-years of NFI10 and NF11 measurements of permanent sample plots were computed by sampling regions to get the right number of years (see Table 6.4-10). The calculation gave an average annual biomass change for each region. The years 2007 to 2011 were common for all sampling regions, and thus used for the comparison.

The stock-change method gave an average net annual carbon stock change in living tree biomass of 9.16 Mt C yr^{-1}. As reported in the NIR of 2019, the gain-loss method produced net carbon stock changes in living tree biomass of 9.67, 10.22, 14.45, 10.20 and 10.00 Mt C yr^{-1} for 2007, 2008, 2009, 2010 and 2011 respectively. The averages were 10.91 Mt C yr^{-1} and -40.01 as Mt of CO$_2$ yr^{-1}. One reason for the lower sink estimate when using the stock-change method is the exclusion of the northernmost sampling region from the calculation. It was judged to increase the sink by -0.2 Mt C yr^{-1} based on the change in the growing stock volume. The second reason is that harvest removals were exceptionally low in 2009 which resulted in a high net sink. The stock-change method is not able to capture this kind of inter-annual variation as the annual harvest volume is not currently built into the interpolation to produce variation. The third reason behind the difference in net biomass change is the difference in the data employed; permanent plots were used for the stock-change method whereas both permanent and temporary plots were used for the gain-loss method.

The result can be compared with the uncertainty reported for the net biomass change. The uncertainty assessed from NFI11 data (change in living biomass) and the drain statistics is 22.48% (see Section 6.4.3.1) which means a confidence interval from 8.6 to 27.7. In this regard, the estimate based on permanent sample plots is within the given uncertainty limits. As a result, the gain-loss method based on the use of NFI data as applied in the GHG inventory gives reliable estimates for annual tree biomass change considering the uncertainty.

Table 6.4-10 Comparison of the results based on the stock-change method and the gain-loss method according to the 2019 submission.

Sampling region	**Mid-year**		**Biomass stock**		**Average annual change**			
	NFI10	NFI11	NFI10	NFI11	Stock-change method		GHGI's gain-loss method	
			Mt C	Mt C	Mt C yr^{-1}	Mt CO$_2$ yr^{-1}	Mt C yr^{-1}	Mt CO$_2$ yr^{-1}
Åland	2007	2013	3.93	3.97	0.01	-0.03		
Southernmost Finland	2006	2011	264.01	271.09	1.42	-5.20		
Central Finland	2006	2011	248.52	267.93	3.88	-14.23		
Southern North Finland	2007	2011	125.91	133.94	2.01	-7.36		
Southern Lapland and Kuusamo	2007	2011	129.00	136.38	1.84	-6.76		
Total					**9.16**	**-33.58**	**10.91**	**-40.01**

6.4.5 Category-specific recalculations, including changes made in response to the review process

Activity data

The activity data of forest land remaining forest land and lands converted to forest land were recalculated due to new NFI13 data and updated land-use data and error corrections.

Tree biomass

Recalculations on tree biomass including gains, losses and stocks:

- For the 2023 submission, the estimation method for the gains in living tree biomass was modified to conform to the methodology the Finnish NFI applies to volume increment estimation. During the 12th and 13th inventory rounds NFI moved from the increment-core based method (samples collected on temporary plots) to a method based on the remeasured trees on permanent sample plots (Korhonen et al. 2021). The aim was to estimate the tree biomass growth using the remeasured trees and give up applying BECFs to convert tree stem growth to biomass growth. Thereafter the development work continued, and it was discovered that the new method was problematical for biomass estimation. For the 2024 submission, it was decided to revert to use the BECFs to convert volume increment to biomass increment. Also, the correction factors were recalculated from the NFI12. From 1990 to 2013 the biomass growth is 6 to 10 kt CO_2 and thereafter 30 to 56 kt CO_2 smaller than in the 2023 submission. (Figure 6.4-3)
- The NFI13 tree data measured in 2022 was adopted. The new data set is used for biomass gains and stocks.
- Corrected NFI13 sample tree data for the years 2020 and 2021 (remodelled upper diameter of some sample trees and regions). The effects of this recalculation to the biomass gains are presented in Figure 6.4-2). This correction has effects also on biomass stocks, which are used to calculated litter input to soil. https://www.luke.fi/en/statistics/about-statistics/luke-as-a-statistics-compiler/corrections-to-statistical-releases#forest-resources
- Recalculated activity data: area of forest land,
- forest land remaining forest land and lands converted to forest land.
- The main data source for biomass losses is statistics on cutting removals and total drain. There have been changes in the statistics (source Official statistics on roundwood removals and drain/Natural Resources Institute Finland, Luke 2023b):

  > *“New calculation principles for natural drain and waste wood based on the data of the 12th National Forest Inventory measured in 2014–2018 were adopted in the calculation of total drain in 2022. At the same time, data for 2017–2021 were revised, as the new calculation principles apply to these years better than the previous ones. The change reduced total drain by an average of 0.4% during the period.”*

- Lands converted to forest land: Biomass gains and losses were recalculated for the whole time series (Figure 6.4-4). In the 2023 submission, the incorrect area data were used to calculated biomass gains. The cutting removals from afforested lands were recalculated using the more recent NFI data. In 1990, 2 kt CO_2 emission turn to 62 kt CO_2 removal, whereas in 2021 the new removal estimate is 8 kt CO_2 smaller than the previous estimate.
- Because the statistics on drain had changes, and the biomass losses from afforested and deforested lands were recalculated, also biomass losses from Forest land remaining Forest land was recalculated.

Figure 6.4-2 Tree biomass growth (kt C) with uncorrected NFI13 data (black dotted line) and with corrected data (red line). SF=Southern Finland, NF=Northern Finland, min=mineral soils, org=organic soils. The correction decreased growth in mineral soils in Northern Finland and slightly increased in organic soils in Northern Finland

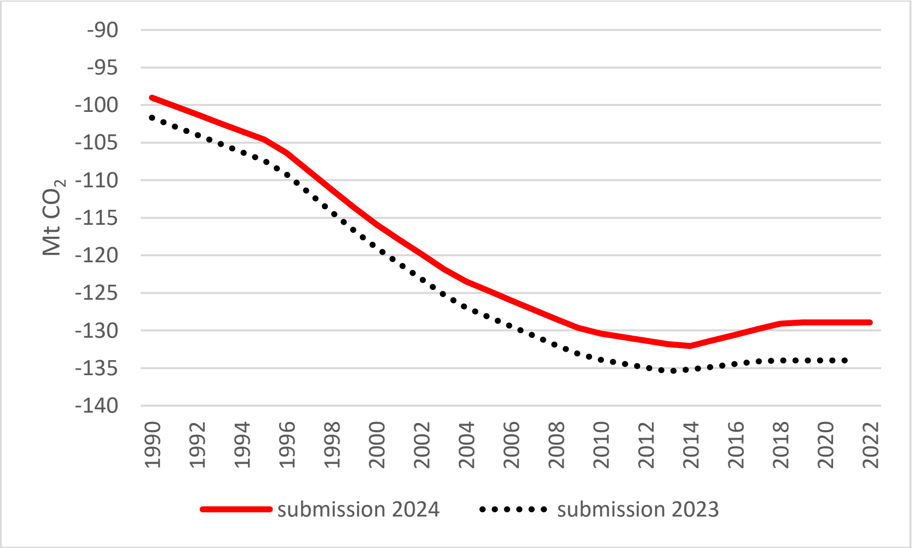


Figure 6.4-3 Recalculated tree biomass growth on Forest Land compared to biomass growth in the 2023 submission

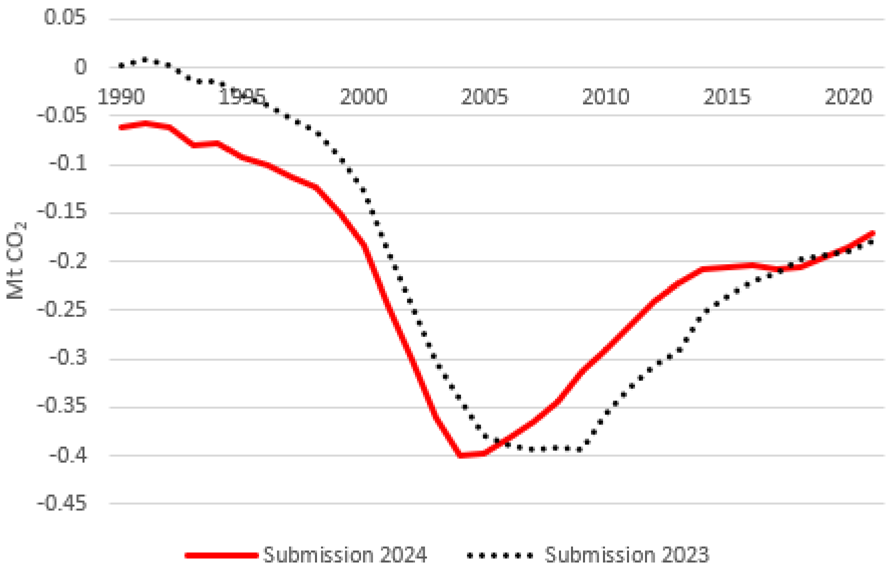


Figure 6.4-4 Net emissions and removals (Mt CO_2) in the category Lands converted to Forest Land in the 2023 submission and after recalculations in the 2024 submission

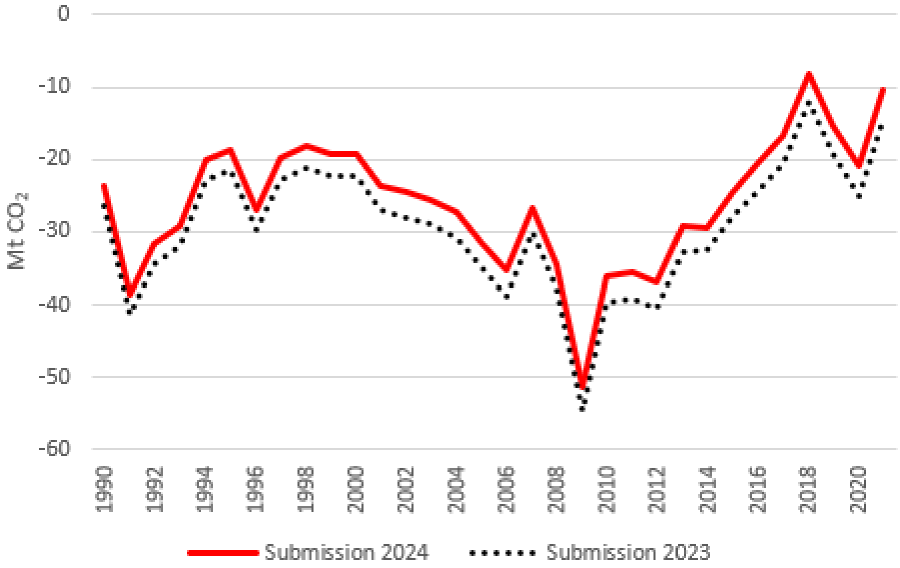


Figure 6.4-5 Change in carbon stock of living biomass on Forest Land remaining Forest Land in submission 2024 and submission 2023

Carbon stock changes in soils

Carbon stock changes on mineral (combined pool of DOM and SOM) and organic soils were recalculated. Recalculated tree biomass stocks and drain affect the litter input to the soil and thus carbon stock changes in soils were also recalculated for Forest Land remaining Forest Land (Figure 6.4-6) and Land converted to Forest Land.

In organic soils, the emissions in 2021 increased by 4% or 0.4 Mt CO_2 and the emissions in 1990 increased by 0.2% or 0.01 Mt CO_2 in 1990 compared to the previous submission due to decrease in litter input. In mineral soils, the removals increased by 1 Mt CO_2 (24%) in 2021 and 0.01 Mt CO_2 (0.2%) in 1990 compared to the 2023 submission.

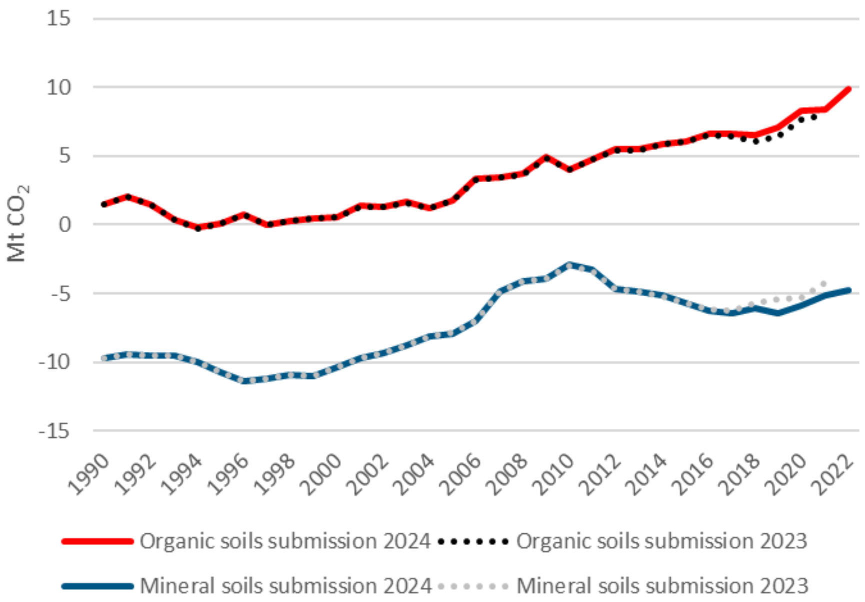


Figure 6.4-6 Carbon stock changes in mineral and organic soils on Forest land remaining Forest land in submission 2024 and submission 2023

The implications of the above-mentioned recalculations are presented in Table 6.4-11.

Table 6.4-11 Implications of recalculations made in the Forest Land category to the emission level in 1990 and 2021 (kt CO_2)

	Submission 2023	Submission 2024	Difference	Submission 2023	Submission 2024	Difference
	1990			2021		
FL remaining FL						
Biomass, gains	-100 719	-98 057	**2 662**	-133 512	-128 432	**5 081**
Biomass, losses	74 315	74 386	**70**	119 099	117 972	**-1 126**
Biomass, total	-26 404	-23 671	**2 733**	-14 414	-10 459	**3 954**
Mineral soil	-9 733	-9 747	**-15**	-4 165	-5 148	**-983**
Organic soil	1 468	1 473	**5**	7 984	8 344	**360**
Total	*-34 669*	*-31 945*	***2 724***	*-10 595*	*-7 263*	***3 331***
Lands converted to FL						
Biomass, gains	-957	-955	**2**	-472	-496	**-24**
Biomass, losses	227	161	**-66**	84	97	**13**
Biomass, total	-730	-794	**-64**	-389	-399	**-11**
Mineral soil	85	84	**0**	-7	-6	**1**
Organic soil	647	647	**0**	216	234	**18**
Total	*1.9*	*-62*	***-64***	*-180*	*-171*	***9***

6.4.6 Category-specific planned improvements

The required actions and measures needed to implement the newer version of Yasso soil model will be examined. Improvement to estimate more accurate carbon stock changes on afforested lands is planned too.

6.5 Cropland (CRF 4.B)

6.5.1 Category description

The net emissions from carbon stock changes in croplands were 8.8 Mt CO_2 in 2022. The CO_2 emissions from cultivated organic soils were 6.8 Mt CO_2 and from mineral soils 1.5 Mt CO_2. The carbon stock change in living biomass was 0.5 Mt CO_2 in 2022. The net emissions from carbon stock changes were 5.4 Mt CO_2 in 1990 and 8.3 Mt CO_2 in 2021. The emissions have increased by 64% since 1990 and increased by 7% since 2021.

The cropland category includes carbon stock changes in soils and living biomass reported as CO_2 emissions.

The area of cropland comprises the area used for arable crops, grass (rotational), permanent horticultural crops, greenhouses, kitchen gardens and set-aside. The area of cropland is divided into land remaining cropland and areas converted to cropland.

Croplands have been a net source of CO_2 since 1990. The mineral soils have been a net source of CO_2 for most of the years, except for 1991 to 1992, and the magnitude of the sink or source has varied mainly as a results of the changes in C input to the soils and climate. Organic soils have been an increasing source of CO_2 due to their increased area. The changes in living biomass vary according to the activities in clearance of forest to new fields (Figure 6.5-1).

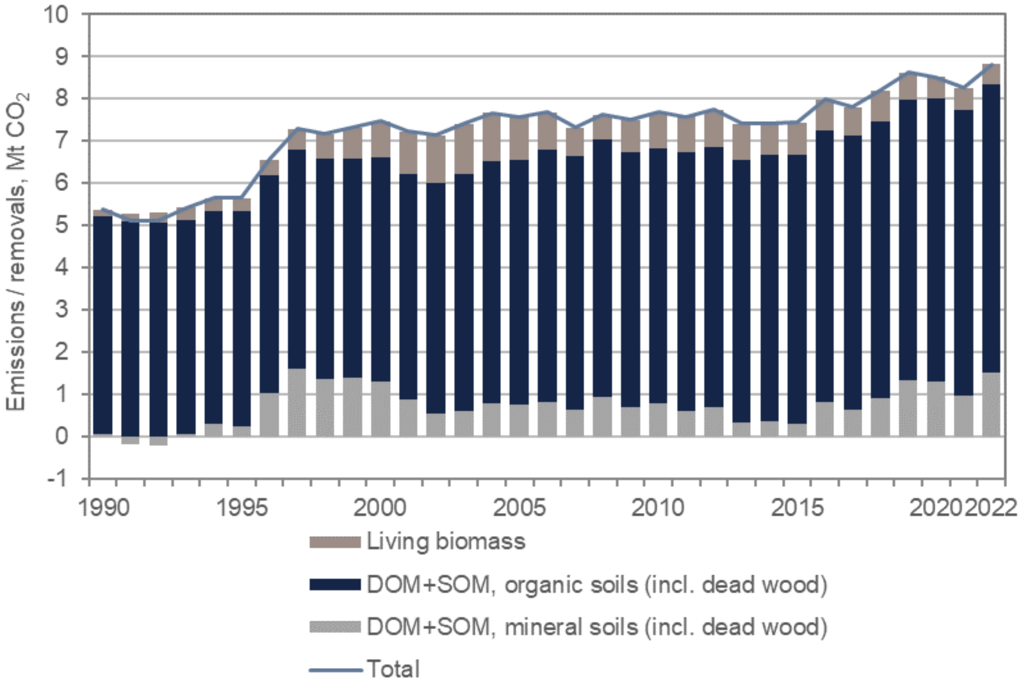


Figure 6.5-1 Emissions and removals in cropland, Mt CO_2

6.5.2 Methodological issues

6.5.2.1 Cropland remaining cropland

Activity data

The area estimates for cropland remaining as cropland were obtained from the NFI data (Table 6.5-1). The distribution of the whole area to mineral and organic soils is based on the NFI and soil database (Lilja et al. 2006, 2009). The proportions of cultivated crop plants grown on mineral and organic soils were obtained from the Land Parcel Identification System of the EU. The area estimate for cultivated organic soils was derived in the manner described in Section 6.3. Organic soils are determined to be soils containing more than 20% organic carbon in the top 20 cm layer of the soil (i.e., about 35% organic matter) and thus the definition corresponds to the 2006 IPCC guidelines.

Table 6.5-1 Area of cropland remaining cropland (kha)

	1990	1995	2000	2005	2010	2015	2020	2021	2022
Mineral soils									
South	1 947	1 939	1 927	1 922	1 916	1 908	1 907	1 909	1 910
North	255	253	249	249	247	248	249	249	250
Organic soils									
South annual crops	57	57	66	66	61	62	61	61	63
South perennial crops	82	82	70	71	78	76	82	83	83
North annual crops	11	12	16	17	17	18	17	18	19
North perennial crops	42	42	39	38	40	39	43	44	45

Carbon stock changes in biomass

The biomass of apple trees and currants is taken into account when calculating the carbon stock change in living biomass. A gain-loss method (2006 IPCC Guidelines, Equation 2.7) corresponding to Tier 2 methodology of the IPCC is used for the calculation. See Appendix_6c.

Carbon stock changes in soil and dead organic matter

Mineral soils

The changes in mineral soil carbon stock were estimated using a model-based Tier 3 approach. The method combines the agricultural statistics, biomass functions and the Yasso07 soil carbon model (Palosuo et al. 2015). A model description of Yasso07 is given in Appendix 6e with the exception of the parameterisation of Yasso07 used in cropland was the one reported in Tuomi et al. (2011b).

The soil C input of cropland was estimated at the level of the 16 regional ELY Centres (The Centres for Economic Development, Transport and the Environment)). Crop yield statistics were converted to annual soil C input using harvest index, shoot/root ratio, root turnover rate and dry matter content as described in Appendix 6j. Crop-specific soil carbon inputs were weighted with the cultivated area of each crop taken from the LPIS, Land Parcel Identification System (EU 1992) to obtain the average regional soil carbon input. The cultivated area of cover crops (Table 5_App_6j) was taken from the database of Finnish Food Authority and the soil C input of cover crops was assumed to be constant as described in Appendix 6j. Manure derived carbon was estimated on the basis of the number of livestock and daily manure production consistently with data used in the Agriculture sector. The chemical quality of litter was as in Table 2_App_6j.

Weather data applied in the modelling were monthly 10 km x10 km gridded data from 1960 to 2022 obtained from the Finnish Meteorological Institute. Mean annual temperature, temperature amplitude and precipitation were calculated for Southern and Northern Finland.

The initialisation of the model was done by running the model using the average climate for 1961 to 1990 with the average soil carbon input from 1990 to 1999 for 100 years starting from the soil C stock of forest land. Modelling the annual changes in soil carbon stock between 1990 and 2022 was done by applying the annual soil carbon input and climate data calculated as a 30 years running average. The Yasso07 simulations were made separately for the mineral soils of Southern and Northern Finland (Figure 6.2-1). The soil carbon stock change simulations based on litter and manure input, weather data and the Yasso07 model resulted in emission factors (see Table 3_App_6j), which were multiplied by the cropland area to calculate the soil CO_2 emissions. The emissions were reported as running five-year averages.

Organic soils

Emissions from organic soils are calculated according to the Tier 2 approach using the following equation (2006 IPCC Guidelines):

$$\Delta C_{ccOrganic} = A * EF$$

where $\Delta C_{ccOrganic}$ = Annual CO_2 emissions from cultivated organic soils in cropland/grassland
A = Land area (ha)
EF = Emission factor (t C ha^{-1} a^{-1}).

For calculating CO_2 emissions from cropland remaining as cropland on organic soils, the emission factors are 5.7 t C ha^{-1} for grass and 7.9 t C ha^{-1} for annual crops (IPCC Wetlands Supplement).

Dead organic matter

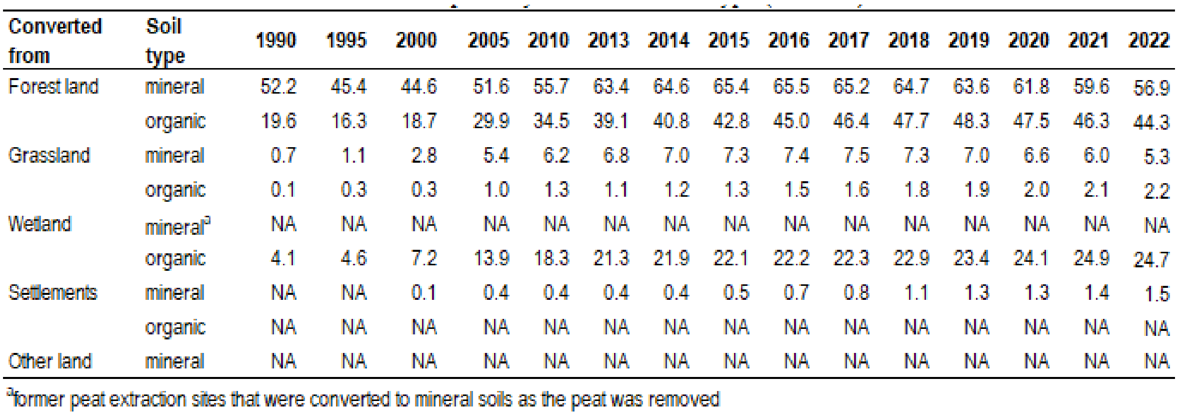
The net carbon stock change in dead organic matter is included in losses in living biomass. The amount of dead branches of currants and apple trees in modern orchards is very low and they are usually chipped and left to decay in the orchards.

6.5.2.2 Land converted to cropland

Activity data

Areas and proportions of mineral and organic soils in the class of land converted to cropland (Table 6.5-2) were estimated using the NFI data together with the soil database as described in Sections 6.2 and 6.3.

Table 6.5-2 Areas of land converted to cropland during the last 20 years by land use and soil type (1,000 ha)



Converted from	Soil type	1990	1995	2000	2005	2010	2013	2014	2015	2016	2017	2018	2019	2020	2021	2022
Forest land	mineral	52.2	45.4	44.6	51.6	55.7	63.4	64.6	65.4	65.5	65.2	64.7	63.6	61.8	59.6	56.9
	organic	19.6	16.3	18.7	29.9	34.5	39.1	40.8	42.8	45.0	46.4	47.7	48.3	47.5	46.3	44.3
Grassland	mineral	0.7	1.1	2.8	5.4	6.2	6.8	7.0	7.3	7.4	7.5	7.3	7.0	6.6	6.0	5.3
	organic	0.1	0.3	0.3	1.0	1.3	1.1	1.2	1.3	1.5	1.6	1.8	1.9	2.0	2.1	2.2
Wetland	mineral[a]	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
	organic	4.1	4.6	7.2	13.9	18.3	21.3	21.9	22.1	22.2	22.3	22.9	23.4	24.1	24.9	24.7
Settlements	mineral	NA	NA	0.1	0.4	0.4	0.4	0.4	0.5	0.7	0.8	1.1	1.3	1.3	1.4	1.5
	organic	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
Other land	mineral	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA

[a] former peat extraction sites that were converted to mineral soils as the peat was removed

Changes in biomass and dead organic matter

The removal of biomass from forest land converted to cropland was estimated using the products of the annual converted areas and mean biomasses by region and soil type removed during conversion (Appendix_6c). The removal of biomass after the conversion of grassland to cropland was 4.1 t C/ha and the increase in the carbon stock during the first year after the conversion from forest land or grassland to cropland was 4 t C/ha, which are national values of mean crop biomasses based on yields. The method corresponds to the Tier 3 method of the IPCC (2006 IPCC Guidelines).

The removal of deadwood from forest land converted to cropland was estimated according to Tier 2 methodology (2006 IPCC Guidelines) using the products of the annual converted areas and the mean deadwood carbon stock (Appendix_6i). The mean deadwood carbon stocks were estimated separately for Southern and Northern Finland but only for organic soils, since they are included in the estimate of soil C in mineral soils (see Appendix_6e). Grassland converted to Cropland consists mostly of abandoned cropland that is taken back to cultivation. The carbon stock change is considered insignificant. Wetlands converted to Cropland are mainly abandoned peat extraction areas where there is no dead organic matter. In the rest of the conversion area the CSC is considered insignificant due to small area. For Settlements converted to Cropland dead organic matter is not included in the soil, however the category is area-wise very small and the CSC is considered insignificant. The likely combined emission level for these insignificant categories is < 0.4 kt CO_2 (See Annex 5).

Carbon stock changes in soil

Mineral soil

Apart from the conversion from settlement to cropland the carbon stock changes in land converted to cropland on mineral soils were estimated using the Yasso07 model (Appendix_6e) and correspond to the Tier 3 method (2006 IPCC Guidelines). The method is the same as for cropland remaining cropland but the initial state of the soil when starting the simulation was as in forest land remaining forest land or grassland remaining grassland. The same annual input data derived from agricultural statistics were used for all classes and the method is described in detail in Appendix 6j. The simulation produces specific emission factors for each year after the conversion. Thus, the land area converted each year since 1970 was multiplied with a specific emission factor depending on the age of the conversion, and the emissions for each inventory year consist of all these conversions.

Emissions due to settlements converted to cropland were estimated using the Tier 1 method (2006 IPCC Guidelines, Section 5.3.3).

Organic soil

The emissions from orgainc soils for conversion from Forest land, Grassland and Wetlands to Cropland were calculated according to Tier 2 methodology using the mean emission factor for the cultivation of grass or other crops on organic soils (6.8 t C ha-1) (IPCC Wetlands Supplement).

6.5.3 Uncertainty assessment and time series’ consistency

Quantitative estimates of uncertainty are provided in Annex 2. The annex also documents assumptions made for the analysis. A description of the uncertainty analysis is included in Section 1.6.

The area estimates in the cropland category are mainly based on the National Forest Inventory. Since the time series were estimated using NFI data, any possible inconsistency due to a different sample design or different classification between inventories was avoided.

The time series are mainly consistent except that the crop yield data are available only from 1995 onwards. Thus, the C input data for modelling the years 1990 to 1994 are based on the average yields from the later years.

6.5.4 Category-specific QA/QC and verification

The quality objectives and the QA/QC and verification plan for the Finnish greenhouse gas inventory at the national inventory level are presented in Section 1.5. The QC procedures are performed according to the QA/QC plan in order to attain these quality objectives. A bilateral quality meeting or a quality desk review is held annually between the inventory unit and the sectoral expert. In the 2023 quality meeting, the short-term and long-term development plans and QC procedures were discussed.

An AFOLU steering group supervises the reporting of emissions and removals for the LULUCF sector. The members, working at Luke, have a broad expertise in using the measurements and methodology to estimate carbon stock changes and greenhouse gases. All changes in methods, activity data and emissions or other factors and parameters are discussed and approved by the steering group before they are introduced to the advisory board (see Section 1.2.1). The steering group meets two to four times per year.

The QA/QC plan includes the QC measures based on the 2006 IPCC Guidelines (Vol 1, Chapter 6, Table 6.1). These measures are implemented every year during the inventory. Potential errors and inconsistencies are documented and corrections are made, if necessary.

The area estimate for cropland in 2016 was compared with the estimate of the area of cultivated land in the field register (LPIS). The area according to the LPIS was found to be 9% smaller than the NFI derived estimate used in the greenhouse gas inventory. The croplands other than in the field register included cultivated lands, less intensive arable lands and edges of cultivated patches. The LPIS is used to register land parcels for the EU subsidy scheme, thus not all fields are covered. The suitability of the Yasso07 model for simulating carbon stock changes in forest land converted to cropland was investigated in a project. The quality assurance and verification results showed that Yasso07 could be used to simulate C stock changes in forest land converted to cropland. The results were published as a peer-reviewed article (Karhu et al. 2011). Other studies confirmed that Yasso07 is also suitable for simulating C stock changes in cropland remaining cropland (Akujärvi et al. 2014, Karhu et al. 2012, Palosuo et al. 2015).

The following programme tool has been implemented to support GHG inventory reporting: the CRFTool programme that automates and provides an error free transfer of inventory results to the CRF Reporter.

6.5.5 Category-specific recalculations including changes made in response to the review process

New area estimates were calculated due to the update of the NFI data and classification error corrections (see Section 6.2). This resulted in a recalculation of the cropland areas since 2009 and all carbon stock changes were recalculated accordingly.

Manure production of livestock was updated to be consistent with the Agriculture sector for the whole time series resulting in the need for recalculation of emissions from cropland soils for the whole time series. An error was found in the calculation of SOC stock change from settlements to cropland. The calculation did not take into account the emissions of the whole 20-year conversion period. The error is now corrected in this submission. The areas of conversion from settlements to cropland are small, and thus the correction had minor effects on the emissions (increased emissions ranging from 0.1 kt CO_2 in 2001 to 2.1 kt CO_2 in 2021). This recalculation was not applicable for 1990 to 2000. The total emissions from cropland soils decreased by 27 kt CO_2 (1%) in 1990 and 194 kt CO_2 (2%) in 2021 due to the recalculations.

In the 2023 submission, incorrect area data were used to calculate carbon losses in living tree biomass to conversion from forest land to cropland. Thus, the losses in living biomass were recalculated for the whole time series. The effects of recalculations on the emissions from living biomass on land converted to croplands were minor for 1990 (reduction of <0.01 kt CO_2) and a reduction of 53 kt CO_2 (9%) for 2021.

The total effects of the recalculations of CSC in the Cropland category are presented in (Table 6.5-3).

Table 6.5-3 Recalculations made in the Cropland category and their implications to the emission level in 1990 and 2021 (kt CO_2.)

Year	2023 submission	2024 submission	difference
1990	5 408	5 381	-27
2021	8 511	8 264	-247

6.5.6 Category-specific planned improvements

To follow the ERT’s recommendation to improve the method for estimating carbon stock changes in living biomass for Cropland converted to other land use or Land converted to Cropland it is planned to develop a method that takes into account the annual carbon stock change in living biomass of apple trees and currants, if it is found that apple trees or currants exist on conversion areas. Estimation of carbon stock changes will be developed for lands converted to Cropland.

The required actions and needed measures to implement the newer version of Yasso soil model will be examined.

6.6 Grassland (CRF 4.C)

6.6.1 Category description

The net emissions from carbon stock changes in grasslands were 0.8 Mt CO_2 in 2022. The emissions from grasslands on organic soils were 0.8 Mt CO_2 in 2022 and the sink for mineral soils was 0.03 Mt CO_2. The sink of living biomass was 0.04 Mt CO_2. In 2021, the net emissions from carbon stock changes in grasslands were also at the level of 0.8 Mt CO_2, whereas they were 1.0 Mt CO_2 in 1990. The emissions in 2022 increased by less than one percent compared to the previous year and deceased by 25% compared to 1990.

In Finland, there are no large grazing land areas or permanent grasslands. The area of grassland consists mostly of abandoned fields that are slowly gaining tree biomass and turning into forest land. The grassland category comprises of long-term grasslands and meadows together with abandoned agricultural areas that have not turned into forest land yet. The area is divided between grasslands remaining as grasslands and land converted to grasslands.

The emissions from grasslands on organic soils have decreased since 1990 (Figure 6.6-1). The main reason for the decrease is the conversion of grassland to cropland. The trend in biomass varies depending on the clearance of new grassland from forest.

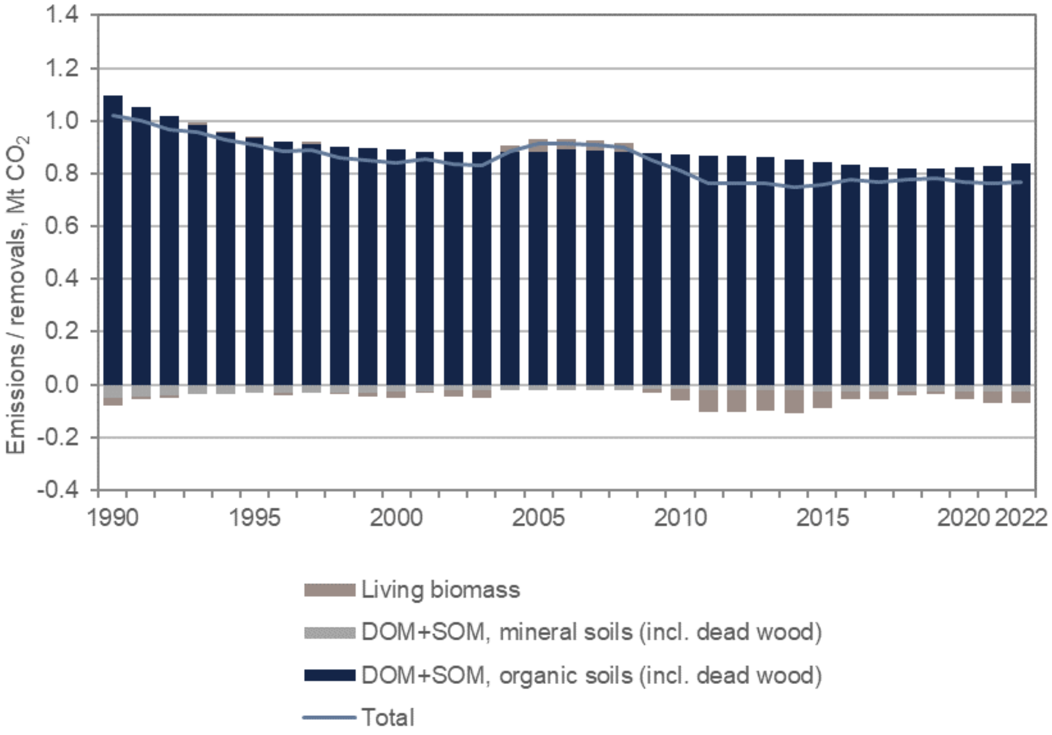


Figure 6.6-1 Emissions and removals in grassland, Mt CO_2

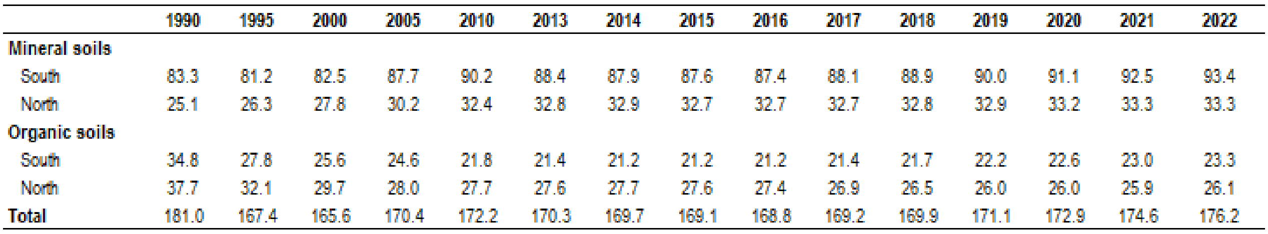
6.6.2 Methodological issues

6.6.2.1 Grassland remaining grassland

Activity data

The area estimate for grasslands (Table 6.6-1) was derived from the NFI data in the manner described in Section 6.3.

Table 6.6-1 Distribution of areas of soil types and management on grassland remaining as grassland (1,000 ha)



	1990	1995	2000	2005	2010	2013	2014	2015	2016	2017	2018	2019	2020	2021	2022
Mineral soils															
South	83.3	81.2	82.5	87.7	90.2	88.4	87.9	87.6	87.4	88.1	88.9	90.0	91.1	92.5	93.4
North	25.1	26.3	27.8	30.2	32.4	32.8	32.9	32.7	32.7	32.7	32.8	32.9	33.2	33.3	33.3
Organic soils															
South	34.8	27.8	25.6	24.6	21.8	21.4	21.2	21.2	21.2	21.4	21.7	22.2	22.6	23.0	23.3
North	37.7	32.1	29.7	28.0	27.7	27.6	27.7	27.6	27.4	26.9	26.5	26.0	26.0	25.9	26.1
Total	181.0	167.4	165.6	170.4	172.2	170.3	169.7	169.1	168.8	169.2	169.9	171.1	172.9	174.6	176.2

Carbon stock changes in biomass

Carbon stock changes in living biomass is estimated for woody biomass using the Tier 2 method, whereas above-and belowground herbaceous biomasses are assumed to be constant as described in Palosuo et al. (2015). A gain–loss method is employed for grasslands with tree cover. Tree cover on these sites is sparse due to the growing circumstances (strong grass growth, wet soil), and do not fill the definition of forest land. These areas are mainly abandoned fields, but occasional removal of trees is possible. The gain in tree biomass is estimated according to a Tier 3 approach and the losses corresponds to a Tier 2 method as described in Appendix_6c. Tree data measures on lands outside forest in the NFI11 and other NFI data are used to estimate the amount of tree biomass and biomass growth on grasslands remaining grassland, and to derive the losses.

Carbon stock changes in soils and dead organic matter

Mineral soils

The area of grassland consists mostly of abandoned fields. Therefore it was assumed that no changes in C stocks occur in this category since no changes were anticipated in the carbon input or quality during the inventory period.

Organic soils

Organic soils are determined to be soils containing more than 20% organic carbon in the top 20 cm layer of the soils and thus defined according to the IPCC methodology.

Emissions from organic soils are calculated using the following equation and corresponds to a Tier 2 method (2006 IPCC Guidelines):

$$\Delta C_{ccOrganic} = A * EF$$

where $\Delta C_{ccOrganic}$ = Annual CO_2 emissions from cultivated organic soils
A = Land area (ha)
EF = Emission factor (3.5 t C ha^{-1} a^{-1}) (Maljanen et al. 2010).

The amount of carbon released is converted to CO_2 by multiplying it by 44/12.

Dead organic matter

The net carbon stock change in dead organic matter was considered insignificant and reported as ‘NE’.

6.6.2.2 Land converted to grassland

Activity data

The area estimate for grasslands was derived from the NFI data in the manner described in Sections 6.2 and 6.3. The area estimates for land converted to grassland divided by soil type are presented in Table 6.6-2.

Table 6.6-2 Areas of land converted to grassland during the last 20 years by soil type (1,000 ha)

Converted from	Soil type	1990	1995	2000	2005	2010	2013	2014	2015	2016	2017	2018	2019	2020	2021	2022
Forest land	mineral	7.7	8.2	8.1	9.6	12.1	11.3	11.1	11.0	11.2	11.2	11.5	11.7	11.8	11.8	11.8
	organic	NA	0.2	1.0	2.3	3.3	3.3	3.4	3.4	3.4	3.4	3.4	3.4	3.3	3.2	3.0
Cropland	mineral	64.6	53.7	45.8	36.5	33.6	36.8	37.8	38.7	39.1	39.1	39.2	39.3	39.9	40.6	42.1
	organic	13.0	12.9	13.2	12.4	12.4	11.9	11.2	10.4	9.4	8.9	8.5	8.3	8.3	8.6	8.7
Wetland	mineral	NA	NA	0.4	1.1	1.2	1.4	1.4	1.4	1.4	1.4	1.4	1.2	1.0	0.8	0.6
	organic	NA	NA	NA	1.7	2.8	3.0	3.1	3.3	3.5	3.7	3.8	3.8	3.9	4.0	4.2
Settlements	mineral	NA	NA	0.4	0.8	0.8	0.9	0.9	1.0	1.0	1.0	0.9	0.9	0.8	0.7	0.6
	organic	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
Other land	mineral	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA

Carbon stock changes in biomass and dead organic matter

The removal of biomass from forest land converted to grassland was estimated using the products of the annual converted areas and mean biomasses by region and soil type removed during conversion (Appendix_6c). The removal of cropland biomass when converted to grassland was 4 t C/ha. An increase in the carbon stock for the first year after the conversion was estimated using the Tier 2 methodology. The amount of carbon added as grass biomass was 4.1 t C/ha (national data). It is assumed that after the conversion areas converted to grassland are treeless or that trees are not removed during conversion to grassland, so no carbon stock change in trees is estimated.

The removal of deadwood in forest land converted to grassland was estimated according to Tier 1 methodology (2006 IPCC Guidelines) using the products of the annual converted areas and the mean deadwood carbon stock removed in the conversion year. The mean deadwood carbon stocks were estimated separately for Southern and Northern Finland for organic soils (see Appendix_6i). In mineral soils, DOM is included in the estimate of soil carbon. Dead organic matter on mineral soils is included in carbon stock changes in soil due to the fact that the Yasso07 soil carbon model estimates carbon stock change for the total of DOM and SOM. For organic soils the dead organic matter in Cropland converted to Grassland is considered to be a small sink due to the stopping of tilling and increasing mean biomass, but the sink is considered insignificant and is thus not reported. Wetlands converted to Grassland are mainly abandoned peat extraction areas where there is no dead organic matter. In the rest of the conversion area the CSC is considered insignificant due to small area. For Settlements converted to Grasslands DOM is not included in soil. This category consists mostly of pulled down barns or other outbuildings. The area is very small and it is considered that no change in the surroundings occurs so this CSC is also considered insignificant. The likely combined emission level for these insignificant categories is < 0.07 kt CO_2 (See Annex 5 and Section 1.7).

Carbon stock changes in soil

Mineral soils

For settlements converted to grassland it is assumed that there are no carbon stock changes in mineral soils, whereas other land-use categories converted to grassland on mineral soils were estimated using the Yasso07 model (Appendix_6e), which corresponds to the Tier 3 method (2006 IPCC Guidelines). The initial state values for the simulation were as in forest land remaining forest land or cropland remaining cropland. The carbon input values were as described in Appendix 6j. The simulation produces land use-specific emission factors for each year after the conversion. Thus, the land area converted each year since 1970 was multiplied with a specific emission factor depending on the age of the conversion, and the emissions for each inventory year consist of all these conversions.

Organic soils

Emissions from organic soils are estimated accordingly to the Tier 2 approach (2006 IPCC Guidelines) with the same method and emission factor that is used for organic soils on Grassland remaining grassland, (3.5 t C ha^{-1} a^{-1}) (Maljanen et al. 2010) (Section 6.6.2.1).

6.6.3 Uncertainty assessment and time series' consistency

Quantitative estimates of uncertainty are provided in Annex 2. The annex also documents assumptions made for the analysis. A description of the uncertainty analysis is included in Section 1.6.

The time series for the carbon stock changes from grasslands is consistent.

6.6.4 Category-specific QA/QC and verification

The quality objectives and the QA/QC and verification plan for the Finnish greenhouse gas inventory at the national inventory level are presented in Section 1.5. The QC procedures are performed according to the QA/QC plan in order to attain these quality objectives. A bilateral quality meeting or a quality desk review is held annually between the inventory unit and the sectoral expert. In the 2023 quality meeting, the short-term and long-term development plans and QC procedures were discussed.

An AFOLU steering group supervises the reporting of emissions and removals for the LULUCF sector. The members, working at Luke, have a broad expertise in using the measurements and methodology to estimate carbon stock changes and greenhouse gases. All changes in methods, activity data and emissions or other factors and parameters are discussed and approved by the steering group before they are introduced to the advisory board (see Section 1.2.1). The steering group meets two to four times per year.

The QA/QC plan includes the QC measures based on the 2006 IPCC Guidelines (Vol 1, Chapter 6, Table 6.1). These measures are implemented every year during the inventory. Potential errors and inconsistencies are documented and corrections are made, if necessary.

The results of a research project showed that Yasso07 can be used for simulating C stock changes in land converted to grasslands (Heikkinen et al. 2014).

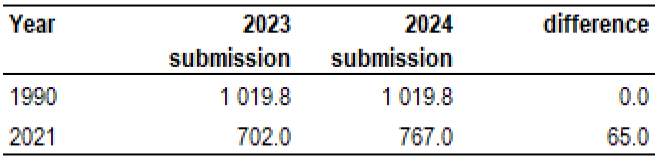
The area estimate for grassland was compared with the previous submission and other data (see Section 6.4.4).

The following programme tool has been implemented to support GHG inventory reporting: the CRFTool programme that automates and provides an error free transfer of inventory results to the CRF Reporter.

6.6.5 Category-specific recalculations, including changes made in response to the review process

New area estimates were calculated due to the updating of NFI data and corrections (see Section 6.2). This resulted in a minor recalculation of the grassland time series since 2008 and all carbon stock changes were recalculated accordingly (Table 6.6-3). The losses in living biomass on forest land converted to grassland were recalculated due to incorrect area data used in the 2023 submission. The effects of this recalculation were minimal (<0.01 kt CO_2).

Table 6.6-3 Recalculations made in the Grassland category and their implications to the emission level in 1990 and 2021 (kt CO_2)



Year	2023 submission	2024 submission	difference
1990	1 019.8	1 019.8	0.0
2021	702.0	767.0	65.0

6.6.6 Category-specific planned improvements

To follow the ERT’s recommendation to justify the use of the current method for estimating carbon stock changes in living biomass for Grassland remaining Grassland, it is planned to examine the method. Furthermore, estimation of other emissions and removals will be developed both for lands converted to grassland and lands remaining grasslands.

6.7 Wetlands (CRF 4.D)

6.7.1 Category description

The total CO_2 emissions from Wetlands were 1.9 Mt of CO_2 for 2022 (Figure 6.7-1). The emissions have increased by 45% compared to the year 1990, when they were 1.3 Mt CO_2, and decreased by 8% compared to 2021, when they were 2.1 Mt CO_2. The most significant source of emissions is the peat extraction areas. According to the 2006 IPCC Guidelines, Vol. 4, wetlands include peat extraction areas and land that is covered or saturated by water for all or part of the year and that does not fall into the Forest land, Cropland, Grassland or Settlement categories (2006 IPCC Guidelines). Wetlands are reported in the sub-categories Wetlands remaining Wetlands (CRF 4.D.1) and Lands converted to Wetlands (CRF 4.D.2) (Table 6.7-1).

Wetlands Remaining Wetlands are divided into unmanaged and managed wetlands. The unmanaged Wetlands consist of natural lakes and rivers, and peatlands that do not fulfil the definition of forest land that is Other Wetlands. These peatlands are, for the most part, undrained and thus can be considered unmanaged (CRF 4.D.1.3). In managed wetlands, the water table is artificially changed (e.g., drained or raised) or they are created through human activity.

All areas converted to Wetlands are considered managed. Land Converted to Wetlands is divided into three subcategories according to the type of conversion: to Peat extraction, Flooded land, or Other Wetland, and for further division within each subcategory the original land use is considered.

N_2O and CH_4 emissions from wetlands are reported in the category CRF 4(II) (see Section 6.10.2). The emissions from peat extraction fields include the emissions from the area of active and temporarily set-aside peat extraction fields and abandoned, non-vegetated peat extraction areas. Emissions from peat combustion are calculated under the energy sector. The CH_4 emissions from land converted to inland waters consist of diffusive emissions during the ice-free period (see Section 6.10.2).

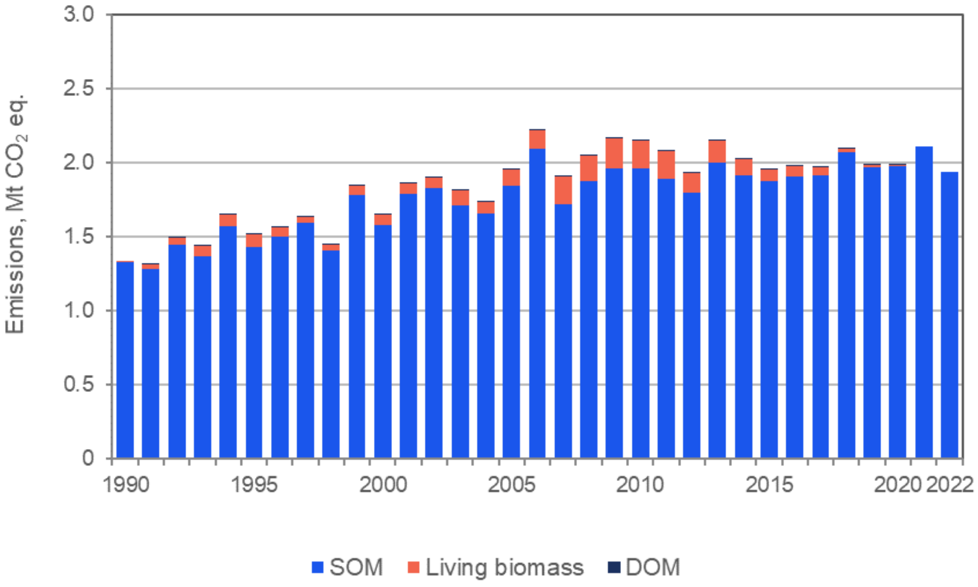


Figure 6.7-1 Emissions from wetlands, Mt CO_2 eq.

Table 6.7-1 Subcategories of Wetlands remaining wetlands and Land converted to Wetlands

CRF classification		Land use classes included in this category
4.D.1	**Wetlands remaining Wetlands**	
4.D.1.1	Peat extraction remaining Peat extraction	
	Peat extraction remaining peat extraction	Emissions from land converted to peat extraction areas more than 5 years ago, and off-site emissions from horticultural peat
	Peat extraction from Wetlands	Emissions from peat extraction converted from other Wetlands 5 or less than 5 years ago
4.D.1.2	Flooded Land remaining Flooded land	
	Inland waters from Wetlands	Reservoirs and human made impoundments converted from Wetlands
	Inland waters managed	Reservoirs and human made impoundments converted over 20 years ago
4.D.1.3	Other Wetlands remaining other wetlands	
	Other WL rem Other WL	Peatlands that do not fulfil the definition of forest land. Undrained and unmanaged
	Other WL from peat extraction	Abandoned peat extraction areas and inland waters converted to other wetlands.
	Inland waters remaining inland waters	Natural lakes and rivers, considered unmanaged
	Other WL managed	Areas converted to other Wetlands (regressed or rewetted forest lands, abandoned grasslands and settlements) over 20 years ago. Managed.
4.D.2	**Land converted to Wetlands**	
4.D.2.1	Land converted for Peat Extraction	
	Forest land	Land converted for Peat Extraction 5 or less than 5 years ago from Forest land
	Cropland	Land converted for Peat Extraction 5 or less than 5 years ago from Cropland
	Grassland	Land converted for Peat Extraction 5 or less than 5 years ago from Grassland
4.D.2.2	Land converted to Flooded land	
	Forest land converted to Flooded land	Reservoirs and human made impoundments converted from Forest land
	Cropland converted to Flooded land	Reservoirs and human made impoundments converted from Cropland
	Grassland converted to Flooded land	Reservoirs and human made impoundments converted from Grassland
	Settlements converted to Flooded land	Reservoirs and human made impoundments converted from Settlements
	Other land converted to Flooded land	Reservoirs and human made impoundments converted from Other land
4.D.2.3	Land converted to Other Wetlands	
	Forest land converted to other Wetlands	Rewetted or regressed (no longer fulfils the definition) forest lands
	Grassland converted to other Wetlands	For example abandoned organic grasslands that do not have enough potential to convert to forest land.
	Settlements converted to other Wetlands	For example dismantled power lines

6.7.2 Methodological issues

6.7.2.1 Wetlands remaining Wetlands

Activity data

The activity data are calculated from the NFI. The conversion period is 20 years, except for five years for peat extraction. Peat extraction areas were estimated for three regions: south boreal, middle boreal and north boreal regions. The regional area information was computed by combining NFI plot data with vegetation zone data. The vegetation zone data (different boreal zones) were obtained from the Finnish Environment Institute (2010).

Peat extraction remaining peat extraction areas also include areas converted from other wetlands. Managed Other Wetlands Remaining Other Wetlands are areas, which were converted to other Wetlands over 20 years ago. Managed inland waters under Flooded Land Remaining Flooded Land are areas, which were converted from other land use over 20 years ago. Land use conversions from other wetlands and peat extraction to inland waters are also reported under Flooded Land Remaining Flooded Land.

Carbon stock changes in living biomass

Losses in living biomass are reported under Peat Extraction Remaining Peat Extraction (CRF 4.D.1.1) and Flooded Land Remaining Flooded Land (CRF 4.D.1.2) using a Tier 3 approach. The loss in living tree biomass is due to the conversion of management practices within the Wetlands category. Losses are reported for the years in which the change has occurred. The same method was used as for the land-use change Forest Land converted to other land use. The Methodology is described in Appendix_6c.

For Other Wetlands Remaining Other Wetlands (CRF 4.D.1.3) carbon stock change in living biomass is assumed to be zero and the notation key ‘NA’ is reported.

Carbon stock changes in dead wood, litter and soil organic matter

Peat Extraction Remaining Peat Extraction

The emissions from peat extraction sites were calculated applying a Tier 2 method (2006 IPCC Guidelines) by multiplying the area estimates by the national emission factors. Emissions from stockpiles and ditches are included in the inventory. In the process of peat extraction, a part of the litter from the forest land converted to the wetland is used to construct a stable ground for peat stockpiles and thus emissions from this part of the litter are included in the emissions measured from the stockpiles of harvested peat. The rest of the litter is mixed with peat during the extraction and its emissions are included in the emissions from the energy sector.

The CO_2 emission factor describing the changes in soil organic matter due to the oxidation of peat in the aerobic layer on the land during peat extraction is based on the research on Finnish peat extraction sites (Alm et al. 2007).

Carbon dioxide emissions from the soil are proportional to the temperature of the soil surface layer and the soil moisture. Therefore, a statistical relationship was established between the CO_2 evolution and soil temperature at a depth of five cm and the position of the water table. It is assumed that the studied sites represent the behaviour of similar sites elsewhere in Finland, but the summertime (snow-free period) CO_2 emissions controlled by temperature and soil moisture regimes are typical for the location. Based on that assumption, regional weather-dependent emission factors were generated. The regional weather patterns were obtained from long-term (30-year) weather statistics, and the daily and hourly temperatures were generated using a weather simulator that corresponded to the measured long-term average monthly temperatures. Wintertime (snow-covered period) gas emissions were calculated using the averages of the observed values. The soil moisture was accounted for by computing the CO_2 emissions for several static summertime water table values separately in order to find reasonable extreme values (close to the minimum and maximum) for the emissions integrated over the course of the year.

Emission factors for CO_2 were computed for 11 locations (weather stations) in Finland. The locations were pooled into climatic zones and the corresponding summertime CO_2 emissions averaged for the entire zone. Three zones were defined: north boreal, middle boreal and south boreal. Separate CO_2 emission factors are provided for the north boreal, middle boreal and south boreal vegetation zones (water table 40 cm) (Table 6.7-2).

The emission factors for stockpiles and ditches are based on national measurements (Nykänen et al. 1996, Alm et al. 2007). It was assumed that 70% of the stockpiles exist throughout of June, July and August (92 days), while they are used for energy production between September and April (and therefore the estimated average wintertime existence of a stockpile is four months, being 122 days). To ensure energy security, approximately 30% of the stockpiles are kept year-round (365 days), and originating emissions were estimated accordingly. However, since 2015 the proportion of year around stockpiles is 50%. Peat extraction sites also include abandoned areas, but stockpiles exist only on areas still used for peat extraction. The share of the area covered by the stockpiles on areas of active peat extraction has been estimated to have remained the same as in previous submissions. The surface area used for peat extraction is acquired from the Association of Finnish Peat Industry (1990 to 1995) and from the YLVA (formerly VAHTI) system from 1996 onwards. Daily emission estimates of CO_2 fluxes for stockpiles during a summer day were 83 g m^{-2}, whereas they were 139 g m^{-2} for a winter day. Summertime flux rates were used for the period between May and October, while wintertime estimates were applied to the period between November and April.

Table 6.7-2 Emission factors used in calculating CO_2 emissions from peat extraction sites (kg CO_2 eq./ha/year) (based on Nykänen et al. 1996, Alm et al. 2007).

		CO_2 emissions 1990 - 2014			CO_2 emissions 2015 onwards		
Source of flux	Share of area	South Boreal	Middle Boreal	North Boreal	South Boreal	Middle Boreal	North Boreal
Stockpiles	2 %	293 955	293 955	293 955	325 125	325 125	325 125
Ditches	7 %	90	90	90	90	90	90
Production	91 %	9 860	9 460	8 400	9 860	9 460	8 400
Total emissions for YLVA area	**100 %**	**14 615**	**14 250**	**13 282**	**15 209**	**14 844**	**13 876**

Off-site emissions from horticultural peat

Off-site CO_2 emissions from peat removed for horticultural use are reported combined with the on-site CO_2 emissions under Peat Extraction Remaining Peat Extraction (4.D.1.1).

Activity data for peat removed for horticultural use are peat production volumes compiled from peat producers (Luke 2023a). Luke statistics are available until 2021, since then the data are requested from the Bioenergy association (bioenergy.fi). AD consist of all horticultural peat produced in Finland including exported peat (2006 IPCC Guidelines). The CO_2 emissions from peat extraction are a key category in Finland and following the IPCC guidelines for reporting key categories, a country-specific emission factor was developed. In Finland, the peat removed for horticultural use is predominantly light and less decomposed, therefore, the weighted average density of horticultural peat (90 g L^{-1}) is less than the value (166 g L^{-1}) upon which the IPCC default emission factor and carbon fraction are based. The country-specific carbon fraction is 0.045 t C m^{-3} air dry peat. Emissions are calculated as $\text{Volume}_{\text{dry peat}}$ multiplied by C fraction $_{\text{vol peat}}$ and immediate emission in the harvesting year is assumed.

Flooded land Remaining Flooded Land

This category is treated as a management change has taken place instead of land use change. Emissions are estimated for lands converted to Inland waters from other Wetlands. The method applied for CO_2 is the Level 1 method presented in 2006 IPCC Guidelines, Vol. 4, Appendix 2. The Level 1 method includes only the diffusive emissions during the ice-free period. Diffusive emissions during the ice-cover period are assumed to be zero. Emissions were assumed to be limited to the first 10 years, which is the default assumption of the method. The emission factor applied for CO_2 is the median IPCC default for Polar/Boreal wet climate: 11.8 kg

CO_2 ha^{-1} day^{-1} (2006 IPCC Guidelines, Table 2A.2, p. Ap2.6). The length of the ice-free period was assumed to be 180 days.

Other Wetlands Remaining Other Wetlands

This category is treated as a management change has taken place instead of land use change. Emissions for peat extraction areas converted to other wetlands are calculated with the emission factor for Dwarf shrub type (Vatkg, 218.9 g C m^{-1} a^{-1}) based on Minkkinen et al. (2007) according to Tier 2 methodology (2006 IPCC Guidelines). Other managed wetlands include also lands that have been converted from former peat extraction sites over 20 years ago. Emissions are computed with the same emission factor, Dwarf shrub type (Vatkg). For land converted from forest land over 20 years ago, the emission factor for *Cladina* type (Jätkg, 185.2 g C m^{-1} a^{-1}) is applied (Minkkinen et al. 2007). Site type classification is from Laine 1989.

6.7.2.2 Land converted to Wetlands

Activity data

The activity data are calculated from the NFI similarly as for Wetlands Remaining Wetlands (See 6.7.2.1).

Carbon stock changes in living biomass

Land converted for Peat Extraction. The removal of biomass from forest land converted to peat extraction was estimated according to Tier 3 methodology using the products of the annual converted areas and mean biomasses by region and soil type removed during conversion. There were no conversions from forest land to peat extraction in 2021 and 2022. For further information on the method, see Appendix_6c. The loss in carbon stock due to the removal of annual non-woody crops from conversion of Cropland to peat extraction in the conversion year was 4 t C/ha, which is a national value of mean crop biomasses based on yields. The corresponding EF for lands converted from Grassland to peat extraction was 4.1 t C/ha.

Land converted to Flooded land. It was assumed that due to the conversion from Forest Land to inland water, all tree biomass is removed. The method corresponds to Tier 3 methodology (2006 IPCC Guidelines). There have been no conversions from forest land to flooded land since 2012. For further information on the method, see Appendix_6c. Due to the conversions from Cropland to Flooded Land, 4 t C ha^{-1} in biomass was assumed to be lost. In the conversion from Grassland to Flooded Land, no loss in biomass is reported, but all biomass was assumed to be left on the site.

Land converted to Other Wetlands. This category consists of organic forest land that have regressed to wetlands, and grassland and settlements converted to Other Wetlands (CRF 4.D.2.3). When forest land regresses to wetlands, the biomass is not removed. The biomass is assumed in steady state, so that gains equal removals.

Carbon stock changes in dead wood, litter and soil organic matter

Land converted to Flooded Land. The emissions were estimated with the same method as for flooded land remaining flooded land (2006 IPCC Guidelines, Vol. 4, Appendix 2).

Land converted for Peat Extraction. The emissions from the deadwood carbon pool due to land-use change were estimated by applying emission factors according to Tier 2 methodology. More details about these emission factors are provided in Appendix_6i. The emissions from lands converted to peat extraction sites were calculated in the same way as emissions for peat extraction remaining peat extraction (See 2006 IPCC Guidelines, Vol. 4, Section 6.7.2.1 and Table 6.7-2). In this conversion category, ‘IE’ is reported for CSC in litter. When Forest Land is converted to peat extraction, after the clear-cutting timber, slash and stumps are removed, the timber is used for wood products, slash and stumps are piled, chipped and used for energy. Losses in the carbon stock due to the removal of these tree components are reported under losses in living biomass. The surface (incl. litter) of the peat is also removed. The surface matter can be combusted with peat in power plants, and in this case, the emissions are reported under the energy sector, or used to construct a stable ground for stockpiles. In that case, the decomposition of litter is included in the emissions from stockpiles. EFs for peat extraction include emissions from production fields, stockpiles and ditches. Emissions due to decomposition of fine dead roots (litter in peat) are included in the EFs from peat production fields.

Land converted to Other Wetlands. This category consists of organic forest land, grassland and settlements that have regressed to wetlands (CRF 4.D.2.3). Emissions from forest land converted to wetlands were estimated according to Tier 2 methodology by applying the emission factors shown in **Virhe. Viitteen lähdettä ei löytynyt.**, whereas Tier 1 method was used for land-use change from grassland and settlement to wetland.

6.7.3 Uncertainty assessment and time series’ consistency

Quantitative estimates of uncertainty are provided in Annex 2. The annex also documents the assumptions made for the analysis.

The uncertainty of wetlands remaining wetlands constitutes that of peat extraction, while uncertainties of other subcategories were excluded due to their minor role. The uncertainty associated with the peat extraction area stems from several different sources. The most important source of uncertainty is associated with CO_2; by volume CO_2 is the most important GHG species emitted from the extraction areas. For CO_2 emission dynamics, the effects of summertime (May to October) temperatures and moisture are important (Alm et al. 2007). The present emission factors do not account for the effect of moisture variation, because no moisture monitoring exists. However, the contribution of inter-annual variations in temperatures was assessed via weather simulations based on statistics from the reference period 1961 to 1990. The simulated temperatures were used in regression transfer models to estimate the contribution of long-term weather variations in CO_2 emissions. The standard deviation of the simulated fluxes varied from 6% to 8% for the cumulative summertime emissions. The SD of CO_2 emissions measured in wintertime was approximately 10%. If the uncertainty for summertime CO_2 emissions is estimated using 2SD (±12-16%), the contribution of winter CO_2 with lower emission rates can be expertly deemed to increase the level of uncertainty to ±25% CO_2 equivalents. On rare occasions, the CO_2 emissions from the extraction field could rise by about 200% (Alm et al. 2007); however, most of the available data support the present lower emission factors.

Uncertainty due to sampling in the area of peat extraction was estimated by the standard method of the Finnish NFI (Table 6.2-2). Applicable data are currently not available for assessing the uncertainty in the estimated loss of tree biomass due to conversion of forest land into peat extraction; the expert judgement 100% was used. For deadwood losses during these conversions, total uncertainty was assumed to be 103%.

The area estimations are based on NFI data and the total areas of peat extraction fields are consistent for the entire time series (1990 to 2022) because they were computed using the same NFI data. Land conversions before 1990 were extrapolated as a constant equal to the NFI9 result.

Tree biomass is estimated using data from NFI data. There should not be any inconsistencies between the inventories because the same methods and tree measurement techniques were used. The CO_2 emissions from flooded land and from land converted to flooded land were estimated with 2006 IPCC Guidelines’ default emission factor values and the uncertainty of those were estimated to be one order of magnitude, i.e. 100%.

6.7.4 Category-specific QA/QC and verification

The quality objectives and the QA/QC and verification plan for the Finnish greenhouse gas inventory at the national inventory level are presented in Section 1.5. The QC procedures are performed according to the QA/QC plan in order to attain these quality objectives. A bilateral quality meeting or a quality desk review is held annually between the inventory unit and the sectoral expert. In the 2023 quality meeting, the short-term and long-term development plans and QC procedures were discussed.

An AFOLU steering group supervises the reporting of emissions and removals for the LULUCF sector. The members, working at Luke, have a broad expertise in using the measurements and methodology to estimate carbon stock changes and greenhouse gases. All changes in methods, activity data and emissions or other

factors and parameters are discussed and approved by the steering group before they are introduced to the advisory board (see Section 1.2.1). The steering group meets two to four times per year.

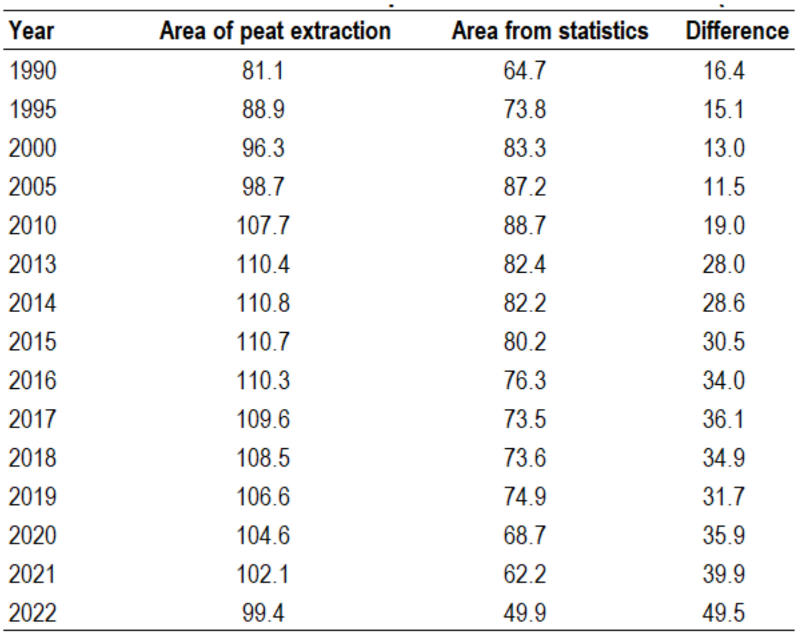
The country-specific emission factor used to estimate off-site emissions from horticultural peat were compared to those of Sweden in 2015. The type and quality of peat in Finland differs from the peat on which the IPCC default EF is based on. The Swedish values were in line with Finnish values.

The quality control procedures specified in the 2006 IPCC Guidelines were followed. In particular, the land areas were critically compared to the statistical ones and the causes for the differences between the two data sources were identified (Section 6.5.4 and Haakana et al. 2015).

The NFI peat extraction areas were compared to statistical areas (Table 6.7-3). The NFI peat extraction also includes cut-over areas, which remain in the category as long as land-use change to a new category is evident. Hence, the NFI covers all peat extraction fields regardless of the size or production activity, only focusing on land use at the time of assessment in the field. In 2013, the data from Western Finland were not received from all peat producers for the compilation of statistics. The statistical data show only areas, which are currently used in peat extraction. The statistical areas for the annual peat extraction areas were acquired from the Association of Finnish Peat Industry (1990 to 1995) and from the YLVA (formerly VAHTI) system from 1996 onwards. Since the data from the YLVA system do not cover all peat extraction areas, they were complemented and evaluated by the Thule Institute (Mäenpää and Jutila 2008). Also, YLVA data since 2007 did not cover all small peat producers (with area < 10 ha) until 1 September 2020, therefore the areas from these years in statistics were complemented by 1,000 to 4,000 ha per year based on the expert judgement. Since 2022 YLVA data is considered complete, but 200 ha of domestic use is added to the area based on expert judgement. The total wetland area was compared with the previous submission and other data (see Section 6.4.4).

The following programme tool has been implemented to support GHG inventory reporting: the CRFTool programme that automates and provides an error free transfer of inventory results to the CRF Reporter.

Table 6.7-3 Area of industrial peat extraction in Finland (1,000 ha) compared to the statistics

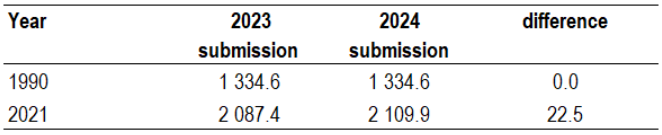


Year	Area of peat extraction	Area from statistics	Difference
1990	81.1	64.7	16.4
1995	88.9	73.8	15.1
2000	96.3	83.3	13.0
2005	98.7	87.2	11.5
2010	107.7	88.7	19.0
2013	110.4	82.4	28.0
2014	110.8	82.2	28.6
2015	110.7	80.2	30.5
2016	110.3	76.3	34.0
2017	109.6	73.5	36.1
2018	108.5	73.6	34.9
2019	106.6	74.9	31.7
2020	104.6	68.7	35.9
2021	102.1	62.2	39.9
2022	99.4	49.9	49.5

6.7.5 Category-specific recalculations

Area estimates were recalculated due to the updated data and corrections to it (see Section 6.2). This resulted in recalculation of the time series since 2009 and all carbon stock changes were recalculated accordingly (Table 6.7-4).

Table 6.7-4 Recalculations made in the Wetlands category and their implications to the emission level in 1990 and 2021 (kt CO_2)



Year	2023 submission	2024 submission	difference
1990	1 334.6	1 334.6	0.0
2021	2 087.4	2 109.9	22.5

6.7.6 Category-specific planned improvements

Improvement of the activity data compilation and estimation method for carbon stock changes for different Wetland sub-categories is planned.

6.8 Settlements (CRF 4.E)

6.8.1 Category description

The areas of Settlements comprise nationally defined built-up land, roads, railroads, gravel collection sites and power lines (see Section 6.2). Finland reports CO_2 emissions from losses in living biomass due to conversion under Forest land, Cropland, Grassland and Wetlands converted to Settlements. Biomass and deadwood loss due to conversion and emissions from litter and soil organic matter after conversion are reported under Forest land converted to Settlements. CO_2 emissions from Land converted to Settlements were 0.8 Mt CO_2 eq. in 2022 and 0.9 Mt CO2 eq. in 2021 as well as in 1990 (Figure 6.8-1). The emissions have decreased by 11% compared to the years 1990 and 2021. At the end of the time series there is a declining trend in the emissions due to declining annual areas converted to Settlements. The 20-year conversion area is, however, declining much less due to bigger annual change in the 2000's.

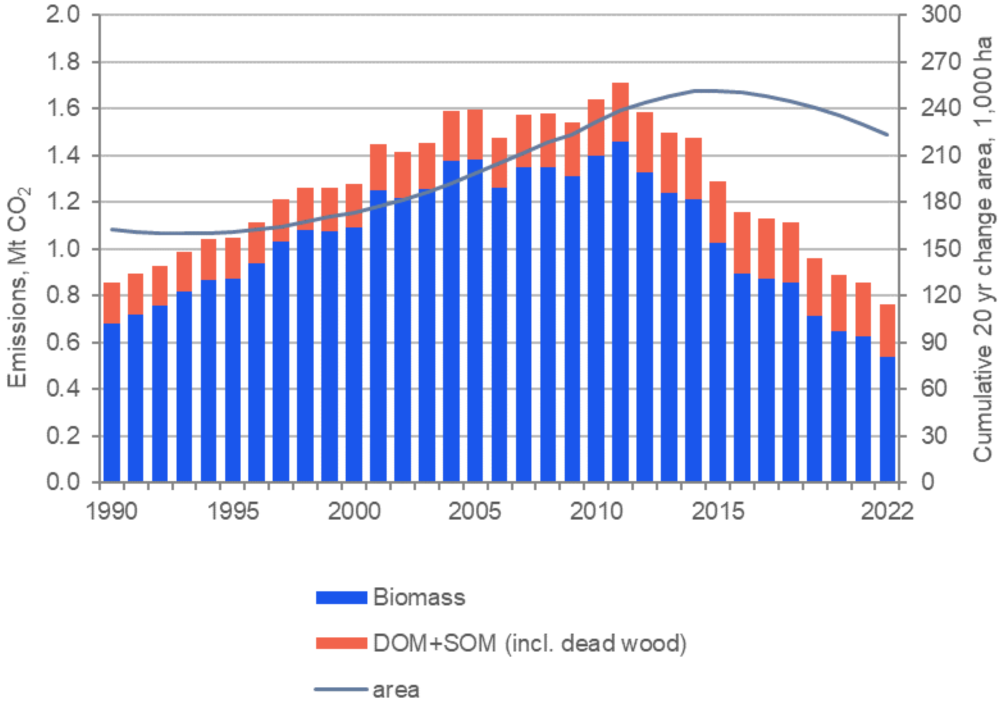


Figure 6.8-1 Emissions (Mt CO_2) from Land Converted to Settlements

6.8.2 Methodological issues

6.8.2.1 Settlements Remaining Settlements

The areas of Settlements Remaining Settlements were calculated from NFI data (See 6.7.2.1). According to the Tier 1 method, it was assumed that there are no changes in biomass, DOM and SOM (mineral soils) carbon pools (2006 IPCC Guidelines, Vol. 4, Ch. 8, p. 8.7, p. 8.13, 8.15), and a notation key 'NA' is reported. About 1% of the total area in this category is on organic soils, of which only a part is drained. Therefore, in the CRF Table 4.B a notation key 'NA' is reported for organic soils. Recommended Tier 1 emission factor for cultivated organic soils cannot be assumed to be appropriate for these cases. Development work to improve the estimation of carbon stock changes of this category is ongoing including the applied assumptions.

6.8.2.2 Land Converted to Settlements

Activity data

The areas of Settlements comprise nationally defined built-up land, traffic lines, gravel collection sites and power lines. The areas of Lands Converted to Settlements were calculated from NFI data. Forest Land converted to built-up land was further subdivided using aerial photographs. The idea of this subdivision was to improve estimation of carbon stock changes in litter and soil organic matter due to land-use change. Annual data of Forest Land converted to built-up land was further divided into the following classes (average values and range of annual percentages for 1990 to 2022 in brackets):

1. Sealed- and gravel soils (31% [31–35%])
2. Turfgrass and grassland type (14% [13–16%])
3. Areas with tree cover (54% [48–56%])
4. Open cliffs (1%)

Carbon stock changes in living biomass

When land is converted to developed use, such as for infrastructure or urban areas, the trees and other biomass are either completely removed or some biomass is left to grow on the site. To estimate the losses in living biomass due to land conversion from forest land to settlements the area was divided into three categories according to the new land use and whether trees still exist after conversion (treeless roads and power lines, other treeless settlements and land with tree cover, such as parks). For land conversions from cropland and grassland to settlements the agricultural biomass is reported as a loss of living biomass at the time of conversion. If biomass is left to grow in the settlement area, the gain in biomass is not estimated and reported. This is due to the fact that we currently do not have enough data for this and the methodology is under development. The methodology corresponds to Tier 3 approach (2006 IPCC Guidelines). For further information on the method see Appendix_6c.

Carbon stock changes in dead wood, litter and soil organic matter

The amount of emissions due to losses in deadwood when Forest Land is converted into Settlements was estimated as the product of the annual converted areas and the emission factors (Appendix_6i). The emissions from carbon stock changes for litter and soil organic matter were estimated similarly with the 2006 IPCC Guidelines' Tier 2 methods. The estimation was done for the following conversion classes:

1. Sealed- and gravel soils
2. Turfgrass and grassland type
3. Areas with forest cover
4. Open cliffs
5. Power and gas lines
6. Gravel collections sites

For classes one and six it was assumed that 20% of the soil carbon stock (including litter and SOM) will be lost during the 20-year transition period. For class two (Forest land converted to grassland type), emissions were estimated with FL converted to GL emission factors. For Forest land converted to settlement types three, four and five (e.g., summer cottage surroundings), the 2006 IPCC Guidelines' method for wooded settlements was used and it was assumed that there is no carbon stock change in the litter and soil organic matter pools. In conversions from Cropland, Grassland and Wetland (peat extraction site) to Settlement there is no dead wood pool in the initial state. There is no litter pool either in conversion from peat extraction sites, and it is assumed that it is negligible in transition from Cropland and Grassland. Therefore, notation key 'NA' is reported for carbon stock change in DOM pool for other conversions than Forest land converted to Settlements.

6.8.3 Uncertainty assessment and time series' consistency

Quantitative estimates of uncertainty are provided in Annex 2. The annex also documents assumptions made for the analysis. A description of the uncertainty analysis is included in Section 1.6.

The uncertainty due to sampling in the area of Settlements was estimated by the standard method of the Finnish NFI (Table 6.2-2).

The area estimations are based on NFI data. The NFI data cover all land-use categories, and the total areas of Settlements and Land Converted to Settlements are consistent for the entire time series because they are computed using the same NFI data. Land conversions before 1990 were extrapolated as a constant equal to the NFI9 result.

Tree biomass was estimated using data based on NFIs. The total uncertainty in the estimated loss of tree biomass based on AD and EF uncertainties was 30%, for the emission from litter and soil carbon lost -70% - +150%, and for dead wood 106%. No inconsistency can be expected between inventories due to the same methods and tree measurement techniques.

6.8.4 Category-specific QA/QC and verification

The quality objectives and the QA/QC and verification plan for the Finnish greenhouse gas inventory at the national inventory level are presented in Section 1.5. The QC procedures are performed according to the QA/QC plan in order to attain these quality objectives. A bilateral quality meeting or a quality desk review is held annually between the inventory unit and the sectoral expert. In the 2023 quality meeting, the short-term and long-term development plans and QC procedures were discussed.

An AFOLU steering group supervises the reporting of emissions and removals for the LULUCF sector. The members, working at Luke, have a broad expertise in using the measurements and methodology to estimate carbon stock changes and greenhouse gases. All changes in methods, activity data and emissions or other factors and parameters are discussed and approved by the steering group before they are introduced to the advisory board (see Section 1.2.1). The steering group meets two to four times per year.

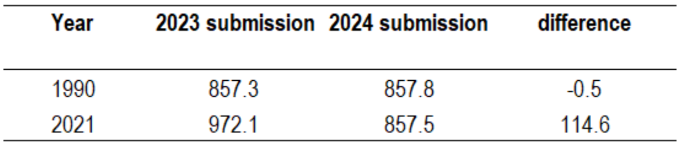
The activity data were compared between the current and previous submission (Section 6.2) and also to the Corine Land Cover 2012 (see Section 6.4.4). The category area based on NFI data is greater than in Corine data, which is based on land cover type. The category in the NFI also includes the areas with tree cover, e.g., parks according to land use.

The following programme tool has been implemented to support GHG inventory reporting: the CRFTool programme that automates and provides an error free transfer of the inventory results to the CRF Reporter.

6.8.5 Category-specific recalculations

New area estimates were calculated due to new data, updating of NFI data and corrections to the data (see Section 6.2). This resulted in recalculations for the time series since 2014 and all carbon stock changes were updated accordingly. The CSC in living biomass and mineral soil on forest land converted to settlements were recalculated for the whole time series (Table 6.8-1). In addition, area data was corrected which resulted in a change in the losses in the living biomass compared to the previous submission.

Table 6.8-1 The difference in the emissions from Land Converted to Settlements due to recalculation between the 2023 and 2024 submissions (kt CO_2)



Year	2023 submission	2024 submission	difference
1990	857.3	857.8	-0.5
2021	972.1	857.5	114.6

6.8.6 Category-specific planned improvements

Estimation of emissions and removals (including activity data and emission factors) for lands converted to settlements will be developed for 2025 and 2026 submissions. Methods to estimate emissions and removals from settlements remaining settlements will also be developed. The aim is to report them for the first time in the 2027 submission.

6.9 Other land (CRF 4.F)

6.9.1 Category description

Other land includes the part of the mineral soils of nationally defined, poorly productive forest land, which do not fulfil the threshold values for Forest Land and barren mineral soils of unproductive land (see Appendix_6a). In principle, Other land is considered unmanaged land, but Lands converted to Other Land are managed. The method for estimating the areas of other lands is provided in in Section 6.3. The monitoring system has detected land-use changes from settlements to other land. This kind of change happens when, for example, a power line is dismantled. No carbon stock changes or non-CO_2 emissions are occurring nor reported in this category.

6.10 Non-CO_2 emissions

6.10.1 Direct N_2O emissions from fertilisation (CRF 4 (I))

6.10.1.1 Category description

This category covers direct nitrous oxide emissions from forest fertilisation (CRF 4 (I)) (Figure 6.10-1). There are two types of forest fertilisation: growth and forest vitality fertilisations. Nitrogen fertilisers are mainly used to increase growth. There are fertilisers that are only applied to forests and fertilisers like saltpetre and urea, which are used in both agriculture and forestry. The amount of these two types of fertilisers used in forestry is based on the import and production statistics.

N_2O emissions from forest fertilisation declined at the beginning of the 1990s, but increased from 1993 to 2008. After that, the emissions declined again until 2013, after which they were quite steady until a sharp increase from the year 2016 onwards. Since 2020, the emissions from forest N_2O fertilisation have declined again, being 5 kt CO_2 eq. in 2022. This was a decrease of 31% compared to 1990, when the emissions were 18 kt CO_2 eq., and a decrease of 80% compared to 2021, when the emissions were 27 kt CO_2 eq. The amount of fertilises applied to forests in 2022 was especially low, due to the current economic and security situation in Europe affecting the availability and prices of fertilisers. However, the amount of urea used for fertilising multiplied in 2022, which may have been influenced by the cheaper price of urea compared to other nitrogen fertilizers. The reduction in emissions from forest fertilisation in 2022 is in line with the area of fertilised forests, which decreased by two-thirds compared to 2021 (Luke 2023a).

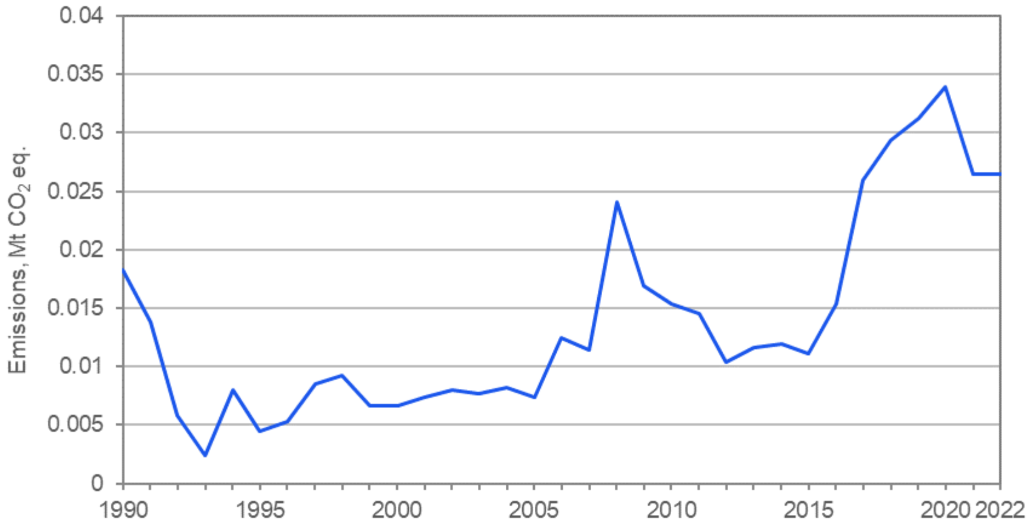


Figure 6.10-1 N_2O emissions from forest fertilisation (Mt CO_2 eq.)

6.10.1.2 Methodological issues

The IPCC default method (Tier 1) is used to estimate N_2O emissions from forest fertilisation (2006 IPCC Guidelines). Equation 11.1 is applied using country-specific activity data and the IPCC default emission factor.

Emission factors and other parameters

The default emission factor of 1% is used (2006 IPCC Guidelines, Vol. 4, Table 11.1).

Activity data

The amount of nitrogen for forest fertilisation is based on the annual import and production statistics for forest fertilisers, from which the amount of nitrogen is derived (Table 6.10-1). Until 2017 the information was produced by Yara Suomi Oy, a company that delivers almost 100% of fertilisers applied to forests. From 2017 onwards the information is obtained from the Finnish Food Authority.

When this submission was made (February 2024), The Finnish Food Authority had still not received the annual declaration information for 2022 of all fertiliser companies. Therefore, missing data were estimated using the change in the fertiliser amounts between 2021 and 2022 for the companies whose data was available for 2022, and assuming the change between 2021 and 2022 for the missing companies was equally large as for the companies with available data. Only 0.92% of the nitrogen content of forest fertilisers needed to be estimated.

Table 6.10-1 The estimated amount of nitrogen (N) applied to Forest Land (1,000 kg/year) (Source: Yara Suomi Oy, Finnish Food Authority)

Year	1990	1995	2000	2005	2010	2013	2014	2015	2016	2017	2018	2019	2020	2021	2022
N (1000 kg/year)	4 404	1 066	1 588	1 800	3 720	2 790	2 849	2 668	3 722	6 249	7 047	7 483	8 118	6 339	1 248

6.10.1.3 Uncertainty assessment and time series' consistency

Quantitative estimates of uncertainty are provided in Annex 2. The annex also documents the assumptions made for the analysis. A description of the uncertainty analysis is included in Section 1.6.

The uncertainty estimate for the activity data is ±10% and for the emission factor -70% to +202% (Default value 0.01 with uncertainty range of 0.003 to 0.03). The same estimates are used in the agricultural sector.

At the beginning of the 1990s, the statistics for forest fertilisers were registered for each fertilising year (starting from the beginning of July), while the statistics for recent years only concern the calendar year. This inconsistency is considered marginal because the fertilisers may not be used in the same year as they are imported or produced. The data from Yara and Finnish Food Authority were compared and it was found that the data are consistent regardless of the producer and the time series is consistent.

6.10.1.4 Category-specific QA/QC and verification

The quality objectives and the QA/QC and verification plan for the Finnish greenhouse gas inventory at the national inventory level are presented in Section 1.5. The QC procedures are performed according to the QA/QC plan in order to attain these quality objectives. A bilateral quality meeting or a quality desk review is held annually between the inventory unit and the sectoral expert. In the 2024 quality meeting, the short-term and long-term development plans and QC procedures were discussed.

An AFOLU steering group supervises the reporting of emissions and removals for the LULUCF sector. The members, working at Luke, have a broad expertise in using the measurements and methodology to estimate carbon stock changes and greenhouse gases. All changes in methods, activity data and emissions or other

factors and parameters are discussed and approved by the steering group before they are introduced to the advisory board (see Section 1.2.1). The steering group meets two to four times per year.

The general quality control procedures specified in the 2006 IPCC Guidelines were followed. In addition, the nitrogen fertilisation quantities reported here were compared to the total number of areas fertilised annually obtained from statistics (Luke 2023a). It was confirmed that all of the data used in this section cover the whole land area of Finland.

The statistics for N fertilisers applied to forest land and agricultural lands were cross-checked. No discrepancy was found.

The following programme tool has been implemented to support GHG inventory reporting: The CRFTool programme that automates and provides an error free transfer of the inventory results to the CRF Reporter.

6.10.1.5 Category-specific recalculations

No recalculations.

6.10.1.6 Category-specific planned improvements

The aim is to include N_2O emissions form nitrogen fertilisers applied to settlements (like parks and golf courses) in the inventory for 2025 submission.

6.10.2 Non-CO_2 emissions from drainage and rewetting and other management of organic and mineral soils (CRF 4 (II))

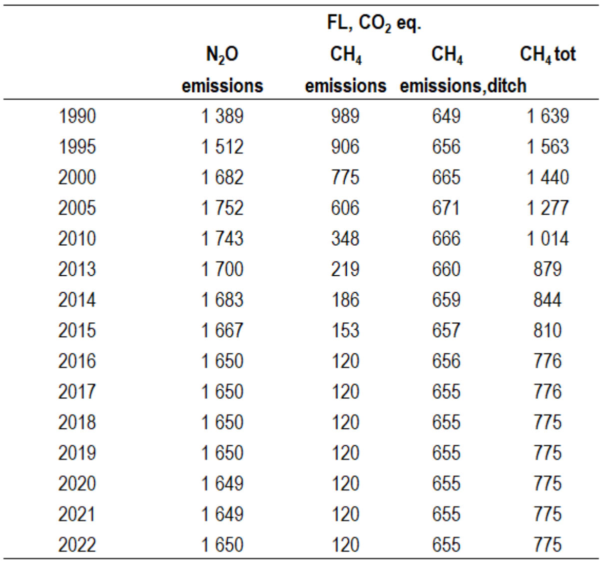
6.10.2.1 Category description

Finland reports non-CO_2 emissions in the CRF Table 4 (II) that is, N_2O and CH_4 emissions from drained organic forest soils (both Forest Land Remaining Forest Land and Land Converted to Forest Land), N_2O and CH_4 emissions from peat extraction areas, and CH_4 emissions from land converted to inland waters and to other wetlands. CO_2 emissions from peat extraction areas and land converted to inland waters are reported in category 4.D Wetlands (Section 6.7).

N_2O emissions from drained organic soils on croplands and grasslands are reported under the Agriculture sector, Category 3.D.

In 2022, the N_2O emissions from drained organic forest soils were 1.7 Mt CO_2 equivalents, while CH_4 emissions were 0.8 Mt CO_2 equivalents in total, see Table 6.10-2. This estimate includes emissions from both Forest Land Remaining Forest Land and those converted to Forest Land. In 1990, the N_2O and CH_4 emissions were 1.4 Mt CO_2 eq. and 1.6 Mt CO_2 eq., respectively, whereas they were 1.6 Mt CO_2 eq. and 0.8 Mt CO_2 eq in 2021. The N_2O emissions have increased by 19% and the CH_4 emissions have decreased by 53% since the year 1990. Compared to 2021, the changes in N_2O and CH_4 emissions were less than 0.1%.

Table 6.10-2 Methane and nitrous oxide emissions from Forest Land, kt CO_2 eq.



	FL, CO_2 eq.			
	N_2O emissions	CH_4 emissions	CH_4 emissions,ditch	CH_4 tot
1990	1 389	989	649	1 639
1995	1 512	906	656	1 563
2000	1 682	775	665	1 440
2005	1 752	606	671	1 277
2010	1 743	348	666	1 014
2013	1 700	219	660	879
2014	1 683	186	659	844
2015	1 667	153	657	810
2016	1 650	120	656	776
2017	1 650	120	655	776
2018	1 650	120	655	775
2019	1 650	120	655	775
2020	1 649	120	655	775
2021	1 649	120	655	775
2022	1 650	120	655	775

6.10.2.2 Methodological issues

CH_4 and N_2O emissions from drainage and rewetting

Emission factors (based on Ojanen et al. 2018) for N_2O emissions by soil fertility for drained organic forest lands have been given in Table 6.10-4. The fertility classification was based on the one presented in Table 6.4-1, but slightly modified to match emission factor classes provided by Ojanen et al. 2018.

The CH_4 emissions consist of emissions from drained land (97.5% of the area, country-specific EFs) and from ditches (2.5% of the area, default fraction and EF 217 kg CH_4 ha^{-1} for boreal/ temperate zone given the IPCC Wetlands Supplement). Country-specific emission factors for CH_4 from drained organic land by drainage class are net emission of 11.6 kg CH_4 ha^{-1} for poorly or recently drained land and net uptake of -2.8 kg CH_4 ha^{-1} for well drained land (based on Ojanen et al. 2010) (Table 6.10-4). Emissions were estimated with Tier 2 and with Tier 1 (ditches) methods by multiplying land areas of drained organic forest soils with emission factors. The uncertainty in the emission factors for CH_4 was estimated as standard errors of mean: 11.6 ± 4.8 kg CH_4 ha^{-1}, and -2.8 ± 0.4 kg CH_4 ha^{-1} (Ojanen et al. 2010).

The non-CO_2 emissions from peat extraction fields include the CH_4 and N_2O emissions from the area of active and temporarily set-aside peat extraction fields and abandoned, non-vegetated peat extraction areas, emissions from stockpiles and emissions from ditches (Table 6.10-3), following principles of IPCC Wetlands Supplement, Tier 2 methodology. Total emission factors vary depending on existence of stockpiles, which exist only on sites that are in active use and reported in VAHTI/YLVA system (see Section 6.7.2). Also, CH_4 emissions from peat extraction fields that were converted to other wetlands are reported under this category, and the emission factors are those based on CH_4 from poorly drained organic soils. (Ojanen et al. 2010). N_2O emissions do not occur in rewetted organic soils (IPCC Wetlands Supplement).

Table 6.10-3 Emission factors used in calculating non-CO_2 emissions from peat extraction sites (kg CO_2 eq./ha/year). Emission factors of stockpiles are applied only for the YLVA area. (Nykänen et al. 1996, Alm et al. 2007)

Source of flux	**Share of area**	**CH_4 1990 - 2014**	**CH_4 2015 onwards**	**N_2O 1990 - 2014**	**N_2O 2015 onwards**
Stockpiles	2 %	6 275	6 768	910	1 043
Ditches	7 %	3 724	3 724	1	1
Production	91 %	105	105	961	961
Total emissions	**100 %**	**468**	**478**	**895**	**897**

Table 6.10-4 Emission factors and their uncertainty for N_2O emissions from drained forest land (by fertility class) and for CH_4 emissions (by drainage condition), based on Ojanen et al. (2010, 2018)

Site type	**N_2O emissions, g N_2O m^{-2} a^{-1}**		**Ditch condition**	**CH_4 emissions, g CH_4 m^{-2} a^{-1}**	
	EF	**SE**		**EF**	**SE**
Herb-rich type (Rhtkg)	0.331	0.101	Poor	1.16	0.48
Vaccinium myrtillus type I (MtkgI)	0.177	0.052	Good	-0.28	0.04
Vaccinium myrtillus type II (MtkgII)	0.323	0.123			
Vaccinium vitis-idaea type I (PtkgI)	0.064	0.004			
Vaccinium vitis-idaea type II (PtkgII)	0.098	0.022			
Dwarf shrub type (Vatkg)	0.043	0.009			
Cladina type (Jätkg)	0.029	0.007			

CH_4 emissions from flooded land

CH_4 emissions were estimated with the Tier 1 method of the 2006 IPCC Guidelines, Vol. 4, Appendix 3. The Tier 1 method includes only the diffusive emissions during the ice-free period. Emissions during the ice-cover period are assumed to be zero. The emission factor applied for CH_4 is the median IPCC default for Polar/Boreal wet climate: 0.086 kg CH_4 ha^{-1} day^{-1} (2006 IPCC Guidelines, Vol. 4, Table 3A.2, p. Ap3.5). The length of the ice-free period was assumed to be 180 days. Following the 2006 IPCC Guidelines, once an area is flooded, the CH_4 emissions will be sustained from thereon, in contrast to CO_2 emissions, which are limited to the first 10 years.

CH_4 and N_2O emissions from regressed wetlands

N_2O emissions for organic forest land, grassland and settlements that have regressed to wetlands were calculated with the emission factor for Dwarf shrub type (Vatkg) (Table 6.10-4) according to Tier 2 methodology (2006 IPCC Guidelines). CH_4 emissions were calculated with the emission factor for poor ditch condition (Table 6.10-4).

6.10.2.3 Uncertainty assessment and time series' consistency

Quantitative estimates of uncertainty are provided in Annex 2. The annex also documents assumptions made for the analysis. A description of the uncertainty analysis is included in Section 1.6.

The uncertainties for emission factors were reported in Table 6.10-4, while uncertainties of land areas were estimated as described in Section 6.2. The total uncertainty was propagated according to the 2006 IPCC Guidelines. It was assumed that the uncertainties between site types were independent from each other. The uncertainty of emissions from drained forest land due to drainage and re-wetting were assumed to be 82% for

CH_4 and 80% for N_2O emissions. These error estimates combine uncertainties of the land area estimate and that of the emission factor.

The aggregated uncertainty of non-CO_2 emissions from land converted to wetlands and also from lands remaining wetlands were assumed to be up to 170%. This high uncertainty results from small land areas and also from the fact that there is a limited amount of data behind the measurements.

The fluxes of CH_4 and N_2O from peat extraction sites vary in a complex way and the range of observations around the mean was skewed. Therefore, the uncertainties cannot be estimated simply by combining the variances. If the uncertainty for summertime CO_2 emissions from peat extraction is estimated using 2SD (±12-16%), the contribution of winter non-CO_2 emissions (CH_4, N_2O) with lower emission rates can be expertly deemed to increase the level of uncertainty to ±25% CO_2 equivalents. It was assumed that the combined uncertainty for the land area estimate and emissions was 55% for non-CO_2 emissions from peat extraction lands.

The CH_4 emissions from flooded land and from land converted to flooded land were estimated with the 2006 IPCC Guidelines’ default emission factor values and the uncertainty of those were estimated to be one order of magnitude, i.e. 100%.

6.10.2.4 Category-specific QA/QC and verification

The quality objectives and the QA/QC and verification plan for the Finnish greenhouse gas inventory at the national inventory level are presented in Section 1.5. The QC procedures are performed according to the QA/QC plan in order to attain these quality objectives. A bilateral quality meeting or a quality desk review is held annually between the inventory unit and the sectoral expert.

An AFOLU steering group supervises the reporting of emissions and removals for the LULUCF sector. The members, working at Luke, have a broad expertise in using the measurements and methodology to estimate carbon stock changes and greenhouse gases. All changes in methods, activity data and emissions or other factors and parameters are discussed and approved by the steering group before they are introduced to the advisory board (see Section 1.2.1). The steering group meets two to four times per year.

The following programme tool has been implemented to support GHG inventory reporting: The CRFTool programme that automates and provides an error free transfer of the inventory results to the CRF Reporter.

6.10.2.5 Category-specific recalculations

New area estimates were calculated due to updating of NFI data and data corrections (see Section 6.2). The updates of data resulted in recalculation for the whole time series, in case of peat extraction for 2009 to 2021 (Table 6.10-5).

Table 6.10-5 The difference in non-CO_2 emissions from drainage and rewetting and other management of organic and mineral soils due to recalculation between the 2023 and 2024 submissions (kt CO_2 eq.)

		Submission 2023	Submission 2024	Difference	Submission 2023	Submission 2024	Difference
		1990			2021		
A. Forest Land							
CH_4, kt		58.5	58.5	**0.0**	27.7	27.7	**-0.01**
N_2O, kt		5.2	5.2	**0.0**	6.2	6.2	**-0.004**
Area, kha		4274.5	4274.5	**0.0**	4313.4	4311.9	**-1.5**
D. Wetlands				**0.0**			
CH_4, kt		1.8	1.8	**0.0**	2.7	2.7	**0.0**
N_2O, kt		0.2	0.2	**0.0**	0.3	0.3	**0.00**
Area, kha		89.3	89.3	**0.0**	147.9	148.2	**0.3**
	D.1 Peat extraction lands						
	CH_4, kt	1.7	1.7	**0.0**	2.10	2.11	**0.0**
	N_2O, kt	0.2	0.2	**0.0**	0.3	0.3	**0.00**
	Area, kha	81.1	81.1	**0.0**	102.9	102.1	**-0.82**
	D.2 Flooded lands						
	CH_4, kt	0.1	0.1	**0.0**	0.2	0.2	**0.013**
	N_2O, kt	NA	NA	**NA**	NA	NA	**NA**
	Area, kha	8.1	8.1	**0.0**	14.6	15.5	**0.9**
	D.3 Other wetlands (please specify)						
	CH_4, kt	0.002	0.002	**0.0**	0.3	0.3	**0.00**
	N_2O, kt	0.0001	0.0001	**0.0**	0.007	0.007	**0.0001**
	Area, kha	0.2	0.2	**0.0**	30.4	30.6	**0.3**

6.10.2.6 Category-specific planned improvements

Rewetting of peat soils is one climate measure in Finland (for example, presented in the national Climate Plan for the Land Use Sector (MMM 2023)). Compilation of rewetted area data will start in 2024 and is expected to be available for the GHG inventory for the 2026 submission at the earliest, provided that related emission factors and other parameters are also available.

6.10.3 Direct N_2O emissions from N mineralisation/immobilisation (CRF 4 (III))

6.10.3.1 Category description

This category consists of direct N_2O emissions from N mineralisation/immobilisation associated with loss or gain of soil organic matter resulting from change of land use of mineral soils. Total emissions from N mineralisation in 2022 were 23.7 kt CO_2 eq. This was a decrease of 7% compared to the year 1990, when the emissions were 25.6 kt CO_2 eq., and a decrease of 5% compared to 2021, when the emissions were 24.9 kt CO_2 eq. There was an increasing trend in the levels of these emissions from the mid-2000's until the peak year of 2016. After that the emissions have been decreasing slightly (Figure 6.10-2).

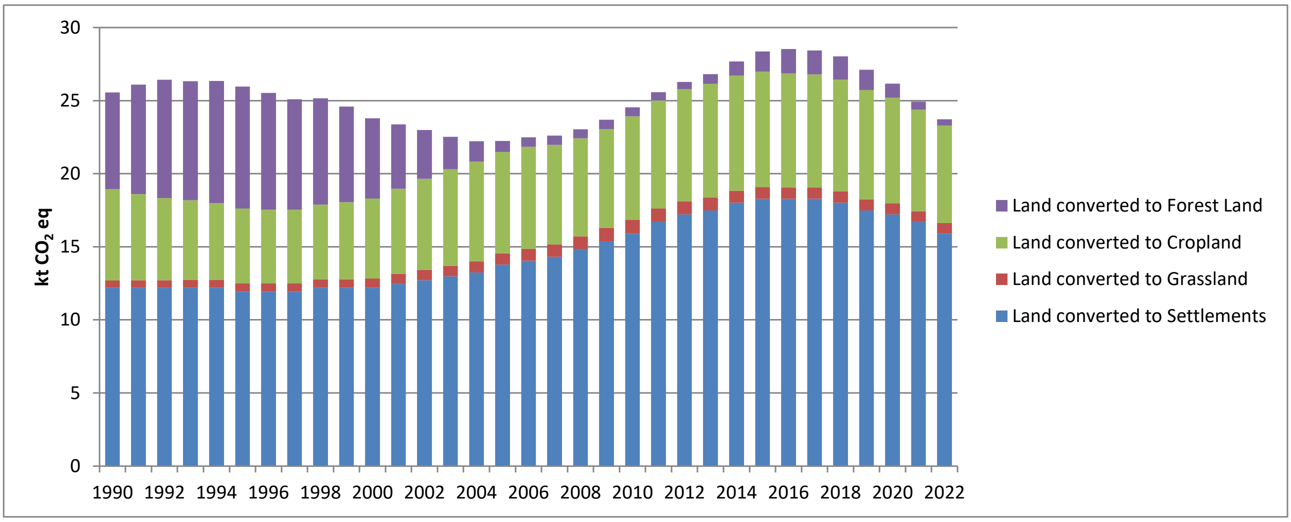


Figure 6.10-2 N_2O emissions from nitrogen mineralisation (kt CO_2 eq.)

6.10.3.2 Methodological issues

Methods

N_2O emissions were calculated applying Tier 1 methodology according to Equations 11.2 and 11.8 in the 2006 IPCC Guidelines, Vol. 4:

$N_2O_{SOM} – N = EF * F_{SOM}$

where
$N_2O_{SOM} – N$ = additional emissions arising from the land-use change, kg N_2O-N a^{-1}
EF = IPCC default EF, 0.01 kg N_2O-N/kg N
$N_{net\text{-}min}$ = N released annually by net soil organic matter mineralisation, kg N a^{-1}

$F_{SOM} = \Delta C * 1 / C{:}N$ ratio

where
ΔC = carbon loss from soil as a result of conversion, kg C a^{-1} (see Sections 6.5, 6.6 and 6.8)
C:N ratio = ratio of C to N in soil organic matter, kg C/kg N

Emission factors and other parameters

The IPCC default emission factor of 1% is used (2006 IPCC Guidelines). In the case of forest land converted into cropland, a national value for the C:N ratio was used. Based on published data for the C:N ratio of the humus layer (Hilli et al. 2008) and unpublished data for the C:N ratio of the 0-20 cm layer of the mineral soil (Karhu et al. 2011), a value of 21.4 was obtained. For other conversion types, a default C:N ratio of 15 was used.

Activity data

The area estimate was obtained as described in Section 6.3. The estimation of the carbon stock change in mineral soils due to land-use change is described in Sections 6.4.2, 6.5.2, 6.6.2 and 6.8.2.

6.10.3.3 Uncertainty assessment and time series' consistency

Quantitative estimates of uncertainty are provided in Annex 2. The annex also documents the assumptions made for the analysis. A description of the uncertainty analysis is included in Section 1.6.

The time series are consistent.

6.10.3.4 Category-specific QA/QC and verification

The quality objectives and the QA/QC and verification plan for the Finnish greenhouse gas inventory at the national inventory level are presented in Section 1.5. The QC procedures are performed according to the QA/QC plan in order to attain these quality objectives. A bilateral quality meeting or a quality desk review is held annually between the inventory unit and the sectoral expert.

An AFOLU steering group supervises the reporting of emissions and removals for the LULUCF sector. The members, working at Luke, have a broad expertise in using the measurements and methodology to estimate carbon stock changes and greenhouse gases. All changes in methods, activity data and emissions or other factors and parameters are discussed and approved by the steering group before they are introduced to the advisory board (see Section 1.2.1). The steering group meets two to four times per year.

The following programme tool has been implemented to support GHG inventory reporting: The CRFTool programme that automates and provides an error free transfer of the inventory results to the CRF Reporter.

6.10.3.5 Category-specific recalculations

The time series was recalculated as a result of updated area data (see Section 6.2) and recalculation of the carbon stock changes for land converted to forest land, cropland and grassland (see Sections 6.4.5, 6.5.5 and 6.6.5). An error found in the calculation of SOC stock change from settlement to cropland was corrected (see Section 6.5.5). The correction also had an impact on the direct N_2O emissions.

N_2O emissions from N mineralisation were 24.5 kt CO_2 eq. for the year 2021 and 25.5 for the year 1990 in the previous submission whereas they were 28.0 kt CO_2 eq. for the year 2021 and 28.7 kt CO2 eq. for the year 1990 in this submission.

6.10.3.6 Category-specific planned improvements

No improvements are planned at the moment.

6.10.4 N_2O emissions from N leaching and runoff (CRF 4 (IV))

6.10.4.1 Category description

N_2O emissions from N leaching related to land use conversions were calculated for all classes of mineral soils converted to cropland or grassland if they experienced C stock loss. The total amount of emissions reported in this category was 1.22 kt CO_2 eq. in 2022. The emissions have increased by 12% since 1990, when the emissions were 1.09 kt CO_2 eq., and decreased by 6% since 2021, when the emissions were 1.30 kt CO_2 eq.

6.10.4.2 Methodological issues

Methods

The N_2O emissions were calculated applying Tier 1 methodology for conversion to the grassland category and Tier 2 methodology for conversion to the cropland category according to Equation 11.10 of the 2006 IPCC Guidelines:

$N_2O_L - N = F_{SOM} * Frac_{LEACH} * EF$

where
$N_2O_L - N$ = emissions from leaching and runoff of mineralised N related to land-use change (kg N_2O-N a^{-1})
$F_{SOM} = \Delta C * 1 / C:N$ ratio (kg N a^{-1})
$Frac_{LEACH}$ = fraction of N lost through leaching
EF = emission factor for N_2O emissions per N lost through leaching (N_2O-N/kg N)

Emission factors and other parameters

The IPCC default fraction of leached N (0.3) and emission factor of 0.0075 N_2O-N/kg N are used for conversion to grassland categories (2006 IPCC Guidelines). For conversion to cropland categories the country-specific fraction of leached N of 0.144 and the emission factor of 0.011 N_2O-N/kg N (IPCC 2019 Refinement) are used corresponding to the ones used in the Agriculture sector.

Activity data

The area estimate was obtained as described in Section 6.3. The reduction of the C stock due to conversion was determined as described in Sections 6.5 and 6.6.

6.10.4.3 Uncertainty assessment and time series' consistency

Quantitative estimates of uncertainty are provided in Annex 2. The annex also documents the assumptions made for the analysis. A description of the uncertainty analysis is included in Section 1.6.

The time series are consistent.

6.10.4.4 Category-specific QA/QC and verification

The quality objectives and the QA/QC and verification plan for the Finnish greenhouse gas inventory at the national inventory level are presented in Section 1.5. The QC procedures are performed according to the QA/QC plan in order to attain these quality objectives. A bilateral quality meeting or a quality desk review is held annually between the inventory unit and the sectoral expert.

An AFOLU steering group supervises the reporting of emissions and removals for the LULUCF sector. The members, working at Luke, have a broad expertise in using the measurements and methodology to estimate carbon stock changes and greenhouse gases. All changes in methods, activity data and emissions or other factors and parameters are discussed and approved by the steering group before they are introduced to the advisory board (see Section 1.2.1). The steering group meets two to four times per year.

The following programme tool has been implemented to support GHG inventory reporting: The CRFTool programme that automates and provides an error free transfer of the inventory results to the CRF Reporter.

6.10.4.5 Category-specific recalculations

The time series was recalculated as a result of updated area data (see Section 6.2) and recalculation of the carbon stock changes for land converted to cropland and grassland (see Sections 6.5.5 and 6.6.5).

The fraction of leached N and the emission factor for N_2O emissions per N lost through leaching for conversion to cropland categories were updated to correspond to the ones used in the Agriculture sector.

An error found in the calculation of SOC stock change from settlement to cropland was corrected (see Section 6.5.5). The correction also had an impact on the N_2O emissions from N leaching and runoff.

6.10.4.6 Category-specific planned improvements

It is planned to include indirect N_2O emissions from nitrogen fertilisers applied to soils in forest land and settlements in the 2025 submission.

6.10.5 Biomass burning (CRF 4 (V))

6.10.5.1 Category description

This category includes greenhouse gas emissions (CO_2, CH_4, N_2O) and other air emissions (NO_x and CO) from wildfires on Forest Land, Cropland and Grassland and from controlled burnings on Forest land. Restoration burnings are reported under controlled burning in CRF 4(V). All wildfires on croplands and grasslands are reported under 4.C.1 Grassland Remaining Grassland because they are reported under one class in national fire statistics. The total emissions in 2022 were 0.30 kt CO_2 eq. from wildfires, 0.08 kt CO_2 eq. from restoration burnings, and 0.53 kt CO_2 eq. from controlled burnings, 0.92 kt CO_2 eq. in total **(**Figure 6.10-3). From this Grassland wildfires emitted only 0.03 kt CO_2 eq. The total emissions have decreased by 82% compared to 5.0 kt CO_2 eq. in 1990 and by 44% compared to 1.6 kt CO_2 eq. in 2021. Emissions depend on the AD, which varies highly between years due to high weather condition dependency of the controlled burning and wildfires and restoration burnings. However, there has a decreasing trend in controlled burning from 1990's to mid-2000's, which can be explained by applied forest management practices. In 2020, the controlled burning area was relatively large whereas in 2022 it was close to the average of the past ten years.

On Forest land, CO_2 emissions from wildfires and restoration burnings are included in CSCs in living biomass. For controlled burnings, to avoid double counting, CO_2 emissions from cutting residues are reported under carbon stock changes in dead organic matter (litter) and hence reported as IE under the Biomass burning (CRF 4(V)). Average approximated estimates of CO_2 emissions on forest land from controlled burning, restoration burning and wildfires are 9.2 kt, 0.4 kt and 5.0 kt, respectively.

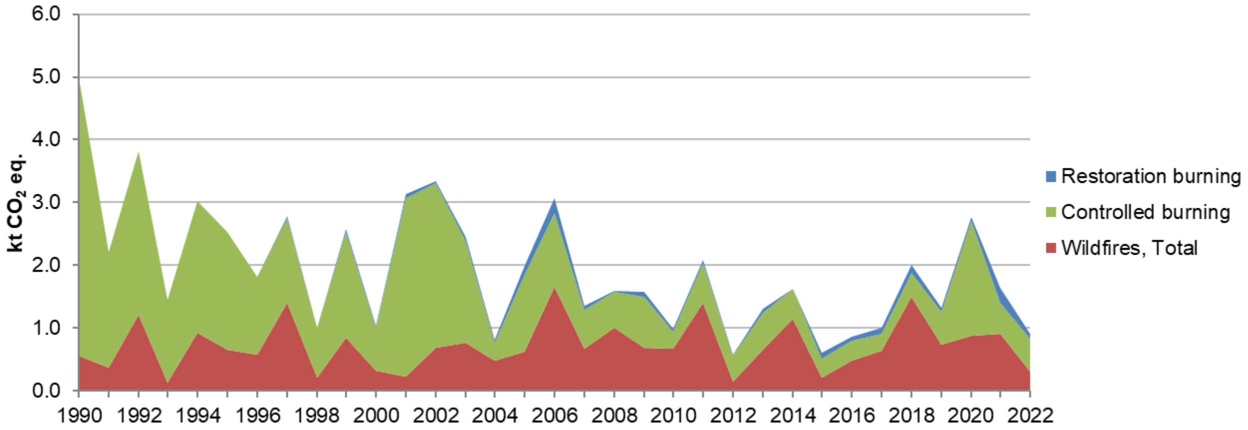


Figure 6.10-3 Emissions from biomass burning (kt CO_2 eq.)

6.10.5.2 Methodological issues

The default IPCC Tier 2 method was applied using national activity data and IPCC default emission factors. Equation 2.27 was used to estimate CO_2 and non-CO_2 emissions from biomass burning (2006 IPCC Guidelines).

On Forest Land default emission factors from the 2006 IPCC Guidelines (Table 2.5, p. 2.47) were applied, namely 1,569 for CO_2, 4.7 for CH_4, 0.26 for N_2O, 3.0 for NO_x and 107 for CO. These EFs were also applied for burning of woody biomass on Grassland wildfires. The corresponding emission factors for non-woody biomass burnt on Grassland were 2.3 for CH_4, 0.21 for N_2O, 3.9 for NOx, 65 for CO.

Restoration burnings are calculated in the same way as wildfires but reported under controlled burning in CRF 4(V).

Wildfires

The mean biomasses of the growing stock on forest land by tree species groups were estimated from the NFI8, NFI9, NFI10, NFI11 and NFI12 data (See the methods described in Section 6.2). On Land Converted to Forest Land the mean burning biomasses were calculated as the mean biomass of the growing stock in this category in the NFI11. Woody biomasses on Grassland wildfires were also calculated from the NFI11 data.

The biomass of the understorey was added to the total biomass on Forest land. The used biomass of the field layer was 782 kg ha^{-1} and the bottom layer was 1,534 kg ha^{-1} (Muukkonen et al. 2006). The estimated average total biomass per hectare of burned area has been approximately 60 tonnes. The combustion efficiency is based on expert judgement[22] and it was assumed that 7.5% (±2.5%) of the tree biomass, 20% (±10%) of the field layer biomass and 12.5% (±7.5%) of the bottom layer biomass would burn. Separate combustion efficiencies for afforested areas were not available and the combustion efficiencies of forest land were used. The IPCC default carbon fraction (50%) was used.

For clear-cut forests, emissions were estimated as those from controlled burnings i.e. prescribed burnings.

The applied non-woody aboveground biomass on grassland wildfires was 2.3 tonnes C ha^{-1}, which is derived from the same calculations as in Section 6.5.2.2 Land Converted to Cropland, when grassland is converted to cropland. The combustion efficiency for woody biomass was the same as in wildfires on forest land and for non-woody biomass 50% (EMEP/EEA 2016). CO_2 emissions are reported from burned woody biomass, whereas non-CO_2 emissions are reported on all burned grasslands.

Applying Equation 2.8 in IPCC Wetlands Supplement refined with expert judgements showed that the expected value for emissions from wildfires on Wetlands (4.D.1, 4.D.2) were 0.9 kt CO_2 eq. on average in 1996 to 2016 and can be considered insignificant and is reported as ‘NE’. For wildfires on Land Converted to Wetlands and Settlements there is no method available in the 2006 IPCC Guidelines.

Controlled burning

Controlled burning refers to post-logging burning of harvest residues (prescribed burning). It is assumed that prescribed burnings are carried out only on Forest Land and on mineral soils. The mean volume of the growing stock on these sites was estimated based on the NFI data for mature stands. The estimates were made separately for Southern and Northern Finland.

The volume of cutting residues was calculated by multiplying the mean volume by the dry crown mass. The used crown mass (kg) per mean volume (m^3) after the final cut of the mature stand was as follows (Hakkila 1991):

	Southern Finland	Northern Finland
Scots pine	82.1	107.4
Norway spruce	164.4	217.5

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[22] Ilkka Vanha-Majamaa (Finnish Forest Research Institute) and Timo Heikkilä (Ministry of the Interior), 2007

Broad-leaved trees	82.8	120.1

The used biomass for the bottom layer was 1,935 kg ha^{-1} and for the field layer it was 770 kg ha^{-1} (Muukkonen et al. 2006). It was assumed, according to expert judgement,[23] that 25% (±5%) of the tree biomass, 20% (±10%) of the field layer biomass and 12.5% (±7.5%) of the bottom layer biomass would burn. The IPCC default carbon fraction (50%), emission ratios and N/C ratio were used.

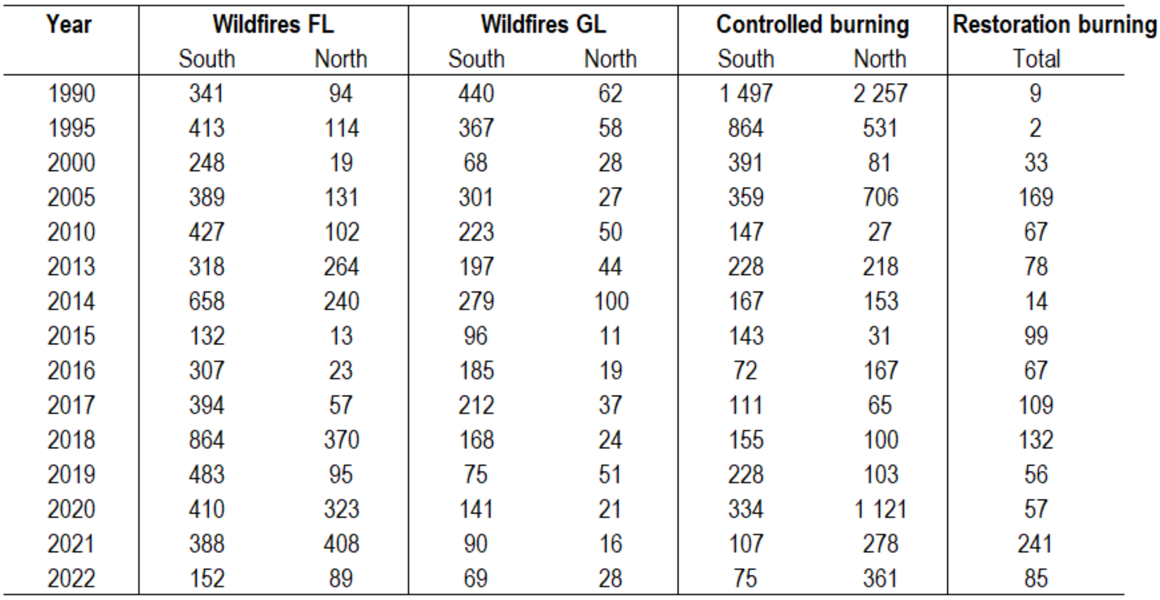
Activity data

The activity data of the burned area are presented in Table 6.10-6. The information source for the area of wildfires is the Ministry of the Interior that provided the database of individual land fires to be used in the estimation. In that database, the forest area has been divided into clear-cut areas and into stocked forests. Grasslands are grouped in the database with croplands and reeds, which all together form one non-separable group. Wildfire statistics are not collected in Åland, there the emissions are estimated on the basis of fire occurrences in the neighbouring municipalities Kemiönsaari, Parainen, Naantali and Kustavi and in relation to forest areas. Wildfire statistics prior to 1996 were less detailed and included only forest fires for Southern and Northern Finland. Therefore, in Åland an average area of fires on Forest land in 1996 to 1999 was applied for 1990 to 1995. Åland's wildfire area on Forest land is very small, on average 5 ha in 1990 to 2022. All wildfire areas on Grassland are extrapolated estimates in 1990 to 1995 including Åland.

The area of prescribed burnings comes from the information compiled by the forestry organisations and companies that carry out prescribed burnings. The statistics are compiled by the Finnish Forest Research Institute until 2014 and Luke from 2015 onwards. Activity data for restoration burnings come from Metsähallitus (state-owned enterprise). The statistics of restoration burnings were compiled by Luke until 2021 (Luke 2023a) and before 2007 by Biodiversity.fi, which was financed by the Ministry of Environment. Since 2022 the information on areas of restoration burnings is requested directly from Metsähallitus.

The areas of wildfires on Forest Land Remaining Forest Land and Land Converted to Forest Land are not directly available from the activity data. However, NFI data and the database of individual fires showed that in 2009 wildfires also occurred on Land Converted to Forest Land. Hence the areas burned in wildfires were calculated using the proportion of remaining and converted forest land areas out of the total forest area and allocating the total wildfire areas accordingly. The area burned on Land Converted to Forest Land was 4 ha in 2009.

Table 6.10-6 Burned area, ha



Year	Wildfires FL		Wildfires GL		Controlled burning		Restoration burning
	South	North	South	North	South	North	Total
1990	341	94	440	62	1 497	2 257	9
1995	413	114	367	58	864	531	2
2000	248	19	68	28	391	81	33
2005	389	131	301	27	359	706	169
2010	427	102	223	50	147	27	67
2013	318	264	197	44	228	218	78
2014	658	240	279	100	167	153	14
2015	132	13	96	11	143	31	99
2016	307	23	185	19	72	167	67
2017	394	57	212	37	111	65	109
2018	864	370	168	24	155	100	132
2019	483	95	75	51	228	103	56
2020	410	323	141	21	334	1 121	57
2021	388	408	90	16	107	278	241
2022	152	89	69	28	75	361	85

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[23] Ilkka Vanha-Majamaa (Finnish Forest Research Institute) and Timo Heikkilä (Ministry of the Interior), 2007

6.10.5.3 Uncertainty assessment and time series' consistency

Quantitative estimates of uncertainty are provided in Annex 2. The annex also documents the assumptions made for the analysis. A description of the uncertainty analysis is included in Section 1.6.

Based on expert judgement, uncertainty in the activity data (area) for biomass burning is estimated at ±10%. Uncertainty concerning combustion efficiencies is 10%. The uncertainties in emission factors are based on the 2006 IPCC guidelines (Vol. 4, Table 2.5). The total annual uncertainty of emission factors was calculated related to the emissions in each category based on the 2006 IPCC guidelines (Vol. 1, Ch. 3, Eq. 3.2). The uncertainty of EFs for the year 1990 and 2022 were estimated to be 55% and 54%, respectively. The uncertainties are twice the relative standard errors.

The Ministry of the Interior compiles the area statistics on wildfires and they are based on information provided by rescue authorities. The time series of the activity data are consistent.

6.10.5.4 Category-specific QA/QC and verification

The quality objectives and the QA/QC and verification plan for the Finnish greenhouse gas inventory at the national inventory level are presented in Section 1.5. The QC procedures are performed according to the QA/QC plan in order to attain these quality objectives. A bilateral quality meeting or a quality desk review is held annually between the inventory unit and the sectoral expert.

An AFOLU steering group supervises the reporting of emissions and removals for the LULUCF sector. The members, working at Luke, have a broad expertise in using the measurements and methodology to estimate carbon stock changes and greenhouse gases. All changes in methods, activity data and emissions or other factors and parameters are discussed and approved by the steering group before they are introduced to the advisory board (see Section 1.2.1). The steering group meets two to four times per year.

The general quality control procedures specified in the 2006 IPCC Guidelines were followed. The possibility of emission/removal estimates overlapping with other sources has been checked. Land areas with wildfires and controlled burning were reviewed using the latest statistics (Finnish Statistical Yearbook of Forestry 2014, Luke 2023a). It was confirmed that all of the data used in this section cover the whole land area of Finland.

The following programme tool has been implemented to support GHG inventory reporting: The CRFTool programme that automates and provides an error free transfer of the inventory results to the CRF Reporter.

6.10.5.5 Category-specific recalculations

The recalculations were made due to corrections of the AD data classifications under Grassland remaining Grassland in 2018–2021. The share of wildfires on converted and remaining forest lands was recalculated. The results were rounded to 6 decimals.

6.10.5.6 Category-specific planned improvements

No planned improvements.

6.11 Harvested Wood Products (CRF 4.G)

6.11.1 Category description

The Harvested Wood Products (HWP) pool was a net sink of 3.3 Mt CO_2 in 2022. Compared to the year 2021 (net sink of 3.7 Mt CO_2) the sink decreased by 13% and compared to 1990 (net sink of 3.0 Mt CO_2), the sink increased by 10%. HWP has been a net sink for the whole reported time series except for the year 2009. The annual fluctuations in the time series are due to changes in the economic situation and demand of wood products (see Section 2.2.4). In 2009, the global economic recession reduced the demand for forest industry products and the roundwood markets were the slowest in 25 years (Finnish Statistical Yearbook of Forestry 2010). The most important component of the HWP sink has been sawn wood. The sink of sawn wood was at its lowest level in 2009 being 0.8 Mt CO_2 and its highest in 2000 at 5.1 Mt CO_2. Wood panels have been a small sink or source from 1990 to 2022, varying between a source of 0.1 Mt CO_2 and a sink of 0.6 Mt CO_2. Paper and paperboard have also acted both as a sink and as a source. The paper and paperboard category is sensitive to the changes in production, since the lifetime of paper is much shorter than that of sawn wood and wood panels (Figure 6.11-1).

The year 2020 was challenging for the forest industry because of decreased demand due to the pandemic and strikes related to industrial actions on sawmills and plywood factories. In addition one paper mill and two paper machines were closed which cut down the paper production. The sink was at its lowest level since 2009, being only 1.3 Mt CO_2. The production of sawn wood and chemical pulp increased again in 2021 causing the sink to return to the 2019 level. In 2022, the production of all wood product categories decreased compared to the previous year due to the weak economic situation, a large strike at the beginning of the year, and the closing of one paper mill (The Finnish Forest Industries 2023). However, due to imports from Russia ceasing and prices of imported wood increasing, the share of domestic wood in the production increased.

HWP is a key category based on level assessment using Approach 1 and Approach 2.

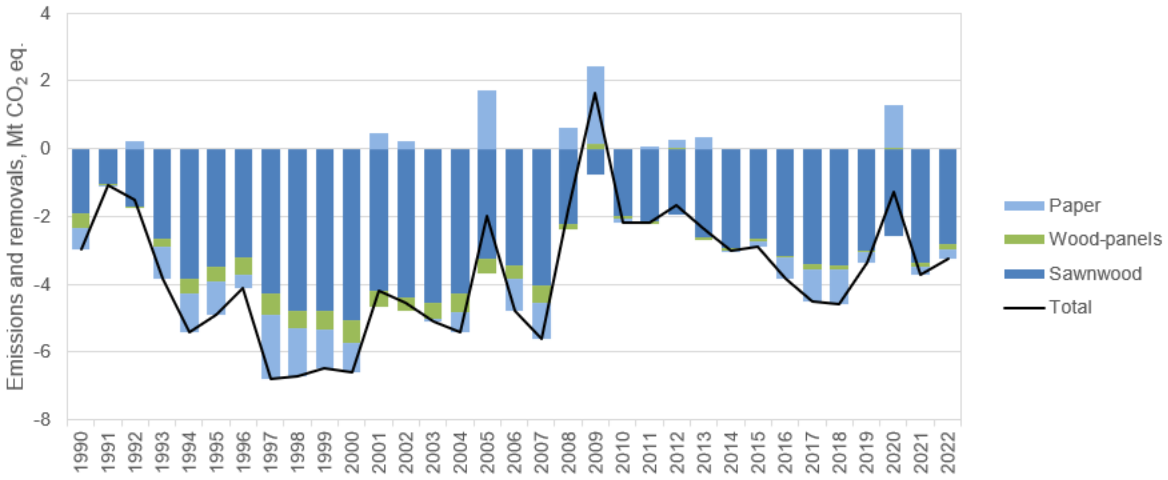

Figure 6.11-1 Emissions and removals from the HWP categories sawn wood, wood panels and paper products

HWP is reported as a carbon stock change in production-based HWP stocks originating from wood harvested in Finland and divided to two categories: 1) HWP produced and consumed domestically and 2) HWP produced domestically and exported. HWP comprise of solid wood products (sawn wood and wood panels) and paper products (wood pulp). A more detailed, country-specific classification of wood products was used (Table 6.11-2). The production quantity of pulp was used as a proxy for paper and paperboard production. In Finland, more than 98% of wood pulp is used for paper and paperboard production, and less than 2% (dissolving wood pulp) for textile and hygiene products, which are exported (percentages are for 2020 to 2022)[24]. Wood pulp

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[24] FAOSTAT: http://fao.org/faostaten/#home

production for other purposes than paper and paperboard has started mainly in 2012. The annual change of HWP in domestic solid waste disposal sites in (SWDS) is not reported as it is only an information item.

6.11.2 Methodological issues

6.11.2.1 Methods

The Production Approach is used to estimate the carbon stock change in HWP (2006 IPCC Guidelines, Vol. 4, Annex 12.A.1). This approach was selected to keep the Convention reporting comparable with the KP reporting. The approach and the reporting scheme encompass domestically produced HWP originating from domestic harvest separately for domestically consumed and exported using as detailed country-specific classification for HWP categories as possible (Hamberg et al. 2016).

To estimate the HWP contribution, the variables 2A HWP in use, and 2B HWP in SWDS, for which the wood originated from domestic harvest, were needed (2006 IPCC Guidelines, Vol. 4, Table 12.1).

$$\Delta C_{HWP_{DC}} = \Delta C_{HWP\ IU_{DC}} + \Delta C_{HWP\ SWDS_{DC}}$$

Since the carbon stock change in SWDS is not estimated, the variable 2B ($\Delta C_{HWP\ SWDS_{DC}}$) was set to zero, and only the variable 2A ($\Delta C_{HWP\ IU_{DC}}$) was estimated. The method to estimate the annual carbon stock change of variable 2A is a Tier 2 method. The annual change in carbon stock in the HWP pool was estimated using a flux-data method with default half-lives and country-specific activity data and country-specific carbon conversion factors for different products. The decay of HWP is estimated employing the first order decay (FOD) function (2006 IPCC Guidelines, Vol. 4, Equation 12.1).

Activity data

Carbon stock changes were estimated starting from 1900 when the initial stock was assumed to be zero. Country-specific data for sawn wood, wood panels and pulp (production and exports) since year 1961 were downloaded from the FAOSTAT database since the data were easily accessible (FAO 2023). Activity data downloaded from the FAOSTAT database were compared with national statistics where applicable. Luke compiled national statistics on production until 2021, after which production data published by the Finnish Forest Industries were used for the comparison. Production data of mechanical and semi-chemical, and chemical wood pulp for the years 2012 to 2020[25] and chemical wood pulp for the year 2022[26] were taken from the national statistics since the data in FAOSTAT database differed from national data. Data for the years 1900 to 1960 were collected from national statistics (Finnish Statistical Yearbook of Forestry 1971, Forest Statistics 1902-1961, Kuisma 1993, Kunnas 1973, Osara et al. 1948, Statistical Yearbook of Finland 1900-2014, Wallden 1980). Since 1955 onwards statistics concerning sawn wood include both industrially and domestically produced sawn wood but before that only sawn wood produced industrially. Therefore, data before 1955 were complemented with domestically produced sawn wood (Osara et al. 1948, Pöntynen 1962, Saari 1934). HWP data for the years 1900 to 1943 were corrected to correspond to the present borders of Finland based on the change in growing stock volume estimated from the NFI data.

Subcategories for wood-based panels, i.e., veneer sheets, plywood, and particle and fibre board were used. Fibre board was further divided into the subcategories HDF, MDF and LDF (high, medium and low-density fibre board). Wood pulp used to estimate paper and paper board quantities was divided into the subcategories mechanical, semi-chemical and chemical wood pulp. Sawn wood and veneer sheets were divided further into subcategories according to tree species (spruce, pine and birch) as well as plywood (spruce, birch) was. The shares of different tree species (Norway spruce, Scots pine, silver and downy birch) for sawn wood, veneer sheet and plywood production were calculated from national statistics in Finland (Finnish Statistical Yearbook of Forestry 1971, 2001, 2014, Luke 2023a, Osara et al. 1948, Pöntynen 1962, Statistical Yearbook of Finland

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[25] Luke: https://www.luke.fi/en/statistics

[26] The Finnish Forest Industries: https://www.metsateollisuus.fi/en/home

1900-2014). Tree species subdivisions were not used for particle and fibre board because these products have target densities of wood material regardless of tree species used.

Data concerning the proportion of domestic roundwood in sawn wood, wood-based panel and wood pulp production were gathered from different statistics (Finnish Statistical Yearbook of Forestry 1971, 2001, 2014, Luke 2023a, Osara et al. 1948, Pöntynen 1962, Statistical Yearbook of Finland 1900-2014). As exact data concerning the share of domestic wood residues in wood-based panel and wood pulp production were not available, the proportion of domestic roundwood used for sawn wood, and plywood and veneer sheet production was used to estimate it, since wood residues originate from the sawn wood, plywood and veneer sheet production (see Finnish Statistical Yearbook of Forestry 2014, *p*. 24).

Calculations were done separately for each HWP category in domestic use and exported. The domestic use was calculated as follows:

$$WP_{DPDC}(i) = WP_{DP}(i) - WP_{DPEX}(i)$$

where $WP_{DPDC}(i)$ is the domestic consumption of the HWP category WP produced domestically from domestic wood in year i (m^3 y^{-1}), $WP_{DP}(i)$ is the production of the HWP category WP produced domestically from domestic wood in year i (m^3 y^{-1}) and $WP_{DPEX}(i)$ is the export of the HWP category WP produced domestically from domestic wood in year i (m^3 y^{-1}). Changes in carbon stock changes in paper and paperboard were estimated using wood pulp. Here, the exported amount of wood pulp out of the total wood pulp production was calculated using the proportion of exported paper and paperboard out of the total production of paper and paper board.

Emission factors and other parameters

The production of different HWP categories was converted to carbon using carbon conversion factors based on density values (oven dry mass per air dry volume). These country-specific conversion factors are marked as ‘IE’ in the CRF tables and presented only in the NID (Table 6.11-2). Country-specific density values, $r_{0,u}$ (kg m^{-3}), for Finnish tree species used to produce sawn wood and veneer sheets were calculated from dry-matter mass over fresh wood volume based on Kärkkäinen (2007, *p*. 140, modified from the formula 8.13) (Table 6.11-1).

$$r_{0,u} = m_0/V_u = 100Ru_f/\left(100u_f - b_v\left(u_f - u\right)\right)$$

where m_0 is oven dry mass (kg), V_u is air dry volume when moisture content is 12% (m^3), R is dry-matter mass per unit volume of fresh wood (kg m^{-3}), u_f is fibre saturation point (%), i.e., point when the volume of wood does not increase anymore although moisture ratio increases, b_v is shrinkage of wood volume from fresh to dry (%) ($b_v = u_f d_r = u_f(R/1000)$, where d_r is relative dry matter mass per unit volume of fresh wood (kg m^{-3}) / 1000 (kg m^{-3}) (see Kärkkäinen, 2007, *p*. 193, formula 9.15), u is air dry moisture ratio, 12% (see Kärkkäinen, 2007, *p*. 139, formula 8.2). Dry-matter masses per unit volume of fresh wood per tree species were provided by Hakkila (1979) and fibre saturation point values by Koponen (1985) (Table 6.11-1).

Table 6.11-1 Dry-matter mass per unit volume of fresh wood (kg m^{-3}) and fibre saturation point (%) values for Scots pine (*Pinus sylvestris*), Norway spruce (*Picea abies*) and silver and downy birch (*Betula pendula* and *B. pubescens*)

Tree species	Density (kg m^{-3}) (dry-matter mass per unit volume of fresh wood)[a]	Fibre saturation point (%)[b]
Scots pine (*Pinus sylvestris*)	403	28.1
Norway spruce (*Picea abies*)	380	29.3
Birch (*Betula pendula* and *B. pubescens*)	483	30.6

[a] Hakkila (1979). Determined from wood without bark.

[b] Koponen (1985)

The carbon fraction of 0.5 for sawnwood and veneer sheets was employed similarly to the biomass estimation when calculating changes of the standing stock of living biomass. Conversion factors were calculated by multiplying density values by carbon fraction values (Table 6.11-2). Conversion factors for other products were derived from respective Environmental Product Declarations (standardized document about environmental impact of products) and information collected from producers. However, default values of IPCC (2006 IPCC Guidelines, IPCC KP Supplement) were used for fibre board compressed, medium-density fibreboard, and wood pulp.

Table 6.11-2 Factors for converting volume units to carbon (based on Hamberg et al. 2016)

HWP categories	Density (Mg m^{-3}) (oven dry mass per air dry volume)	Carbon fraction	C conversion factor (Mg C m^{-3}) (per air dry volume)
Sawnwood and other industrial roundwood			
• Scots pine[a]	0.431	0.5	0.216
• Norway spruce[a]	0.407	0.5	0.204
• Silver an downy birch[a]	0.531	0.5	0.266
Wood-based panels			
Veneer sheets			
• Scots pine[a]	0.431	0.5	0.216
• Norway spruce[a]	0.407	0.5	0.204
• Silver and downy birch[a]	0.531	0.5	0.266
Plywood			
• Silver and downy birch[b]	0.66	0.489	0.323
• Norway spruce[b]	0.45	0.493	0.222
Particle board[c]	0.7	0.45	0.315
Fibre board			
• Fibre board, compressed[d]	0.925	0.491	0.454
• Hard board (HDF)[e]	0.94	0.495	0.465
• Medium-density fibre board (MDF)[f]	0.691	0.427	0.295
• Insulating board (LDF)[b]	0.3	0.495	0.149
	(Mg Mg^{-1}) (oven dry mass per air dry mass)		Mg C Mg^{-1} (per air dry mass)
Wood pulp[g]	0.9	0.5	0.45

[a] Based on formulas of Kärkkäinen (2007). Dry-matter weight per unit volume of green wood was provided by Hakkila (1979), saturation point values by Koponen (1985), and moisture ratio by Kärkkäinen (2007).

[b] Environmental Product Declarations for density values of Finnish products. They are based on ISO 14020 and ISO 14040 standards, and a draft ISO CD 21930. Carbon fractions for plywood are based on Environmental Product Declarations provided by MetsäWood

(2014a, 2014b) and that of insulating board by Puuinfo Ltd. http://www.woodproducts.fi/content/wood-fibre-board (read 26 November 2015).

[c] Koskisen Panel Products Industry for density and carbon fraction (the only producer of particle boards in Finland). https://www.koskisen.com/file/koskipan/?download&version=EN (see KoskiPan (pdf), EN (English), read 25 November 2015). This is based on certificates EN ISO 9001, EN ISO 14001, OHSAS 18001, PEFC ST 2002:2010 and PEFC 2001:2008. See also information provided by Puuinfo Ltd. http://www.woodproducts.fi/content/particle-board (read 26 November 2015).

[d] The conversion factor for fibreboard compressed is calculated from 94% of HDF and 6% of MDF corresponding to the production of HDF and MDF in the years 1995 to 2000 when both consumables were produced in Finland.

[e] Finnish Fibreboard Ltd for density (the only producer of fibre boards in Finland). http://www.kuitulevy.fi/en/buildingboards/lionstandard (see Technical properties). Read 28 August 2015. This is based on EN 622-2. The carbon fraction is based on information provided by Puuinfo Ltd. http://www.woodproducts.fi/content/wood-fibre-board (read 26 November 2015).

[f] Default values provided by IPCC KP Supplement (*p*. 2.122) for density and carbon fraction have been used here. MDF was produced in Finland only in 1995 to 2000.

[g] Wood pulp, excluding dissolving wood pulp, is used to estimate the carbon balance of paper and paper board products because they are used for paper and paperboard production. Default values provided by 2006 IPCC Guidelines (*p*. 12.19) have been used here.

Default half-lives for HWP categories are used. The half-life for sawn wood is 35 years, for wood-based panels 25 years, and for paper and paperboard 2 years (IPCC KP supplement). Country-specific half-lives can be used only for the HWP consumed domestically, and since most of the production has been exported from Finland, country-specific half-life values were not considered. In 2022, 76% of sawn wood, 80% of wood-based panels and 89% of paper and paper board were exported (FAO 2023).

6.11.3 Uncertainty assessment and time series' consistency

Quantitative estimates of uncertainty are provided in Annex 2. The annex also documents assumptions made for the analysis. A description of the uncertainty analysis is included in Section 1.6.

The uncertainties were estimated separately for different products based on 2006 IPCC Guidelines and expert judgement. The total annual uncertainty was calculated related to the carbon stock change in each product category. The uncertainty for the year 2021 was estimated to be 49% (Table 6.11-3).

Table 6.11-3 Uncertainty estimation of the HWP pool

		1990	2022
Sawnwood	Activity data	0.05	0.05
	Share of domestic wood use of the production	0.05	0.05
	Wood density & carbon content	0.15	0.15
	Half-lives	0.5	0.5
	Total	**0.53**	**0.53**
Wood-panels	Activity data	0.05	0.05
	Share of domestic wood use of the production	0.05	0.05
	Wood density & carbon content	0.15	0.15
	Half-lives	0.5	0.5
	Total	**0.53**	**0.53**
Paper & paperboard	Activity data	0.05	0.05
	Share of domestic wood use of the production	0.05	0.05
	Wood density & carbon content	0.1	0.1
	Half-lives	0.5	0.5
	Total	**0.51**	**0.51**
Total		**0.36**	**0.46**

There are no known inconsistencies in the time series. The activity data is based on national data and the applied FAOSTAT data are in agreement with national data, and if differences occur, national data is applied. The borders of Finland have changed during the time series, but the data for the years 1900 to 1943 was corrected to correspond to the present borders.

6.11.4 Category-specific QA/QC and verification

The quality objectives and the QA/QC and verification plan for the Finnish greenhouse gas inventory at the national inventory level are presented in Section 1.5. The QC procedures are performed according to the QA/QC plan in order to attain these quality objectives. A bilateral quality meeting or a quality desk review is held annually between the inventory unit and the sectoral expert.

An AFOLU steering group supervises the reporting of emissions and removals for the LULUCF sector. The members, working at Luke, have a broad expertise in using the measurements and methodology to estimate carbon stock changes and greenhouse gases. All changes in methods, activity data and emissions or other factors and parameters are discussed and approved by the steering group before they are introduced to the advisory board (see Section 1.2.1). The steering group meets two to four times per year.

The following programme tool has been implemented to support GHG inventory reporting: The CRFTool programme that automates and provides an error free transfer of the inventory results to the CRF Reporter

Activity data downloaded from the FAOSTAT database were compared with national statistics compiled by Luke between submissions 2013 and 2021. The downloaded data mostly corresponded to national data. The computation was done with R. Since 2022, Luke no longer publishes national statistics on production and national production data published by the Finnish Forest Industries are used for the comparison.

6.11.5 Category-specific recalculations

Small recalculations of the carbon stock change for the years 2019 to 2021 were made due to updated FAOSTAT activity data. A minor error concerning the production of chemical wood pulp for the year 2012 was discovered and corrected, resulting in recalculations of the time series of paper and paperboard from 2012 onwards. Recalculations for the years 1990 and 2021 are described in Table 6.11-4.

Table 6.11-4 The difference in emissions due to recalculations in the HWP pool between the 2023 and 2024 submissions

	Carbon stock change, kt CO_2	
	1990	**2021**
Submission 2023	-2 952	-3 646
Submission 2024	-2 952	-3 719
Difference 2024-2023	0	-72

6.11.6 Category-specific planned improvements

No planned improvements.

Appendix_6a

National forest inventory

The National Forest Inventory (NFI) is a sampling-based forest inventory system. The sampling design has been fitted to the variability of land use classes and the variation in the structure of the growing stock in different parts of Finland. The 13th inventory was launched in 2019, and the field measurements were completed in 2023. Table 1_App_6a lists the NFI data and the field measurement years of each inventory used to estimate areas and/or carbon stock changes for the greenhouse gas inventory.

Table 1_App_6a. The areas of national land classes in the whole country in the 6th to 13th National Forest Inventories. The total land areas correspond to the official land area provided by the National Land Survey of Finland at the time period of each inventory

Inventory	**Field measurement years**	Forest land	Poorly productive forest land	Unproductive forest land	Other forestry land	Forestry land	Other land	Land total
		1 000 ha						
NFI6	1971-1976	19 738	3 583	3 371	86	26 778	3 772	30 550
NFI7	1977-1984	20 065	3 157	3 049	103	26 374	4 096	30 470
NFI8	1986-1994	20 074	2 983	3 093	151	26 301	4 159	30 460
NFI9	1996-2003	20 338	2 670	3 156	154	26 317	4 130	30 447
NFI10	2004-2008	20 085	2 735	3 259	184	26 263	4 151	30 415
NFI11	2009-2013	20 264	2 502	3 229	198	26 192	4 197	30 389
NFI12	2014-2018	20 276	2 536	3 224	210	26 246	4 144	30 391
NFI13*	2019-2022	20 287	2 584	3 128	229	26 229	4 168	30 396

* NFI13 currently contains data only for four years

The NFI is a systematic cluster sampling. The distance between clusters, the shape of a cluster, the number of field plots in a cluster, and the distance between the plots within a cluster vary in different parts of the country according to the spatial variation of the forests and the density of the road network. Finland has been divided into six sampling regions since the 9th inventory (Figure 1_App_6a, Figure 3_App_6a).

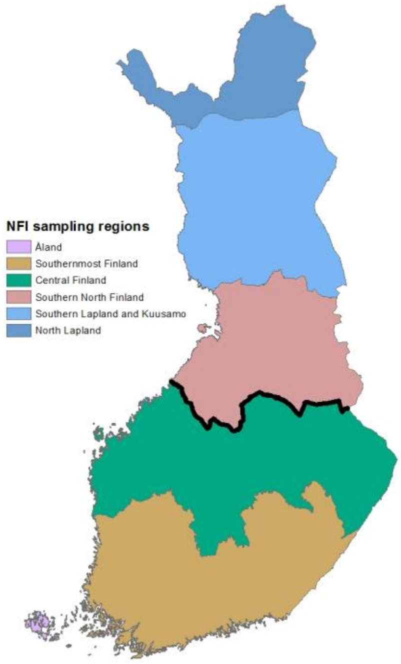
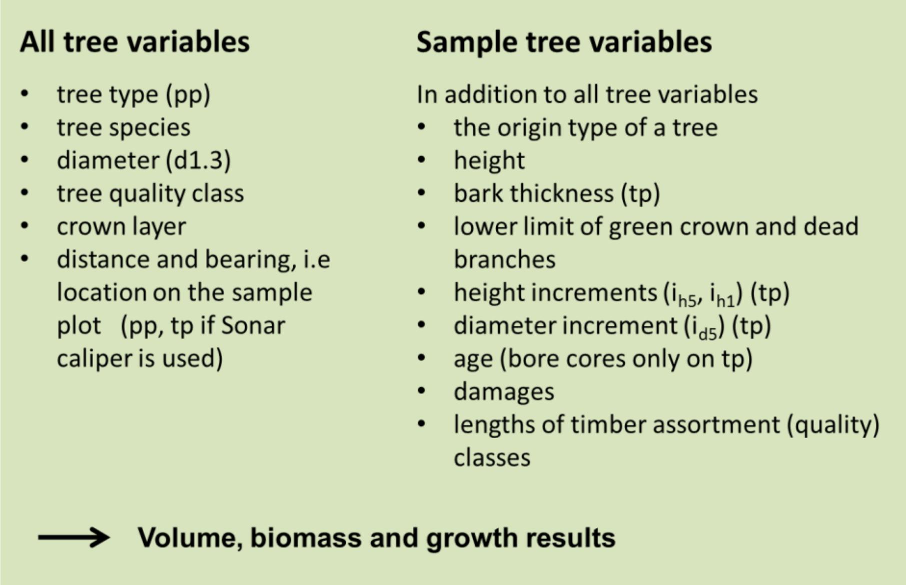


Figure 1_App_6a. NFI10 sampling regions and the boundary of Southern and Northern Finland

On the sample plots, tree- and stand-level information is assessed and measured. Stand-level variables describe, for example, the forest site type, the growing stock, the health of the forest and previous and proposed cuttings. The most important site description variables for the GHG inventory are the land use class, for which both national and FAO definitions are applied, and the fertility class and soil type, which separate the mineral soils from the organic soils. In addition, the conversions between land use classes are assessed for the past 20 years or since 1990, the conversion year is also assessed by observing the plot surroundings in the field.

All trees that will be measured on the sample plots are selected using an angle gauge (relascope). However, since NFI12 trees with a diameter larger or equal to 45 mm are measured from fixed radius plots. All measured trees, so called tally trees, should be at least 1.3 m tall with a minimum diameter of zero cm at a height of 1.3 metres. The measured variables are the tree species, the diameter at breast height, the quality class and the crown story class (Figure 2_App_6a). More variables are measured for sample trees which are selected among tally trees. These additional variables are e.g., the height, the diameter at six metres (until NFI11), the thickness of the bark and the annual increment for the diameter and height over the course of five years. These variables are applied in volume and biomass estimations together with the stand variables. Since NFI12 the diameter at six metres is based on models. Part of the sample tree variables are measured only on temporary plots (Figure 2_App_6a).



All tree variables

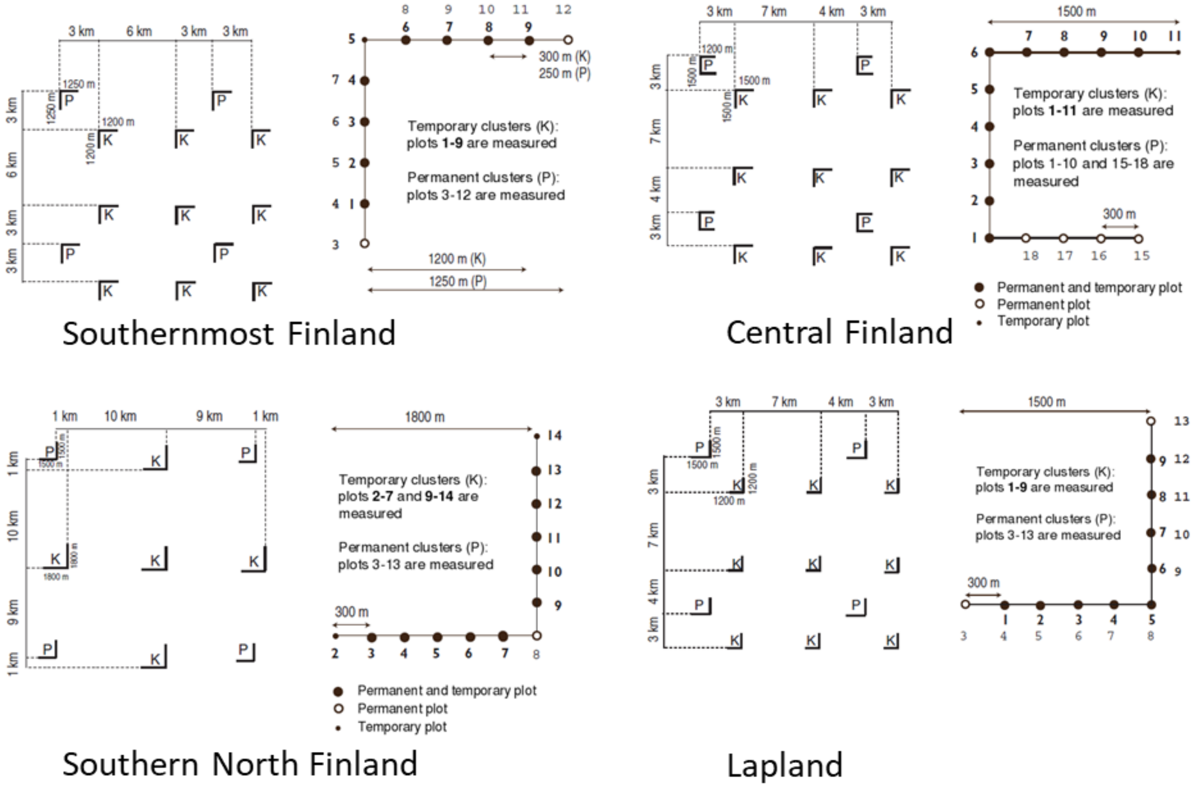
- tree type (pp)
- tree species
- diameter (d1.3)
- tree quality class
- crown layer
- distance and bearing, i.e location on the sample plot (pp, tp if Sonar caliper is used)

Sample tree variables

In addition to all tree variables
- the origin type of a tree
- height
- bark thickness (tp)
- lower limit of green crown and dead branches
- height increments (i_{h5}, i_{h1}) (tp)
- diameter increment (i_{d5}) (tp)
- age (bore cores only on tp)
- damages
- lengths of timber assortment (quality) classes

→ **Volume, biomass and growth results**

Figure 2_App_6a. NFI tree measurements, temporary (tp) and permanent sample plots (pp). Variables are measured for both types of plots if not otherwise indicated.



Southernmost Finland

Central Finland

Southern North Finland

Lapland

Figure 3_App_6a. Sampling design regions in NFI11

The main task of the NFI is to produce forest resource information, such as Forest land area, volume of the growing stock and the annual increment of the growing stock. Based on the field data, reliable forest statistics are calculated for the whole country and for large areas of over 200,000 hectares.

The area estimation is based on the total land area of the calculation region and on the number of centre points of sample plots falling in the stratum of interest (Tomppo et al. 2011). The official land area applied is produced by the National Land Survey of Finland. The area estimate of a land stratum is the number of plot centres in the stratum divided by the total number of plot centres on land and multiplied by the total land area:

$$A_S = \frac{N_S}{N} A, \tag{1}$$

where A_S is the area estimate of stratum s, N_S is the number of centre points in the stratum, N is the number of centre points on land, and A is the land area of the calculation unit (e.g. as the regions in Figure 1_App_6a). The same method is applied for area estimates of inland waters.

More information about the Finnish NFI is available on the following website:
https://www.luke.fi/fi/seurannat/valtakunnan-metsien-inventointi-vmi

Appendix_6b

Estimation of land-use changes

Areas of land use and land-use changes are calculated from NFI data. An inventory cycle takes five years in the NFI, and one-fifth of the plots are measured annually throughout the country. There are less than five years of NFI data for the latest years, therefore, land use information of NFI plots was updated by means of remote sensing data and other spatial data.

Land-use changes and the year of transition are assessed in the NFI. The data were applied for the years preceding the field measurements, for example NFI data measured in 2005–2009 were applied for computing areas of land-use changes from 1990 to 2004. Areas of land-use changes for 2016 to 2022 are based on NFI data and updating of the data with remote sensing and other spatial data. The areas of the latest seven years of the previous submission are always recalculated due to the new NFI data and updating.

The areas were computed as follows:

- Areas of land-use categories for the base year, 2002
- Annual areas of land-use changes for the years 1990 to 2022
- Areas of land-use categories for the other years, 1990 to 2001 and 2003 to 2022.

Annual areas of land-use changes

The moving average method was applied to provide annual estimates of land-use changes for the years 1990 to 2021. The method was used to decrease the sampling error caused by a small number of those sample plots where land-use change has occurred in one specific year.

In the calculation procedure areas of land-use changes were calculated for each year 1990 to 2021 at first. These are called “raw estimates”, calculated directly from the NFI or the updated NFI. The five-year moving average method was applied for “raw estimates” and areas of land-use change in each year were divided by five and spread across five adjacent years, e.g. change areas in 1999 are divided equally for 1997 to 2001. Modifications were needed for the years 1990 to 1991 in order to avoid including changes that took place before 1990 and for 2020 to 2022 because the latest available raw estimate was for the year 2021. The raw estimates for 2022 land-use changes were not used because there was a lack of high resolution up-to-date spatial data.

The computation of raw estimates and moving averages is presented in more detail below.

Raw estimates for land-use changes

The raw estimates, x_t, for the areas of a specific type of land-use change in years *t* = 1990, 1991, . . . , 2009 were computed, separately for Southern Finland and Northern Finland, from the NFI sample plots according to the equation:

$$x_t = \sum_{i \in c_t} a_i,$$

where set c_t contains those plots of Southern Finland and Northern Finland, where the given type of change has been recorded for year *t*, and a_i is the area represented by the sample plot *i*, i.e., the land area of the sampling density region to which the plot i belongs divided by the number of plots on land within that region. Raw estimates for the years 1990 to 2004 were computed from NFI data measured in 2005 to 2009. Estimates for 2005 and onwards were reported by replacing older NFI data with new ones, i.e., 2006 to 2010 measurements were utilised for x_t, t = 2005 and for example 2012 to 2016 measurements were employed when calculating raw estimates of land-use changes in 2011 (x_t, t = 2011). Land use information of NFI data measured in 2018 to 2022 was updated with remote sensing and other spatial data. Raw estimates for land-use changes in 2018 to 2022 are derived from this dataset.

NFI data measured in and after 2010 were not used for the earlier years' changes a) because five year's data were considered sufficient and b) in order to avoid the need to recalculate the whole time series.

Moving averages

The final estimates for land-use changes, y_t for years t = 1992, 1993, . . . , 2019 were computed as simple moving averages,

$$y_t = \frac{1}{5}\sum_{s=t-2}^{t+2} x_{s,}$$

and those for the remaining years near the end-points of the x_t series as weighted averages,

$$\begin{aligned}
y_{1990} &= \frac{2}{5}x_{1990} + \frac{2}{5}x_{1991} + \frac{1}{5}x_{1992}\\
y_{1991} &= \frac{2}{5}x_{1990} + \frac{1}{5}x_{1991} + \frac{1}{5}x_{1992} + \frac{1}{5}x_{1993}\\
y_{2020} &= \frac{1}{5}x_{2018} + \frac{1}{5}x_{2019} + \frac{1}{5}x_{2020} + \frac{2}{5}x_{2021}\\
y_{2021} &= \frac{1}{5}x_{2019} + \frac{2}{5}x_{2020} + \frac{2}{5}x_{2021}\\
y_{2022} &= \frac{2}{5}x_{2020} + \frac{3}{5}x_{2021}
\end{aligned}$$

Annual areas of land use classes

The end of the year 2002 was chosen as a fixed point, due to the five years moving average method and because NFI 2005 to 2009 data are used when estimating any areas in 1990 to 2004. Land use areas for other years were computed on the basis of 2002 area estimates in each land-use category, for example Forest Land, and annual change estimates y_t between different land-use categories (Figure 1_App_6b).

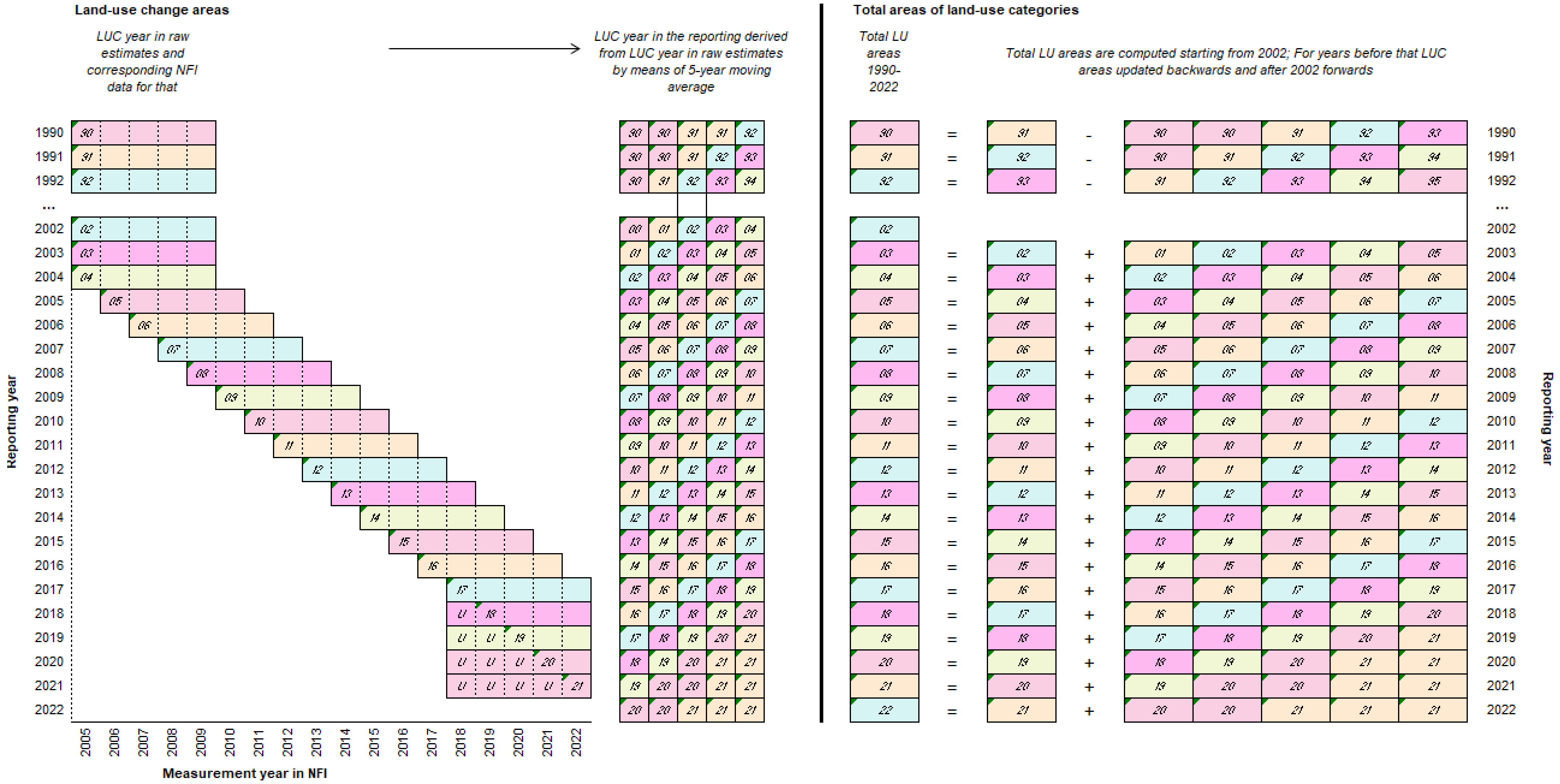


Figure 1_App_6b Calculation of land use and land-use change areas. NFI datasets are compiled in regard to five-year inventory cycles (measurement years). For land-use changes a 5-year moving average is used. Year 2002 is a base year for land-use areas. Index U refers to updated land-use change areas by means of remote sensing data and other spatial data

Appendix_6c

Estimation of woody biomass stocks, gains and losses

Tree biomass stocks and carbon stock changes in Forest Land

Tree biomass stocks in Forest Land

To provide the litter input for the estimation of carbon stock changes in SOM and DOM pools by the Yasso07 model, the annual stocks of living biomass in tree compartments were estimated using tree-level measurements on field sample plots of the NFI, Finnish biomass models and BCEFs derived from NFI data (Repola et al. 2007, Repola 2008, Repola 2009, see Appendix_6d).

The annual biomass stocks were linearly interpolated based on six National Forest Inventories, NFI8-NFI13 (see Appendix_6a). From the mid-year of the currently available NFI13 data, 2020 onwards, the stocks were extrapolated as constant.

The steps of the estimation were:

1. Biomass by tree compartments (c=stem, bark, living branches, dead branches, foliage, stump, roots) and stem volume were computed from sample tree data by soil type (mineral, organic) and region (Southern Finland, Northern Finland) for three tree species group (sp = pine, spruce, broadleaved). For variables measured for sample trees, see Appendix_6a. Biomass conversion and expansion factors, $BCEF_{S,NFI,c,sp,soil,region}$, were computed separately for each NFI as a ratio of appropriately weighted mean biomass and mean stem volume estimated over the NFI sample trees belonging to the respective strata. The Finnish tree-level biomass models were used for biomass estimation (Repola et al. 2007, Repola 2008, Repola 2009, Appendix_6d). The ready-estimated sample tree stem volumes in the NFI data were used.

   The volume of growing stock in forest land was computed separately for each NFI over all trees belonging to the respective strata. Volume of growing stock was converted to biomass using the following equation:

   $$C_{S,NFI,sp,soil,region} = V_{NFI,sp,soil,region} \times BCEF_{S,NFI,c,sp,soil,region} \times CF,$$

   where subscript S refers to stock and V to stem volume. V is the total stem volume estimated using the standard NFI procedures (see e.g., Tomppo et al. 2011). A default value of 0.5 was used for the carbon fraction CF.

2. Each estimate, $C_{S,NFI,sp,soil,region}$, was allocated to the appropriately weighted mean of the measurement dates. The linear trend estimated based on the difference between NFI9 and NFI8 was applied to extrapolate to the years preceding the mean measurement date of NFI8. The trend in total biomass has been increasing since 1990.

Gains in living biomass in Forest Land Remaining Forest Land

The annual gain (growth) in living tree biomass was estimated first for the total forest land and then for Lands Converted to Forest Land. The reminder of these two estimates was the biomass growth for Forest Land Remaining Forest Land. The annual biomass increments were linearly interpolated from the estimates based on six National Forest Inventories (NFI8-NFI13) (see Appendix_6a). From the mid-year for increment of the currently available NFI13 measurements, i.e. 2019 the increment was extrapolated as constant. An extrapolation is needed since the increments measured in a year, represent on average 2.5 years prior to the measurement (field work) year.

Table 1_App_6c. Growing seasons contributing to the estimates of increment based on permanent NFI sample plots and their weighted averages with weights proportional to the contributions. “NFI11-12” is mainly based on NFI11 (2009-2013) and NFI12 (2014-2018) measurements. Northernmost Finland was not measured in NFI12 and the increment estimates there are hence based on change from NFI9 (2003) to NFI11 (2012). “NFI12-13” is mainly based on NFI12 and NFI13 (2019-2022); northernmost Finland on change from NFI11 (2012) to NFI13 (2022)

NFI	Region	Soil	Measured increments from years	Weighted average of increment years
11-12	south	mineral	2009-2018	2013.811
		organic	2009-2018	2013.807
	north	mineral	2003-2018	2012.223
		organic	2003-2018	2013.622
12-13	south	mineral	2014-2022	2018.219
		organic	2014-2022	2018.239
	north	mineral	2012-2022	2017.945
		organic	2012-2022	2018.109

The following estimation steps were performed separately for each stratum: region (Southern Finland, Northern Finland) x soil type (mineral, organic) x tree species group (pine, spruce, broadleaved)

1. Average annual increments of the growing stock (total stem volume) from NFI11 to NFI12 and from NFI12 to NFI13 were estimated using the standard NFI procedures (Korhonen et al. 2021).

2. Biomass conversion and expansion factors (BCEF) for the increments were estimated based on biomass and stem volume increments of those sample trees from permanent plots that were measured both in NFI11 and in NFI12. Above- and below-ground biomass of these trees were predicted for both measurement occasions using the NFI sample tree measurements and Finnish tree-level biomass models (Appendix_6d) and converted to annual increments by dividing the difference in biomass by the time between the measurements. The BCEFs were obtained as ratios of weighted sums of annual biomass increments and stem volume increments over the sample trees. The weights were based on NFI sampling design.

3. Volume increments of step 1, both those based on NFI11-12 and those based on NFI12-13, were multiplied by the BCEFs of step 2, which were based on NFI11-12 (thus using always the BCEFs based on same time period as for the drain, see below) The resulting estimates of annual biomass increment were converted to carbon using the default value of 0.5 for the carbon fraction CF.

4. Each increment estimate was allocated to the time point determined as a weighted average of those years that contribute to the estimate (see Table 1_App_6c), interpolated linearly between these time points and extrapolated as a constant after the latest time points (NFI12-13).

5. The time series reported in earlier submissions, concerning biomass increments for times before the NFI11-12 reference dates (see Table 1_App_6c), were updated to correspond to the new method according to the ratios between NFI11-12 biomass estimates computed in step 3 and previously reported estimates for NFI12, which were based on tree-level five-year increments of breast height-diameter and in the height of the trees measured in the temporary NFI sample plots.

Losses in living biomass in Forest Land Remaining Forest Land

The loss in living tree biomass in Forest Land Remaining Forest Land was estimated as the difference between the estimated biomass of the total drain and the sum of the estimated biomass losses due to Forest Land being converted to other land uses and losses in Land converted to Forest land.

The official statistics on the total drain of growing stock were used to compute the **total losses in living biomass**. Drain is the decrease in the growing stock due to fellings and unrecovered natural losses. Fellings consist of commercial and other roundwood removals and harvesting losses. The annual statistics on commercial removals, including purchased energy wood, are based on the information provided by sampled roundwood purchasers and by Metsähallitus (a state-owned enterprise that administers state-owned land). The sample on industrial roundwood quantities covers more than 95% of total wood quantities recovered by the forest industry. The statistics on industrial roundwood removals has been compared to the statistics on the use of industrial roundwood in 2003 to 2012. The discrepancy between these two statistics was 0.6%. The non-commercial roundwood removals refer to logs for contract sawing and fuelwood used in small-scale housing. The volumes of contract sawing and fuelwood used in small-scale housing have been investigated in ca. 10-year intervals. The latest information for contract sawing was compiled in 2008 to 2010 and for fuelwood used in small-scale housing in 2016 to 2017. The volume of harvesting losses left on the ground has until 2008 been based on the investigations conducted during 1966 to 1971 (Mikkola 1972). The latest estimates are based on the measurements on the NFI permanent sample plots. The volume of unrecovered natural losses is also based on the NFI. The statistics were published by the Statistical Services of Natural Resources Institute Finland (Luke 2023b, Luke 23d, Table 2_App_6c).

The stem volume of the drain was converted to whole tree biomass and biomass of the tree compartments using biomass expansion and conversion factors (BECFs), which were computed from the permanent sample plot data. For time series, two set of BECFs are computed: the first is from NFI9 (measured from 1996 to 2003) to NFI10 (measured from 2004 to 2008), and the second from NFI11 (measured from 2009 to 2013) to NFI12 (measured from 2014 to 2018). Separate expansion factors were computed for the fellings and for the unrecovered natural losses as the ratios of biomass stocks and stem volume stocks estimated from trees harvested or dead between the inventories. The older BECFs were used for 1990 to 2008 and the newer ones from 2009 onwards.

Table 2_App_6c Total drain (million m^3/year)

	Pine	Spruce	Broadleaved	Total
1990	21.3	22.7	11.8	55.8
1995	24.2	26.9	12.8	63.9
2000	27.0	29.2	15.5	71.7
2005	26.0	26.8	15.9	68.8
2010	28.9	23.2	18.7	70.9
2012	30.2	23.7	19.2	73.1
2013	31.4	25.4	20.6	77.4
2014	31.9	25.2	20.5	77.5
2015	33.1	26.1	21.5	80.7
2016	33.2	28.3	21.8	83.3
2017	34.5	28.9	22.1	85.5
2018	37.3	31.1	23.4	91.7
2019	35.4	28.0	22.6	86.0
2020	33.7	26.6	21.3	81.7
2021	36.6	30.6	22.6	89.9
2022	36.0	30.1	22.4	88.6

Carbon stock change in living biomass in Cropland Remaining Cropland

The biomass of apple trees and currants are taken into account when calculating the carbon stock change in the living biomass. A gain-loss method (2006 IPCC Guidelines, Equation 2.7) corresponding to Tier 2 methodology of the 2006 IPCC Guidelines is used for the calculation. The annual carbon stock change is determined as the difference between biomass accumulation due to growth and its loss as removals of old plants. The emissions are allocated to Cropland Remaining Cropland also in cases when cropland was converted to other land-use categories. The following equation is used:

$$\Delta CCcc_{LB} = \sum_i \left(C_{ai} - C_{di}\right)$$
$$B_{hi} = d_i * w_i * Frac_{Dm} * Frac_C$$
$$G_i = B_{hi} / H_{ci}$$
$$C_{ai} = A_i * G_i$$
$$C_{di} = A_{ci} * B_{hi}$$

where
i denotes the plant species (currants, dwarfish apple trees, vigorously growing apple trees)

$\Delta CCcc_{LB}$ = Annual change in carbon stocks in living biomass, tonnes C/a
C_{ai} = Carbon accumulation in a year
C_{di} = Carbon decline in a year
B_{hi} = Above-ground biomass carbon stock at harvest, tonnes C/a
d_i = Density of growing plants
w_i = Weight of an average single plant
$Frac_{Dm}$ = Dry matter content of above-ground biomass
$Frac_C$ = Carbon fraction
G_i = Biomass accumulation rate, tonnes C/ha/a
H_{ci} = Harvest cycle, a
A_i = Area of growing plants
A_{Ci} = Size of cleared area (plants removed).

The parameters used for determining the carbon stock changes in the living biomass for apple trees and currants are presented in Table 3_App_6c. Apple trees were divided into vigorously growing and dwarfish trees, and the typical average values for apple trees and black, red, green or white currant bushes were estimated. The background information (e.g. density, mature weight, dry matter) for the coefficients in Table 3_App_6c was obtained from national experts (Source: Tahvonen, MTT Agrifood Research Finland, pers. comm. and Tanska, Horticulture Union, pers. comm. 2008). The division value (30% of trees are dwarfish) for the year 2007 is an estimate from an inquiry made by the Information Centre of the Ministry of Agriculture and Forestry. The estimate for the year 2017 is that 65% of the trees are dwarfish (Tanska, Horticulture Union, pers. comm. 2017). The proportion of dwarfish trees for the years between 1998 to 2017 has been interpolated and the proportion for the years 2018-2022 extrapolated. Dwarfish trees began to enter to the market in 1997. Natural Resources Institute Finland (Luke) collects data of the area on apple trees and currants (Table 4_App_6c).

Table 3_App_6c National coefficients for living apple trees and currants (cropland remaining cropland)

	Aboveground biomass carbon stock at harvest (t C/ha)	Harvest cycle (a)	Biomass accumulation rate (t C/ha/a)	Biomass carbon loss (t C/ha)
Vigorously-growing apple trees	18	35	0.514	18
Dwarfish apple trees	21	18	1.167	21
Currants	4.02	17	0.236	4.02

Table 4_App_6c Areas of apple trees and currants, ha

	Vigorously growing apple trees	Dwarfish apple trees	Currants
1990	380	0	1 598
1995	419	0	1 723
2000	457	49	2 143
2005	489	157	2 443
2010	403	276	2 007
2013	323	337	1 772
2014	304	365	1 681
2015	279	387	1 607
2016	256	410	1 656
2017	239	445	1 740
2018	212	461	1 740
2019	193	494	1 806
2020	165	507	1 881
2021	142	530	1 968
2022	119	555	2 000

Carbon stock change in living biomass in Grassland Remaining Grassland

The carbon stock change in living biomass is estimated using a Tier 2 gain-loss method (2006 IPCC Guidelines). Since the trees outside forests have been measured only in NFI11 (2009 to 2013) it was not possible to estimate gains in tree biomass in grassland using the same procedure as was used for forest land. Instead of the direct estimation of biomass and biomass growth from the measured trees, the biomass and growth rates were estimated based on measured trees on forest land. The assessed data on trees outside forests were tree species and a diameter at breast height, from which the stem number per hectare by IPCC land use class (converted and remaining), tree species (pine, spruce, broadleaved) and diameter class (one cm) was computed. Then the biomass by tree species and diameter class was computed from forest land sample trees (see Appendix_6a) and merged with the stem number data. The growth rates of growing stock reported by the NFI and based on NFI10 and NFI11 data were used to compute the biomass growth separately for Southern and Northern Finland (Table 5_App_6c).

Table 5_App_6c Growth rates of tree biomass used to compute gains in tree biomass and applied mean biomass increments by tree species in Grassland Remaining Grassland

Tree species	Southern Finland	Northern Finland
Growth rate, %		
- Pine	4.24	3.88
- Spruce	4.89	3.76
- Broadleaved	5.56	4.33
Annual mean biomass increment, t C ha^{-1}		
- Pine	0.028	0.020
- Spruce	0.065	0.024
- Broadleaved	0.420	0.194

Grasslands with tree cover are former croplands, for which agricultural use has ended, and on which a natural forest expansion is taking place. Tree cover on grasslands is sparse (trees are unevenly distributed) and does not fulfil the crown cover criteria that is set for forest land. The trees outside forest land, including grasslands, have been measured once in the NFI11, and therefore there are no data available on the losses in biomass due to harvest or natural mortality.

Since the direct assessment of losses on grassland was impossible, different options were considered to calculate estimates of losses: First, the data from sites (NFI sample plots) on which a land-use change from grassland to forest land had taken place by natural forest expansion, were tried to be used in estimation of losses. However, there were no suitable sample plots in the data on which both land-use change and cutting would have occurred recently. The second option was to compute how much the total drain is compared to the increment on forest lands. The proportion cannot be as high on grassland as on forest land, because grasslands remaining grasslands are not managed for wood production, the trees are small and sparse (based on one measurement in the 11th National Forest Inventory), and do not fulfill the criteria for forest land, especially regarding crown cover. All this indicates that they are not managed like forest land. However, it is possible that some landowners might occasionally remove trees from grassland remaining grassland. Therefore, an expert judgement was made based on examination of losses in living biomass on GL with trees of natural origin converted to FL (measured in the NFI). This is a category to which the GL remaining GL with trees will be converted if the trees are let to grow and a category on which the data was available. As a result, 25% of the average of 65% for forests was used. The result was that about 16% of the increment (gains) is estimated to be removed annually by cutting or by natural mortality from grasslands. The gain from which the losses were computed is the same as that reported for grassland remaining grassland. On average the losses are 0.096 t C/ha in Southern Finland and 0.03 t C/ha in Northern Finland for the grassland where trees exist.

Carbon stock change in living biomass in Land Converted to Forest Land

The gains in land converted to forest land were estimated from NFI12 sample plots separately for land converted from agricultural use and other land uses, Southern and Northern Finland, and for different tree species and age-classes of trees (0-10, 11-20, 21-30, 31- years). Volume estimates were converted to biomass using national biomass models (Appendix_6d). For land converted to forest land from agricultural use, a stratification for trees of natural origin / cultivated trees was made, because the difference between the origin was considered significant. Because areas of land conversion to forest are small, consideration was needed to come up with the most practical stratification to have enough sample plots in each stratum. It was possible to stratify the most significant categories, such as conversions from agricultural areas in more detail than other categories.

The annual gain was then obtained by multiplying the annual mean increments by the corresponding annual areas of the conversion categories.

The **losses in living biomass on Land converted to Forest land** were estimated based on the annual harvest areas and drain volume by tree species and soil type (mineral, organic) calculated from the data from the permanent NFI sample plots (Hamberg et al. 2016) in 2005 to 2020. The harvest volume of the year 2021 is an average of 5 previous years. Harvesting was done as thinnings on lands converted from croplands and grasslands. The time series was extended to cover losses since 1990. Since there is no information available, the average harvest per hectare of 2005 to 2009 was applied for the areas converted 16-20 years ago. The drain was estimated for cropland and grassland converted to Forest land 16-20 years ago, because it is very rare to harvest sites that have been established less than 16 years ago and there was no evidence on this in the NFI data. The harvest volumes were then converted to biomass with the BCEF computed specifically for the converted forest land from NFI data.

Carbon stock changes in living biomass in Forest land converted to other land uses

The **losses in biomass due to the land-use change from Forest land to other land uses** were estimated separately for each conversion type and Southern and Northern Finland based on permanent and updated temporary plots from NFI8 to NFI12. The average removed volume of trees per hectare was calculated. Settlements were divided into three categories according to the new land use and whether trees still exist after the conversion. Finally the mean volumes were converted to biomass with the BCEF computed from NFI data (see above section Tree biomass stocks in Forest Land) and multiplied with the corresponding annual conversion area.

Carbon stock changes in living biomass on Wetlands remaining Wetlands

In the **conversion of other wetlands to peat extraction** the loss in living tree biomass was based on the trees measured from other wetlands suitable for peat extraction i.e., from wetlands where the peat layer is at least 4 meters thick. The mean biomass was estimated using the NFI sample plots which fulfilled the criteria. All biomass is removed from the site due to the conversion. Thus the mean biomass was multiplied with the annual conversion area to calculate the removed total biomass. The same approach was applied to calculate the biomass loss to the **conversion of other wetlands to flooded land**. In these cases, the criterion for the peat layer is not needed, and the mean biomass of all other wetlands was estimated, and then multiplied by the annual conversion area.

Appendix_6d

Biomass models used in estimating tree biomass increment and stock

The applied models are presented in Table 1_App_6d. Repola's Model 1 is based on the tree diameter at breast height (d) [cm] (or 2+1.25*d = dk [cm]) and tree height (h)[m]. Model 2 contains, in addition to the diameter and the height, the tree age at breast height (t_{13}), the length of the living crown (cl) [m] and the crown ration (cr). The diameter/age is shortened to d_a [cm]. Model 3 is based on the previously mentioned variables and bark thickness (bt)[cm], as well as the radial increment during the last five years (i_5)[cm], or, for Scots Pine, the cross-sectional area increment at breast height during the last five years (i_{g5}) [cm^2]. Repola's density model for stem wood is based on diameter, diameter/age and average temperature sum (dd). For estimating the biomass increment, the above-ground biomass is calculated as Repola 2009 above-ground – (Repola 2009 stem wood + Repola 2009 stem bark) + Repola 2007 stem wood density * volume. The stem-wood model is thus replaced with the more accurate stem-wood density model. Marklund's model for needles is used for estimating the biomass of the fine roots of pine and spruce trees (Marklund 1988). The ratios of fine root quantity to modelled needle masses were based on the work by Helmisaari et al. (2007).

Table 1_App_6d Biomass models used in estimating tree biomass increment and stock

Scots pine (Pinus sylvestris)

	Biomass compartment	**Biomass function**	**Reference**	**Applied in**
Repola's multivariate models				
Model 1	stem wood	exp(-3.721+8.103*dk/(dk+14)+5.066*h/(h+12)+(0.002+0.009)/2)	Repola 2009 (4)	inc
	stem bark	exp(-4.548+7.997*dk/(dk+12)+0.357*log(h)+(0.015+0.061)/2)	Repola 2009 (5)	inc, stock
	living branches	exp(-6.162+15.075*dk/(dk+12)-2.618*h/(h+12)+(0.041+0.089)/2)	Repola 2009 (6)	stock
	needles	exp(-6.303+14.472*dk/(dk+6)-3.976*h/(h+1)+(0.109+0.118)/2)	Repola 2009 (7)	stock
	dead branches	0.911*exp(-5.201+10.574*dk/(dk+16))	Repola 2009 (8)	stock
	stump	exp(-6.753+12.681*dk/(dk+12)+(0.010+0.044)/2)	Repola 2009 (10)	inc, stock
	roots	exp(-5.550+13.408*dk/(dk+15)+0.079/2)	Repola 2009 (11)	inc, stock
	above-ground	exp(-3.198+9.547*dk/(dk+12)+3.241*h/(h+20)+(0.009+0.010)/2)	Repola 2009 (9)	inc
Model 2	stem wood	exp(-4.018+8.358*dk/(dk+14)+4.646*h/(h+10)+0.041*log(t_{13})+(0.001+0.008)/2)	Repola 2009 (A1)	inc
	stem bark	exp(-4.695+8.727*dk/(dk+12)+0.228*log(h)+(0.014+0.057)/2)	Repola 2009 (A2)	inc, stock
	living branches	exp(-5.166+13.085*dk/(dk+12)-5.189*h/(h+8)+1.110*log(cl)+(0.020+0.063)/2)	Repola 2009 (A3)	stock
	needles	exp(-1.748+14.824*dk/(dk+4)-12.684*h/(h+1)+1.209*log(cl)+(0.032+0.093)/2)	Repola 2009 (A4)	stock
	dead branches	0.913*exp(-5.318+10.771*dk/(dk+16))	Repola 2009 (A5)	stock
	above-ground	exp(-3.416+9.555*dk/(dk+12)+3.592*h/(h+24)+0.395*cr+(0.008+0.009)/2)	Repola 2009 (A6)	inc
Model 3	stem wood	exp(-4.590+8.520*dk/(dk+9)+5.013*h/(h+16)+0.002*t_{13}+0.002*i_{g5}+(0.001+0.008)/2)	Repola 2009 (A13)	inc
	stem bark	exp(-5.565+9.691*dk/(dk+8)-0.444*d_a+0.068*bt+(0.008+0.058)/2)	Repola 2009 (A14)	inc, stock
	living branches	exp(-4.833+13.126* dk/(dk+10)-4.808* h/(h+4)+0.098*log(i_{g5})+0.727*log(cl)+(0.018+0.059)/2)	Repola 2009 (A15)	stock
	needles	exp(-2.209+9.347*dk/(dk+6)-6.364* h/(h+1)+0.309*log(i_{g5})+0.611*log(cl)+(0.027+0.082)/2)	Repola 2009 (A16)	stock
	dead branches	0.918*exp(-5.798+17.82* dk/(dk+16)-0.738*log(cl)-0.461*log(ig5)-0.017*t_{13})	Repola 2009 (A17)	stock
	above-ground	exp(-3.529+9.337*dk/(dk+12)+3.265*h/(h+18)+0.124*i_5+0.001*t_{13}-0.006*bt+(0.003+0.009)/2)	Repola 2009 (A18)	inc
Repola's density model				
	stem wood density	378.39-78.829*d_a+0.039*dd	Repola 2007 (52)	inc, stock
Marklund's model for needles (estimation of fine roots)				
	needles	exp(12.1095*d/(d+7)+0.0413*h-1.565*log(h)-3.4781)	Marklund 1988 (T-18)	stock

Norway spruce (Picea abies)

	Biomass compartment	Biomass function	Reference	Applied in
Repola's multivariate models				
Model 1	stem wood	exp(-3.555+8.042*dk/(dk+14)+0.869*log(h)+0.015*h+(0.009+0.009)/2)	Repola 2009 (12)	inc
	stem bark	exp(-4.548+9.448*dk/(dk+18)+0.436*log(h)+(0.023+0.041)/2)	Repola 2009 (13)	inc, stock
	living branches	exp(-4.214+14.508*dk/(dk+13)-3.277*h/(h+5)+(0.039+0.081)/2)	Repola 2009 (14)	stock
	needles	exp(-2.994+12.251*dk/(dk+10)-3.415*h/(h+1)+(0.107+0.089)/2)	Repola 2009 (15)	stock
	dead branches	1.343*exp(-4.850+7.702*dk/(dk+18)+0.513*log(h))	Repola 2009 (16)	stock
	stump	exp(-3.964+11.730*dk/(dk+26)+(0.065+0.058)/2)	Repola 2009 (18)	inc, stock
	roots	exp(-2.294+10.646*dk/(dk+24)+(0.105+0.114)/2)	Repola 2009 (19)	inc, stock
	above-ground	exp(-1.808+9.482*dk/(dk+20)+0.469*log(h)+(0.006+0.013)/2)	Repola 2009 (17)	inc
Model 2	stem wood	exp(-4.000+8.881*dk/(dk+12)+0.728*log(h)+0.022*h-0.273*d_a+(0.003+0.008)/2)	Repola 2009 (A7)	inc
	stem bark	exp(-4.437+10.071*dk/(dk+18)+0.261*log(h)+(0.019+0.039)/2)	Repola 2009 (A8)	inc, stock
	living branches	exp(-3.023+12.017*dk/(dk+14)-5.722*h/(h+5)+1.033*log(cl)+(0.017+0.068)/2)	Repola 2009 (A9)	stock
	needles	exp(-0.085+15.222*dk/(dk+4)-14.446*h/(h+1)+1.273*log(cl)+(0.028+0.087)/2)	Repola 2009 (A10)	stock
	dead branches	1.208*exp(-5.317+6.384*dk/(dk+18)+0.982*log(h))	Repola 2009 (A11)	stock
	above-ground	exp(-2.141+9.074*dk/(dk+20)+0.570*log(h)+0.403*cr+(0.006+0.013)/2)	Repola 2009 (A12)	inc
Model 3	stem wood	exp(-3.950+8.534*dk/(dk+12)+0.743*log(h)+0.022*h+0.001*t_{13}-0.071*i_5+(0.003+0.008)/2)	Repola 2009 (A19)	inc
	stem bark	exp(-4.626+9.638*dk/(dk+16)+0.266*log(h)+0.084*bt+(0.013+0.042)/2)	Repola 2009 (A20)	inc, stock
	living branches	exp(-3.950+12.014*dk/(dk+18)-1.296*h/(h+2)+1.528*cr-0.461*d_a+0.112*i_5+(0.011+0.067)/2)	Repola 2009 (A21)	stock
	needles	exp(-4.258+9.200*dk/(dk+12)+0.967*cr+0.287*log(i_5)+(0.022+0.068)/2)	Repola 2009 (A22)	stock
	dead branches	1.091*exp(-0.140+11.293*dk/(dk+14)+3.058*log(cr)-7.014*cr-0.189*log(i_5))	Repola 2009 (A23)	stock
	above-ground	exp(-2.037+9.146*dk/(dk+20)+0.543*log(h)+0.296*cr+(0.007+0.013)/2)	Repola 2009 (A24)	inc
Repola's density model				
	stem wood density	442.03-0.904*dk-82.695*d_a	Repola 2007 (53)	inc, stock
Marklund's model for needles (estimation of fine roots)				
	needles	exp(9.7809*d/(d+12)-0.4873*log(h)-1.8551)	Marklund 1988 (G-16)	stock

Broadleaved trees

	Biomass compartment	Biomass function	Reference	Applied in
Repola's multivariate models				
Model 1	stem wood	exp(-4.879+9.651*dk/(dk+12)+1.012*log(h)+(0.00263+0.00544)/2)	Repola 2008 (7)	inc
	stem bark	exp(-5.401+10.061*dk/(dk+12)+2.657*h/(h+20)+(0.01043+0.04443)/2)	Repola 2008 (8)	inc,stock
	living branches	exp(-4.152+15.874*dk/(dk+16)-4.407*h/(h+10)+(0.02733+0.07662)/2)	Repola 2008 (9)	stock
	foliage	exp(-29.556+33.372*dk/(dk+2)+(0.077)/2)	Repola 2008 (12)	inc,stock
	dead branches	2.073*exp(-8.335+12.402*dk/(dk+16))	Repola 2008 (10)	stock
	stump	exp(-3.574+11.304*dk/(dk+26)+(0.02154+0.04542)/2)	Repola 2008 (13)	stock
	roots	exp(-3.223+6.497*dk/(dk+22)+1.033*log(h)+(0.048+0.02677)/2)	Repola 2008 (14)	stock
	above-ground	exp(-3.654+10.582*dk/(dk+12)+3.018*h/(h+22)+(0.00068+0.00727)/2) + foliage	Repola 2008 (11)	inc
	below-ground	exp(-2.726+7.652*dk/(dk+24)+0.799*log(h)+(0.02623+0.02152)/2)	Repola 2008 (15)	inc
Model 2	stem wood	exp(-4.886+9.965*dk/(dk+12)+0.966*log(h)-0.135*d_a+(0.00160+0.00537)/2)	Repola 2008 (A1)	inc
	stem bark	exp(-5.433+10.121*dk/(dk+12)+2.647*h/(h+20)+(0.01059+0.04419)/2)	Repola 2008 (A2)	inc,stock
	living branches	exp(-5.067+14.614*dk/(dk+12)-5.074*h/(h+12)+0.092*cl+(0.01508+0.05663)/2)	Repola 2008 (A3)	stock
	foliage	exp(-20.856+22.320*dk/(dk+2)+2.819*cr+(0.01082+0.04355)/2)	Repola 2008 (A6)	inc,stock
	dead branches	2.149*exp(-7.996+11.824*dk/(dk+16))	Repola 2008 (A4)	stock
	above-ground	exp(-3.659+10.588*dk/(dk+12)+2.996*h/(h+22)+0.0006*t_{13}+(0.00049+0.00711)/2) + foliage	Repola 2008 (A5)	inc
Model 3	stem wood	exp(-4.915+9.984*dk/(dk+12)+0.981*log(h)-0.180*d_a+(0.0014+0.00534)/2)	Repola 2008 (A7)	inc
	stem bark	exp(-5.304+8.498*dk/(dk+8)+3.380*h/(h+22)+0.382*log(bt)+(0.01135+0.03508)/2)	Repola 2008 (A8)	inc,stock
	living branches	exp(-5.918+12.867*dk/(dk+10)-3.573*h/(h+10)+0.238*log(i_5*10.)+0.095*cl+0.007*t_{13}+(0.01171+0.043)/2)	Repola 2008 (A9)	stock
	dead branches	1.788*exp(-16.113+37.902*dk/(dk+6)-17.342*h/(h+10)-0.063*t_{13}-0.166*i_5*10)	Repola 2008 (A10)	stock
	above-ground	exp(-3.713+10.616*dk/(dk+12)+3.235*h/(h+22)+0.007*i_5*10.-0.214*(dk/t_{13})+(0.00673)/2) + foliage	Repola 2008 (A11)	inc
Repola's density model				
	stem wood density	431.43 + 28.054 * log(dk)–- 52.203 * d_a	Repola 2007 (54)	inc, stock

Appendix_6e

Description of the Yasso07 soil carbon model

The Yasso07 model describes the decomposition of organic matter (Tuomi et al. 2011b). The model is driven by the litter quantity, litter quality, temperature, and precipitation. The model structure (Figure 1_App_6e) constitutes five state variables: water solubles (W), ethanol solubles (E), acid hydrolysables (A), compounds that are neither soluble nor hydrolysable (N) and a humus (H) fraction. The arrows indicate the transfer of litter into the system, the transfer between state variables and also the transfer from the soil system to the atmosphere as CO_2 respiration.

The Yasso07 model is based on the litter bag, wood decomposition and soil carbon measurements. These measurements have been used to calibrate the model using McMC (Markov chain Monte Carlo) techniques (Tuomi et al. 2011b). The Yasso07 soil carbon model has been calibrated against the soil carbon measurements, which includes the soil organic matter to a depth of 1 metre.

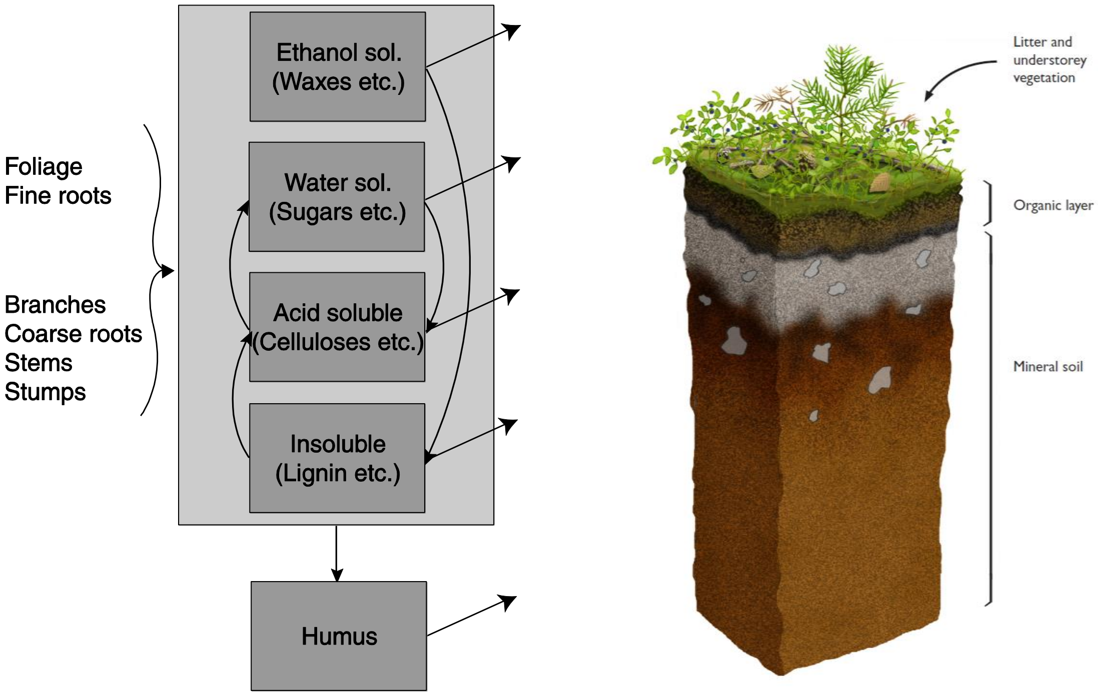


Figure 1_App_6e The structure of the Yasso07 soil carbon model (left) and an illustration of the soil profile (right)

The decomposition sensitivity of the organic matter has been described in the Yasso07 model by a Gaussian function, where the temperature and precipitation affect the decomposition modifier k (see Tuomi et al. 2008 and 2009). k is defined follows:

$$k_i(C) = \alpha_i exp(\beta_1 T + \beta_2 T^2)(1- exp[\gamma P_a]),$$

where T is the temperature (Celsius) and P_a is the annual precipitation and $\alpha_i, \beta_1, \beta_2$ and γ the parameters (Table 1_App_6e and Figure 2_App_6e). When the Yasso07 model is applied at an annual time resolution, it requires a mean annual temperature, annual precipitation, and temperature amplitude [0.5*(minimum monthly mean - maximum monthly mean)] as input.

In the Yasso07 model, the size of woody material also affects the decomposition rate (Tuomi et al. 2011a). The size-dependent coefficient $h_s(d)$ multiplies the decomposition factors and, therefore, slows down the decomposition of woody material. The size-dependent coefficient $h_s(d)$ has been defined using the following equation:

$$h_s(d) = \min\{(1 + phi_1 d + phi_2 d^2)^r, 1\},$$

where phi_1, phi_2 and r are the parameters (Table 1_App_6e and Figure 2_App_6e). The equation results in a value of one when d approaches a small value.

Table 1_App_6e Parameter values and their uncertainty used in the Yasso07 model simulations for mineral forest soils. Scandinavian parameter set, see Rantakari et al. (2012) for details. See also Figure 2_App_6e

Parameter	Value	Unit	Meaning
aA	-0.517	a^{-1}	decomposition rate of A
aW	-3.552	a^{-1}	decomposition rate of W
aE	-0.346	a^{-1}	decomposition rate of E
aN	-0.266	a^{-1}	decomposition rate of N
p1	0.0449	.	mass flow from W to A
p2	0.0029	.	mass flow from E to A
p3	0.978	.	mass flow from N to A
p4	0.637	.	mass flow from A to W
p5	0.312	.	mass flow from E to W
p6	0.0187	.	mass flow from N to W
p7	0.0225	.	mass flow from A to E
p8	0.0117	.	mass flow from W to E
p9	0.001	.	mass flow from N to E
p10	0.336	.	mass flow from A to N
p11	0.042	.	mass flow from W to N
p12	0.0899	.	mass flow from E to N
b1	0.0895	C^{-1}	temperature dependence parameter
b2	-0.0023	C^{-2}	temperature dependence parameter
y	-2.94	m^{-1}	precipitation dependence parameter
ω_1	-0.081	$a^{-1}m^{-1}$	precipitation induced leaching (Europe)
pH	0.0015	10^{-3}	mass flow from A,W,E,N to humus
aH	-0.00024	$10^{-3}\ a^{-1}$	humus decomposition coefficient
phi_1	-0.539	cm^{-1}	size dependence parameter
phi_2	1.186	cm^{-2}	size dependence parameter
r	-0.263	.	size dependence parameter

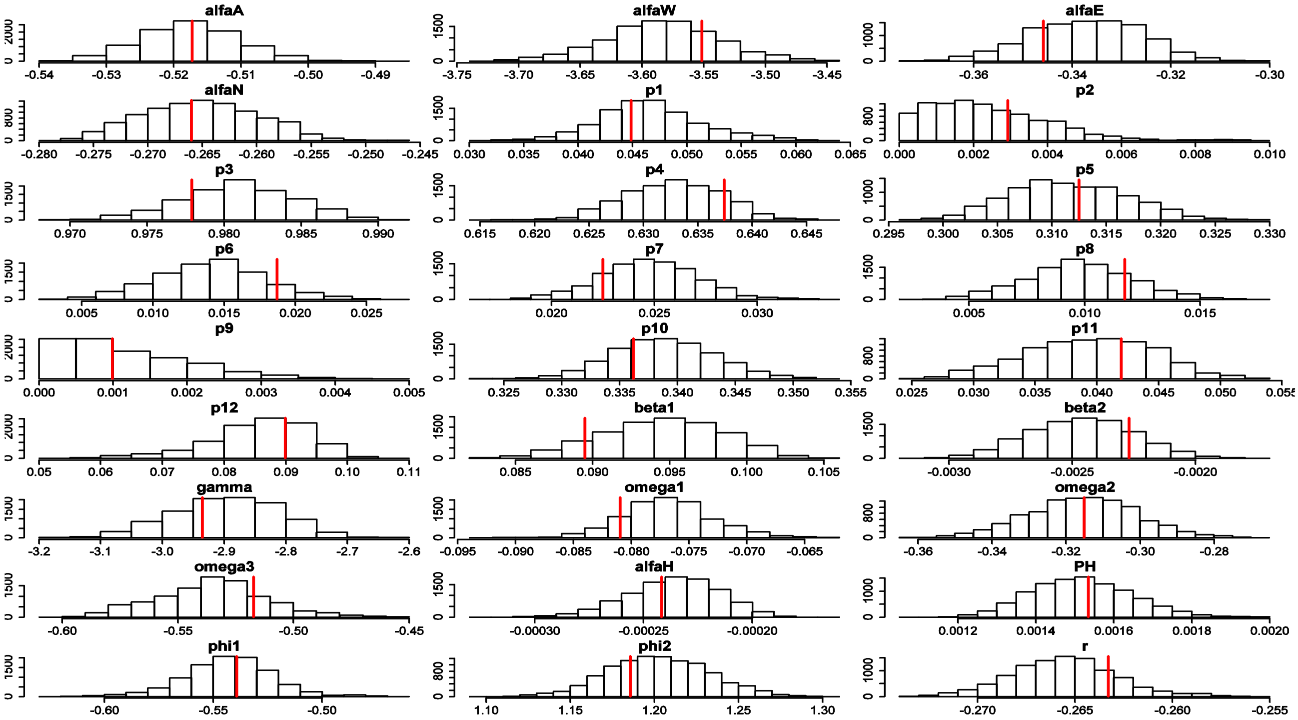
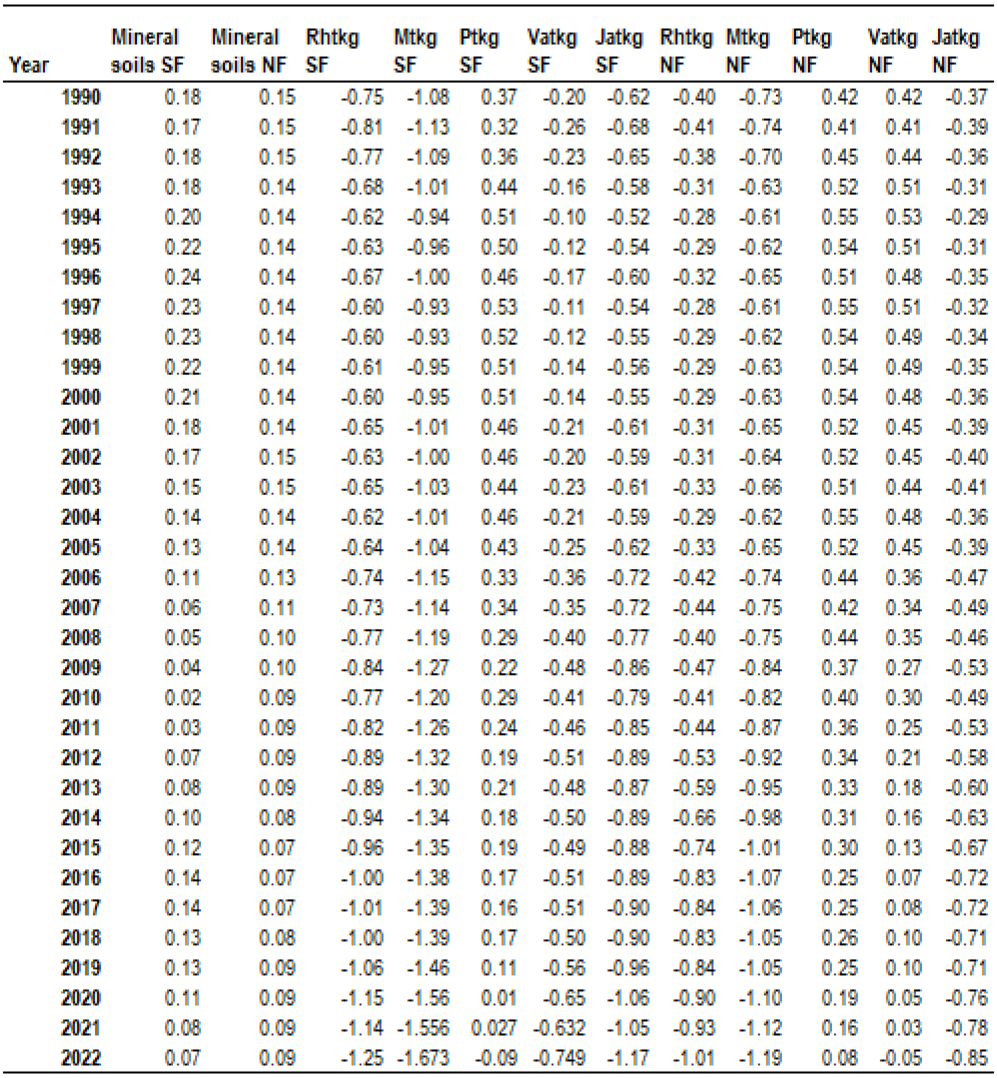


Figure 2_App_6e Probability distributions of the Yasso07 model parameters (Scandinavia 22.12.2011), applied to mineral forest soils. The vertical line indicates the location of the maximum posterior estimates

Appendix_6f

Emission factors for soil organic matter and dead organic matter for Forest Land remaining Forest Land and for Land converted to Forest Land

Table 1_App_6f The aggregated annual emission factors for soil organic matter (SOM) and dead organic matter (DOM) for forest land remaining forest land. Emission factors are listed separately for Southern (SF) and Northern Finland (NF) and by fertility type for drained peatlands, tonnes C per ha (negative numbers represent a loss of carbon). Abbreviations: Rhtkg = Herb-rich type, Mtkg = *Vaccinium myrtillus* type, Ptkg = *Vaccinium vitis-idaea* type, Vatkg = Dwarf shrub type, Jatkg = *Cladonia* type.



Year	Mineral soils SF	Mineral soils NF	Rhtkg SF	Mtkg SF	Ptkg SF	Vatkg SF	Jatkg SF	Rhtkg NF	Mtkg NF	Ptkg NF	Vatkg NF	Jatkg NF
1990	0.18	0.15	-0.75	-1.08	0.37	-0.20	-0.62	-0.40	-0.73	0.42	0.42	-0.37
1991	0.17	0.15	-0.81	-1.13	0.32	-0.26	-0.68	-0.41	-0.74	0.41	0.41	-0.39
1992	0.18	0.15	-0.77	-1.09	0.36	-0.23	-0.65	-0.38	-0.70	0.45	0.44	-0.36
1993	0.18	0.14	-0.68	-1.01	0.44	-0.16	-0.58	-0.31	-0.63	0.52	0.51	-0.31
1994	0.20	0.14	-0.62	-0.94	0.51	-0.10	-0.52	-0.28	-0.61	0.55	0.53	-0.29
1995	0.22	0.14	-0.63	-0.96	0.50	-0.12	-0.54	-0.29	-0.62	0.54	0.51	-0.31
1996	0.24	0.14	-0.67	-1.00	0.46	-0.17	-0.60	-0.32	-0.65	0.51	0.48	-0.35
1997	0.23	0.14	-0.60	-0.93	0.53	-0.11	-0.54	-0.28	-0.61	0.55	0.51	-0.32
1998	0.23	0.14	-0.60	-0.93	0.52	-0.12	-0.55	-0.29	-0.62	0.54	0.49	-0.34
1999	0.22	0.14	-0.61	-0.95	0.51	-0.14	-0.56	-0.29	-0.63	0.54	0.49	-0.35
2000	0.21	0.14	-0.60	-0.95	0.51	-0.14	-0.55	-0.29	-0.63	0.54	0.48	-0.36
2001	0.18	0.14	-0.65	-1.01	0.46	-0.21	-0.61	-0.31	-0.65	0.52	0.45	-0.39
2002	0.17	0.15	-0.63	-1.00	0.46	-0.20	-0.59	-0.31	-0.64	0.52	0.45	-0.40
2003	0.15	0.15	-0.65	-1.03	0.44	-0.23	-0.61	-0.33	-0.66	0.51	0.44	-0.41
2004	0.14	0.14	-0.62	-1.01	0.46	-0.21	-0.59	-0.29	-0.62	0.55	0.48	-0.36
2005	0.13	0.14	-0.64	-1.04	0.43	-0.25	-0.62	-0.33	-0.65	0.52	0.45	-0.39
2006	0.11	0.13	-0.74	-1.15	0.33	-0.36	-0.72	-0.42	-0.74	0.44	0.36	-0.47
2007	0.06	0.11	-0.73	-1.14	0.34	-0.35	-0.72	-0.44	-0.75	0.42	0.34	-0.49
2008	0.05	0.10	-0.77	-1.19	0.29	-0.40	-0.77	-0.40	-0.75	0.44	0.35	-0.46
2009	0.04	0.10	-0.84	-1.27	0.22	-0.48	-0.86	-0.47	-0.84	0.37	0.27	-0.53
2010	0.02	0.09	-0.77	-1.20	0.29	-0.41	-0.79	-0.41	-0.82	0.40	0.30	-0.49
2011	0.03	0.09	-0.82	-1.26	0.24	-0.46	-0.85	-0.44	-0.87	0.36	0.25	-0.53
2012	0.07	0.09	-0.89	-1.32	0.19	-0.51	-0.89	-0.53	-0.92	0.34	0.21	-0.58
2013	0.08	0.09	-0.89	-1.30	0.21	-0.48	-0.87	-0.59	-0.95	0.33	0.18	-0.60
2014	0.10	0.08	-0.94	-1.34	0.18	-0.50	-0.89	-0.66	-0.98	0.31	0.16	-0.63
2015	0.12	0.07	-0.96	-1.35	0.19	-0.49	-0.88	-0.74	-1.01	0.30	0.13	-0.67
2016	0.14	0.07	-1.00	-1.38	0.17	-0.51	-0.89	-0.83	-1.07	0.25	0.07	-0.72
2017	0.14	0.07	-1.01	-1.39	0.16	-0.51	-0.90	-0.84	-1.06	0.25	0.08	-0.72
2018	0.13	0.08	-1.00	-1.39	0.17	-0.50	-0.90	-0.83	-1.05	0.26	0.10	-0.71
2019	0.13	0.09	-1.06	-1.46	0.11	-0.56	-0.96	-0.84	-1.05	0.25	0.10	-0.71
2020	0.11	0.09	-1.15	-1.56	0.01	-0.65	-1.06	-0.90	-1.10	0.19	0.05	-0.76
2021	0.08	0.09	-1.14	-1.556	0.027	-0.632	-1.05	-0.93	-1.12	0.16	0.03	-0.78
2022	0.07	0.09	-1.25	-1.673	-0.09	-0.749	-1.17	-1.01	-1.19	0.08	-0.05	-0.85

Table 2_App_6f The aggregated annual emission factors for soil organic matter (SOM) and dead organic matter (DOM) stock change on lands converted to forest land on mineral soils and on drained organic soils, tonnes C per ha (minus is a loss of carbon)

Time since conversion	Cropland mineral SF	Cropland mineral NF	Grassland mineral SF	Grassland mineral NF	Settlement mineral SF	Settlement mineral NF
1	-1.29	-0.53	-1.92	-1.19	0.53	1.06
2	-0.99	-0.38	-1.39	-0.83	0.53	0.85
3	-0.81	-0.31	-1.14	-0.70	0.55	0.72
4	-0.67	-0.26	-0.96	-0.60	0.58	0.61
5	-0.57	-0.22	-0.71	-0.52	0.60	0.53
6	-0.42	-0.19	-0.51	-0.46	0.63	0.46
7	-0.30	-0.16	-0.34	-0.40	0.65	0.41
8	-0.20	-0.14	-0.20	-0.36	0.61	0.36
9	-0.12	-0.12	-0.08	-0.32	0.58	0.32
10	-0.04	-0.10	0.02	-0.28	0.55	0.28
11	0.02	-0.09	0.10	-0.25	0.53	0.25
12	0.07	-0.07	0.18	-0.22	0.52	0.22
13	0.12	-0.06	0.24	-0.10	0.50	0.20
14	0.16	-0.05	0.35	0.01	0.49	0.18
15	0.19	0.10	0.43	0.10	0.48	0.16
16	0.22	0.22	0.50	0.17	0.47	0.14
17	0.24	0.33	0.56	0.24	0.46	0.12
18	0.26	0.42	0.62	0.30	0.46	0.11
19	0.28	0.50	0.66	0.35	0.45	0.10
20	0.30	0.58	0.70	0.40	0.45	0.09

Time since conversion	Cropland organic SF	Cropland organic NF	Grassland organic SF	Grassland organic NF	Peat extraction SF	Peat extraction NF	Settlement organic SF	Settlement organic NF
1	-5.42	-5.07	-2.16	-1.87	-1.41	-1.40	-1.45	-0.90
2	-5.42	-5.07	-2.16	-1.87	-1.41	-1.40	-1.45	-0.90
3	-5.42	-5.07	-2.16	-1.87	-1.41	-1.40	-1.45	-0.90
4	-5.42	-5.07	-2.16	-1.86	-1.41	-1.40	-1.45	-0.90
5	-5.42	-5.07	-2.08	-1.84	-1.41	-1.40	-1.45	-0.90
6	-5.42	-5.07	-2.00	-1.83	-1.41	-1.40	-1.45	-0.90
7	-5.36	-5.07	-1.92	-1.82	-1.35	-1.35	-1.45	-0.90
8	-5.31	-5.06	-1.84	-1.80	-1.29	-1.30	-1.45	-0.90
9	-5.26	-5.06	-1.76	-1.79	-1.23	-1.25	-1.45	-0.90
10	-5.20	-5.06	-1.68	-1.78	-1.16	-1.21	-1.45	-0.90
11	-5.15	-5.05	-1.60	-1.76	-1.10	-1.16	-1.45	-0.90
12	-5.10	-5.05	-1.52	-1.69	-1.04	-1.11	-1.45	-0.90
13	-5.04	-5.04	-1.44	-1.63	-0.98	-1.06	-1.45	-0.90
14	-4.99	-5.04	-1.35	-1.57	-0.91	-1.02	-1.45	-0.90
15	-4.94	-5.03	-1.26	-1.51	-0.85	-0.97	-1.45	-0.90
16	-4.88	-5.04	-1.18	-1.45	-0.76	-0.92	-1.45	-0.90
17	-4.83	-5.05	-1.09	-1.40	-0.67	-0.88	-1.45	-0.90
18	-4.78	-5.06	-1.00	-1.34	-0.58	-0.83	-1.45	-0.90
19	-4.73	-5.08	-0.92	-1.28	-0.49	-0.78	-1.45	-0.90
20	-4.67	-5.09	-0.83	-1.22	-0.40	-0.73	-1.45	-0.90

Appendix_6g

Assessment of parameter uncertainty in tree biomass models

The uncertainty in the estimates of biomass stocks and their increment in living trees was assessed based on the simplest versions of biomass models in which the explanatory variables were tree species, approximate stump diameter, *d*, and tree height, *h*. For single trees, the biomass predictions from these models are of the form

(A6g.1)

$$\hat{y}=\exp(\alpha_0 + \alpha_1 d + \alpha_2 h),$$

where α_i's are parameters that are specific to each tree species group (pines, spruces, deciduous species) and to each biomass component. Following Ståhl et al. (2014), the uncertainty in biomass prediction (A6g.1) due to the uncertainty in parameter values was approximated using

$$\mathrm{Var}(\hat{y}) \approx \sum_{i=1}^{2}\sum_{j=1}^{2} \alpha_i\, \alpha_j \hat{y}\,^2 \mathrm{Cov}\left(\alpha_i, \alpha_j\right).$$

The parameter uncertainty in a mean biomass estimate over *m* trees of the same species was obtained through

$$\mathrm{Var}\left(\frac{1}{m}\sum_{k=1}^{m} \hat{y}_k\right) \approx \sum_{i=1}^{2}\sum_{j=1}^{2}\left(\frac{1}{m}\sum_{k=1}^{m} \alpha_i \hat{y}_k\right)\left(\frac{1}{m}\sum_{k=1}^{m} \alpha_j \hat{y}_k\right)\mathrm{Cov}\left(\alpha_i, \alpha_j\right).$$

In particular, this implies that the parameter uncertainty in mean stock over *m* trees of the same species with equal diameters and heights is equal to the parameter uncertainty in single-tree prediction, which makes sense, because the same parameter values with the same error in them are applied in each prediction.

Appendix_6h

Estimating the uncertainty of carbon stock changes for Forest land on mineral soils

Uncertainty of the litter input of living trees

Uncertainty in the estimated biomass stocks of the different components (foliage, branches, stem, stump and roots) was assessed in the same way as for the biomass increment (Section 6.4.3, Table 1_App_6h)

Table 1_App_6h Uncertainties in the estimates of biomass stocks on mineral soils based on NFI11 (2009 to 2010)

Tree species	Region	Sampling uncertainty, %					Parameter uncertainty, %				
		stem	branches	foliage	stump	roots	stem	branches	needles/ foliage	stump	roots
pine	south	2	2	2	2	2	2	7	10	12	12
	north	5	4	4	4	4	2	7	10	11	11
spruce	south	3	3	3	3	3	3	7	10	25	32
	north	12	8	9	9	9	3	8	10	24	30
deciduous	south	3	4	3	4	3	2	9	15	12	16
	north	14	9	11	14	13	3	14	22	15	25

The parameter uncertainty of fine roots was assumed to be similar to that of foliage, because the amount of fine roots was estimated as a ratio between estimated leaf mass and fine roots, based on models by Marklund (1988) and ratios by Helmisaari et al. (2007).

The uncertainties of litter turnover rates (i.e. reciprocal of life span) for each biomass component were based on the work by Peltoniemi et al. (2006). The turnover rates were assumed to be independent between components.

Uncertainty of the litter input of understorey vegetation

Litter production from ground vegetation was assessed through vegetation coverage measurements of the Finnish NFI, cover to biomass models and with turnover rates. The litter input of ground vegetation, such as shrubs, herbs and grasses, and mosses, of both Southern and Northern Finland was estimated with the data of 3000 permanent sample plots, described in more detail by Mäkipää and Heikkinen (2003), the biomass models (Muukkonen and Mäkipää 2006, Muukkonen et al. 2006) and the litter turnover rates from Liski et al. (2006).

The litter input of understorey was simulated for each sample plot defined as forest land on mineral soil. The uncertainty of biomass model estimates were included by utilising parameter uncertainties and variance-covariance matrices (Muukkonen et al. 2006). It was assumed that the coefficient of variation of litter turnover rate was 10% for each vegetation group (bryophates, lichens, dwarf shrubs and herbs & grasses).

Uncertainty of the litter input of loggings and natural mortality

The uncertainty in the litter input from harvesting residues and natural mortality was assessed as described for the total drain in Section 6.4.3. Uncertainties of biomass estimates for the different components are given in Table 2_App_6h and Table 3_App_6h.

Table 2_App_6h Combined sampling and parameter uncertainties, %, in the biomass of fellings

Tree species	Region	stem	branches	foliage	stump	roots
pine	south	11	12	14	16	17
	north	13	14	17	18	17
spruce	south	10	12	13	29	36
	north	59	50	50	60	63
deciduous	south	18	21	26	27	29
	north	49	54	61	56	55

Table 3_App_6h Combined sampling and parameter uncertainties, %, in the biomass of natural mortality

Tree species	Region	stem	branches	foliage	stump	roots
pine	south	31	32	29	31	35
	north	47	58	76	55	47
spruce	south	31	31	32	38	42
	north	41	28	40	41	52
deciduous	south	41	43	54	51	58
	north	59	59	71	57	60

Uncertainty of the Yasso07 model

The Yasso07 model has been estimated by the so-called Bayesian approach, where the McMC (Markov chain Monte Carlo) approach was used (Tuomi et al. 2011b). The Yasso07 model consists of 24 parameters that define decomposition of acid, water, ethanol and non-soluble compounds (Appendix 6e). These parameters also define transfers between different compounds, sensitivity of decomposition to temperature and precipitation, humus decomposition and the impact of size to decomposition of the woody material.

The McMC method was used to sample parameter space and this produced a sample of parameter combinations that were used to simulate the impact of model parameter uncertainty to the soil carbon stock change estimate.

The simulation of uncertainty

The Monte Carlo simulation methods were applied when the uncertainties of different sources were combined. Firstly, the uncertainty of biomass sampling error of living trees was simulated and consecutive NFIs were assumed to be independent from one another, while it was assumed that different biomass components of the same inventory correlate fully (i.e. same random numbers were applied). Implementing the sampling error uncertainty separately allowed us to treat NFIs independently, which introduced variation into mean biomass trends from the 1970s to 2014. Secondly, the model errors and litter turnover uncertainties were simulated by the biomass components. Also, uncertainties of natural mortality, harvesting residues and understorey vegetation were simulated. The uncertainties of biomass and litter input were assumed to be normally distributed.

The soil carbon model Yasso07 was run to steady state with the first year’s litter input (1972 for Southern Finland and 1975 for Northern Finland). This simulation of steady state was done with maximum a *posteriori* point estimates of Yasso07 parameters. During each realisation of litter input time series, the soil carbon stock change was simulated with different parameter combinations, meaning that steady state and time series simulation were done independently with regard to Yasso07 parameters. The parameter combinations of Yasso07 were the same during the simulation of each realisation ensuring the full autocorrelation between consecutive years due to soil model uncertainty. The use of parameter combinations took into account that some of the probability density functions (PDF) of the parameters were non-normal and some of the parameters were correlated with each other.

The uncertainty of the soil carbon stock change was obtained as a result of the Monte Carlo simulation. The uncertainty bounds were estimated from the PDF of the soil carbon stock change. For details of the uncertainty analysis of soil carbon stock change, see Lehtonen and Heikkinen (2015).

Appendix_6i

Emission factors for dead wood loss

The carbon stock estimate of deadwood was based on NFI10 measurements, where the quantity of deadwood was mapped by decomposition classes. The density and carbon content estimates were based on the estimates presented by Mäkinen et al. (2006) (Table 1_App_6i).

Table 1_App_6i Emission factors for dead wood loss due to deforestation (t C/ha)

Region	Soil	Emission factor
south	mineral	0.530
	organic	0.388
north	mineral	1.280
	organic	0.515

Appendix_6j

Method for estimating C stock changes in croplands and grasslands

Estimation of biomass

Above-ground and below-ground biomasses of croplands were calculated based on the national yield statistics (yield per hectare) of main crop plants divided into 16 regions (Luke 2023a). Yield statistics were converted to biomass using the calculation scheme proposed by Palosuo et al (2015) applying national parameters (Table 1_App_6j). In Finnish conditions, similar approaches to calculate crop biomasses have been used in a previous study by Hakala et al. (2016).

Table 1_App_6j Parameters for calculating plant biomass

		DM	HI	SR/RootDM	TR	LO
Annual crops	Winter wheat	0.86	0.42	5.6	0.41	0.02
	Spring wheat	0.86	0.42	5.6	0.41	0.02
	Rye	0.86	0.4	5.6	0.41	0.02
	Barley	0.86	0.53	5.6	0.41	0.02
	Oats	0.86	0.46	5.6	0.41	0.02
	Turnip rape	0.92	0.35	5.1	0.41	0.02
	Rape	0.92	0.35	5.1	0.41	0.02
	Pea	0.87	0.5	5	0.41	0.02
	Potato	0.22	0.55	5	0.41	0.02
	Sugar beet	0.21	0.66	5	0.41	0.02
Perennial crops	Hay	0.86	0.84	4 036*	0.41	0.1
	Silage	0.34	0.84	4 036*	0.41	0.1
Cover crops	Grass-clover mixt	800*	-	1200*	0.41	-

DM= dry matter, HI= harvest index, SR= ratio of shoot and root biomass, RootDM= root dry matter, TR= turnover rate of the roots (i.e. rhizodeposition, root exudates), LO= yield losses

*In the case of hay, silage and cover crops a constant root biomass, and for cover crops also constant aboveground biomass per hectare was assumed.

Yield losses were assumed to take place after harvesting, and, therefore, yield biomass (BM_Y) was calculated from the harvested yield as:

$$BM_Y = Yield * (1 + LO) \times DM$$

Above-ground biomass (BM_{AG}) was calculated as follow:

$$BM_{AG} = \frac{BM_Y}{HI}$$

Below-ground biomass (BM_{BG}) of annual crop plants was calculated as:

$$BM_{BG} = \frac{BM_{AG}}{SR}$$

Fallow and perennial crops were assumed to have the same constant below-ground biomass per hectare (Table 1_App_6j). Above-ground biomass of fallow was assumed to be 5,375 kg ha^{-1} in the south and 4,845 kg ha^{-1} in the north. Hectare-based biomasses were weighted with the area of each cultivated crop plants taken from the Land Parcel Identification System of the EU. Since grasslands are mainly abandoned fields, the above- and below-ground biomasses of fallow were used for grassland vegetation as well.

Based on the study by Känkänen (2019), the above- and below-ground dry matter biomasses of cover crops were assumed to be 800 and 1200 kg ha^{-1}, respectively.

Nitrogen in crop residues

Nitrogen content of crop residues for estimating the N_2O emissions for CRF 3.D were calculated based on the crop plant biomasses (see above). Nitrogen in above-ground residues (N_{AG}) and below-ground biomass (N_{BG}) were taken into account.

$$N_{AG} = (BM_{AG} - BM_Y) \times NC_{AG}$$

$$N_{BG} = \frac{BM_{BG}}{RL} \times NC_{BG}$$

where RL is the length (years) of the crop rotation (one for annual crops and 3.5 for perennial crops) and NC_{AG} and NC_{BG} are species/group-specific nitrogen contents of above- and below-ground biomasses (2006 IPCC Guidelines; Table 11.2). Grass-clover mixture values are used for cover crops as circa70 % of cover crops are graminoids and 30% clover (Känkänen 2019).

Soil carbon input

Soil carbon input consists of plant residues and manure. Carbon input through plant residues were estimated on the basis of plant biomass (see above).

Above-ground carbon input from plant residues was calculated as follow (0.45 refers to carbon content of 45%):

$$CI_{AG} = (BM_{AG} - BM_Y) \times 0.45$$

Below-ground carbon input was calculated as:

$$CI_{BG} = BM_{BG} \times \left(\frac{1}{RL} + TR\right) \times 0.45$$

where *RL* is the length (years) of the crop rotation (one for annual crops and 3.5 for perennial crops) and TR is the root turnover rate.

Manure-derived carbon (CI_{manure}) was calculated based on the regional numbers of livestock and livestock-specific rates of volatile solids in manure (Appendix_5a) and assuming that 50% of the volatile solids is carbon. Total soil carbon input was then obtained as a sum of above- (CI_{AG}) and below-ground plant residues (CI_{BG}) and carbon from manure (CI_{manure}). The C input was divided into fractions based on its chemical quality (Table 2_App_6j)

Table 2_App_6j Acid, water and ethanol soluble and non-soluble fractions of litter and manure C input for the Yasso07 model

Plant litter	A	W	E	Ns
Cereals	0.71	0.08	0.03	0.18
Pea	0.63	0.14	0.02	0.21
Potato	0.23	0.48	0.05	0.24
Sugarbeet	0.26	0.54	0.04	0.16
Turnip rape	0.42	0.27	0.04	0.27
Oilseed rape	0.40	0.34	0.04	0.22
Grasses	0.46	0.32	0.04	0.18
Cover crops	0.56	0.27	0.08	0.09
Manure	0.65	0.12	0.07	0.16

Emission factors

The emission factors are derived from the model simulation as described in Section 6.5. For cropland remaining cropland, they can be either negative (loss of C) or positive (gain of C) depending on the C input rate of each year (Table 3_App_6j). For land use conversions, they are usually negative with the exception of the conversion of cropland to grassland (Table 4_App_6j).

Table 3_App_6j Emission factors for cropland remaining cropland (t C ha^{-1})

Year	South	North
1990	0.005	0.016
1995	-0.03	0.01
2000	-0.16	-0.08
2005	-0.08	-0.08
2010	-0.08	-0.09
2013	-0.02	-0.06
2014	-0.03	-0.06
2015	-0.02	-0.04
2016	-0.09	-0.05
2017	-0.07	-0.04
2018	-0.11	-0.02
2019	-0.17	-0.04
2020	-0.16	-0.05
2021	-0.12	-0.04
2022	-0.19	-0.06

Table 4_App_6j Aggregated emission factors for land conversions of different ages (t C ha^{-1})

Time since conversion	FL/WL-CL South	FL/WL-CL North	GL-CL South	GL-CL North	FL/WL-GL South	FL/WL-GL North	CL-GL South	CL-GL North
1	-1.27	-0.15	-0.80	-0.78	-0.46	0.65	0.68	0.71
2	-1.12	-0.18	-0.61	-0.62	-0.50	0.46	0.51	0.56
3	-0.99	-0.18	-0.52	-0.54	-0.47	0.37	0.43	0.48
4	-0.90	-0.19	-0.44	-0.47	-0.45	0.30	0.36	0.42
5	-0.83	-0.19	-0.39	-0.42	-0.43	0.24	0.31	0.37
6	-0.77	-0.19	-0.35	-0.38	-0.42	0.20	0.28	0.34
7	-0.72	-0.19	-0.32	-0.35	-0.40	0.17	0.25	0.30
8	-0.69	-0.19	-0.30	-0.32	-0.39	0.14	0.23	0.28
9	-0.66	-0.18	-0.28	-0.30	-0.38	0.12	0.21	0.26
10	-0.63	-0.18	-0.26	-0.28	-0.37	0.10	0.20	0.24
11	-0.61	-0.18	-0.25	-0.26	-0.36	0.09	0.19	0.23
12	-0.59	-0.18	-0.24	-0.25	-0.35	0.08	0.18	0.22
13	-0.57	-0.17	-0.23	-0.24	-0.34	0.07	0.17	0.21
14	-0.55	-0.17	-0.22	-0.23	-0.33	0.06	0.17	0.20
15	-0.53	-0.17	-0.22	-0.22	-0.32	0.06	0.16	0.19
16	-0.52	-0.16	-0.21	-0.21	-0.31	0.05	0.16	0.19
17	-0.51	-0.16	-0.20	-0.21	-0.30	0.05	0.15	0.18
18	-0.49	-0.16	-0.20	-0.20	-0.29	0.05	0.15	0.18
19	-0.48	-0.16	-0.19	-0.20	-0.29	0.05	0.14	0.17
20	-0.47	-0.15	-0.19	-0.19	-0.28	0.04	0.14	0.17

Cover crops

Cover crops are included in plant biomass, crop residue N and soil carbon input calculations. Their surface area is available from 2015 (Finnish Food Authority) and used to calculate the cover crop share from the total crop land area.

Table 5_App_6j Area of cover crops in Finland (ha).

Year	Area (ha)
1990	0
1995	0
2000	0
2005	0
2010	5 786
2013	6 217
2014	6 434
2015	258 410
2016	140 045
2017	125 862
2018	122 775
2019	123 009
2020	138 431
2021	143 281
2022	144 930

Appendix_6k

Method for estimating C stock changes from drained organic forest soils

The estimation of soil CO_2 balance on drained organic forest soils is based on the annual difference between the release of CO_2 from decomposing soil organic matter (OM), or heterotrophic soil respiration and the C entering the soil through plant litter input (Alm et al. 2023). Annual CO_2 release from decomposing peat and decomposing aboveground and belowground litter of living trees and ground vegetation, is calculated using empirical regression models given in Ojanen et al. (2014) (Table 1_App_6k). The soil CO_2 release estimates produced by the regression models do not include CO_2 release from harvest residues or from naturally died trees. The CO_2 release from these litter components is therefore estimated using the Yasso07 decomposition model. Since the Yasso07 model produces the remaining OM pool after decomposition, the CO_2 release from decomposing aboveground and belowground harvest residues and stump and stem wood of recently naturally died trees is calculated by subtracting the remaining OM pool from the inputs of these residues.

Plant litter input consists of litter from living trees (excluding fine root litter), arboreal fine root litter (roots of trees and dwarf shrubs with ≤2 mm diameter), ground vegetation litter (excluding dwarf shrub fine root litter) and litter originating from forest harvests and natural tree mortality. To estimate litter input from living trees, the mean biomass of each tree component (stem bark, branch, foliage, stump, and coarse roots) is multiplied by the turnover rate of each tree component similarly as in mineral soils. To calculate arboreal fine root litter input, fine root biomass is first estimated for each peatland forest site types by using site type mean basal area of trees and site type mean of dwarf shrub cover (Table 2_App_6k) as predictors in empirical regression models (Table 3_App_6k), obtained from Ojanen et al. (2014). Arboreal fine root litter input is then estimated by multiplying fine root biomass by fine root turnover rate measured for each site type (Table 2_App_6k). The mean combined aboveground and belowground litter input from ground vegetation (excluding dwarf shrub fine root litter input) is calculated for each peatland forest site types using site type mean BA as a predictor in empirical regression models (Table 4_App_6k), obtained from Ojanen et al. (2014). Harvesting residues consist of foliage, branches, waste wood and stumps. The calculation of litter input from harvest residues is similar to that presented for mineral soils. Litter input from unrecovered natural losses consists of all biomass components of trees and is calculated following similar methods as for mineral soils.

Table 1_App_6k Empirical regression models of CO_2 release from peat and litter decomposition for peatland forest site types. The regression models are from Ojanen et al. (2014), except that the constants for the V. myrtillus and V. vitis-idaea site types are weighted means of constants of the two subtypes; BA = tree stand basal area (m^2 ha^{-1}), T = mean May–October air temperature (°C).

Drained peatland forest site type	Decomposition (g CO_2 m^{-2} a^{-1})
Herb rich drained peatland forest	$-1383 + 14.74 \times BA + 242.8 \times T$
Vaccinium myrtillus drained peatland forest	$-1440 + 14.74 \times BA + 242.8 \times T$
Vaccinium vitis-idaea drained peatland forest	$-1662 + 14.74 \times BA + 242.8 \times T$
Dwarf shrub drained peatland forest	$-1771 + 14.74 \times BA + 242.8 \times T$
Cladonia drained peatland forest	$-1814 + 14.74 \times BA + 242.8 \times T$

Table 2_App_6k Dwarf shrub cover, obtained from Ojanen et al. (2014), and turnover rate of tree fine roots.

Drained peatland forest site type	**Dwarf shrub cover (% of area)**	**Tree fine root turnover rate (1 a^{-1})**
Herb rich drained peatland forest	7	0.8
Vaccinium myrtillus drained peatland forest	15	0.5
Vaccinium vitis-idaea drained peatland forest	32	0.7
Dwarf shrub drained peatland forest	45	0.2
Cladonia drained peatland forest	40	0.2

Table 3_App_6k Regression models from Ojanen et al. (2014) for estimating mean arboreal fine root (≤ 2 mm diameter) biomass (g m^{-2}) for peatland forest site types in southern and northern Finland. BA = mean basal area (m^2 ha^{-1}); decid = deciduous trees; $cover_{shrub}$ = mean dwarf shrub cover (% of area).

Region	**Arboreal fine root biomass (g m^{-2})**
Northern Finland	$-53.2 + 8.80 \times BA_{pine} + 6.61 \times BA_{spruce} + 17.3 \times BA_{decid} + 4.81 \times cover_{shrub}$
Southern Finland	$120 + 8.80 \times BA_{pine} + 6.61 \times BA_{spruce} + 17.3 \times BA_{decid} + 4.81 \times cover_{shrub}$

Table 4_App_6k Regression models of litter input from ground vegetation (combined dry mass of aboveground and belowground litter excluding dwarf shrub fine root litter) in different peatland forest site types. Models are from Ojanen et al. (2014), except for the constants of *V. myrtillus* and *V. vitis-idaea site types*, which are area weighted means of constants of their subtypes; BA = basal area (m^2 ha^{-1}).

Drained peatland forest site type	**Ground vegetation litter input (g m^{-2} $year^{-1}$)**
Herb rich drained peatland forest	$227 - 4.52 \times BA$
Vaccinium myrtillus drained peatland forest	$227 - 4.52 \times BA$
Vaccinium vitis-idaea drained peatland forest	$256 - 4.52 \times BA$
Dwarf shrub drained peatland forest	$298 - 4.52 \times BA$
Cladonia drained peatland forest	$187 - 4.52 \times BA$

7 WASTE (CRF 5)

7.1 Overview of the sector

The following problems caused by the CRF Reporter have been identified:

- *Part of the notation key explanations and official comments which are saved in the CRF Reporter are not visible in the CRF Tables.*

Emissions from the waste sector were 1.7 million tonnes of carbon dioxide equivalent (Mt CO_2 eq.) in 2022. This was 4% of the total greenhouse gas emissions in Finland. In the Finnish inventory, emissions from the waste sector cover CH_4 emissions from solid waste disposal sites including solid municipal, industrial, construction and demolition wastes and municipal (domestic and commercial) and industrial sludges. In addition, the waste sector includes CH_4 emissions from domestic and industrial wastewater treatment plants and uncollected domestic wastewaters and from biological treatment of solid waste (composting and anaerobic digestion). N_2O emissions are generated from nitrogen input of fish farming, as well as from domestic and industrial wastewater treatment and composting. Solid waste disposal on land (landfills and dumps) causes relatively large CH_4 emissions in Finland, while emissions from wastewater handling and from biological treatment are smaller (Figure 7.1-1).

NMVOC emissions from solid waste disposal sites and from wastewater handling are also estimated in the Finnish inventory (see Chapter 9). General assessment of completeness can be found in Section 1.7 and a more detailed assessment is included in Annex 5.

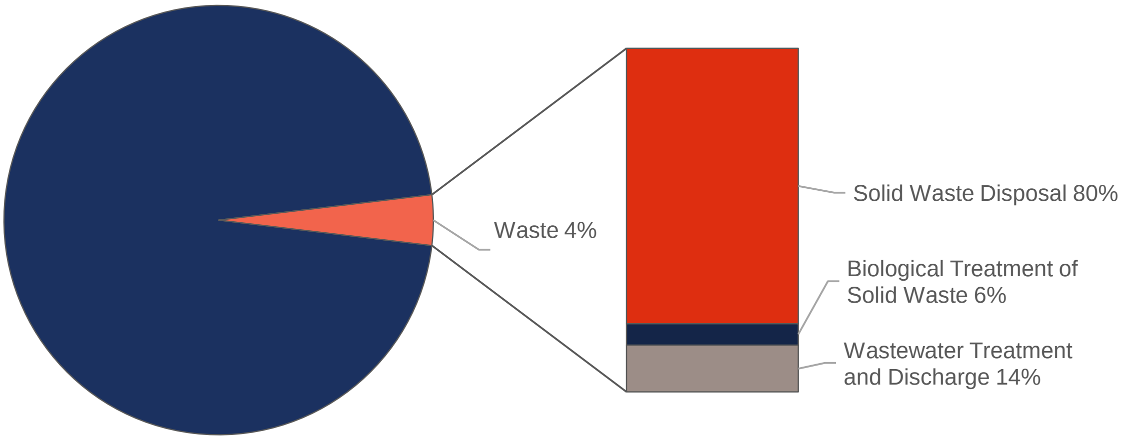


Figure 7.1-1 Greenhouse gas emissions from the waste sector in 2022 compared with total greenhouse gas emissions in Finland

CH_4 emissions from landfills are the most significant greenhouse gas emissions in the waste sector. Solid waste disposal on land contributes 80%, wastewater treatment 14% and biological treatment (composting and anaerobic digestion) 6% of this sector’s total emissions. Compared to 2021, emissions decreased by 5% in 2022 and since 1990, these emissions have decreased by 67%. A small increase in the emissions in 2006 followed from an increased amount of waste landfilled and a low landfill gas recovery rate due to temporary technical problems at one major landfill gas recovery plant (Figure 7.1-2). After the implementation of the new Waste Act (1994) and the Landfill Directive (1999/31/EC) and the ban of organic waste to landfills since 2016 (Government Decree 2013) minimisation of waste generation, recycling and reuse of waste material, landfill gas recovery and alternative treatment methods to landfills have been endorsed. Similar developments have occurred in the treatment of industrial waste, and municipal and industrial sludges. While the emissions from solid waste disposal on land have decreased, the emissions from composting have increased until 2007, after which the changes in the emissions have been small. Anaerobic digestion is a very small but growing source of CH_4 emissions in the waste sector. CH_4 emissions from this source were 0.1 kt CO_2 eq. in 1990 and over 14 kt in 2022. In addition, the increase of waste incineration (for more information, see Section 7.4) has decreased the emissions from landfills from 2008 onwards. The energy produced in waste incineration is utilised and the emissions are, therefore, reported in the energy sector. Implementation of landfill gas recovery has also had a significant decreasing impact on the emissions.

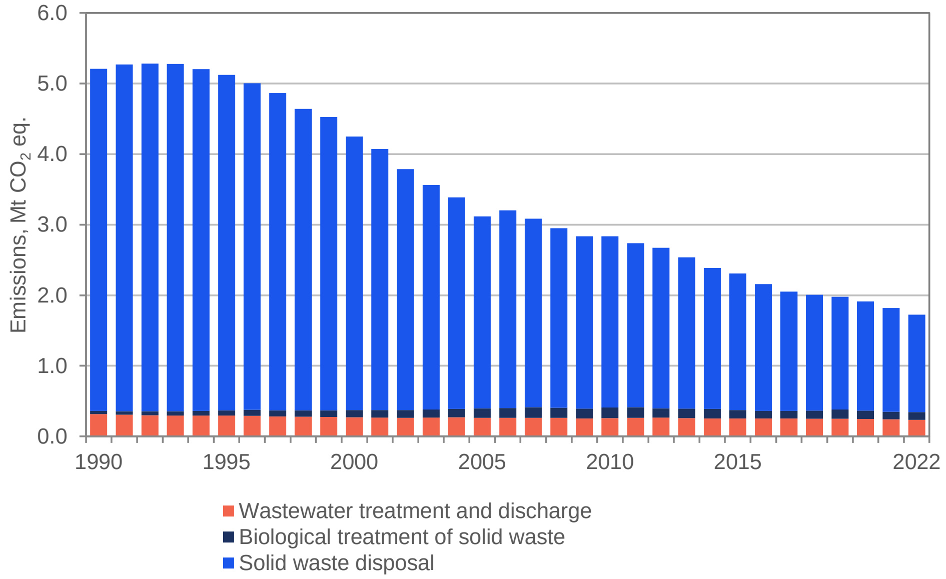


Figure 7.1-2 Trend in the waste sector's emissions (Mt CO_2 eq.)

The emission trend in the waste sector by subcategory and gas is presented in Table 7.1-1. Waste handling produces emissions of which only a part is reported in the waste sector. Emissions from waste incineration and emissions from waste collection and transportation are reported in the energy sector (see Figure 7.1-3).

Table 7.1-1 Emissions in the waste sector by source and gas (Mt CO_2 eq.)

	1990	1995	2000	2005	2010	2013	2014	2015	2016	2017	2018	2019	2020	2021	2022
Solid waste disposal	**4.85**	**4.75**	**3.88**	**2.72**	**2.43**	**2.14**	**2.00**	**1.94**	**1.80**	**1.69**	**1.64**	**1.60**	**1.55**	**1.47**	**1.38**
Methane	4.85	4.75	3.88	2.72	2.43	2.14	2.00	1.94	1.80	1.69	1.64	1.60	1.55	1.47	1.38
Biological treatment of solid waste	**0.05**	**0.07**	**0.10**	**0.13**	**0.15**	**0.13**	**0.13**	**0.12**	**0.10**	**0.11**	**0.11**	**0.13**	**0.12**	**0.11**	**0.11**
Methane	0.03	0.05	0.06	0.09	0.10	0.09	0.09	0.08	0.07	0.07	0.08	0.09	0.08	0.07	0.07
Nitrous oxide	0.02	0.03	0.04	0.05	0.05	0.05	0.05	0.04	0.03	0.03	0.04	0.04	0.04	0.03	0.03
Wastewater treatment and discharge	**0.32**	**0.30**	**0.27**	**0.26**	**0.26**	**0.26**	**0.26**	**0.26**	**0.25**	**0.25**	**0.25**	**0.25**	**0.24**	**0.24**	**0.23**
Methane	0.25	0.23	0.21	0.20	0.20	0.19	0.19	0.19	0.19	0.19	0.18	0.18	0.18	0.18	0.17
Nitrous oxide	0.07	0.06	0.06	0.06	0.07	0.07	0.07	0.07	0.07	0.07	0.07	0.07	0.07	0.07	0.06
Total	**5.21**	**5.12**	**4.25**	**3.12**	**2.84**	**2.54**	**2.39**	**2.31**	**2.16**	**2.05**	**2.01**	**1.98**	**1.91**	**1.82**	**1.73**

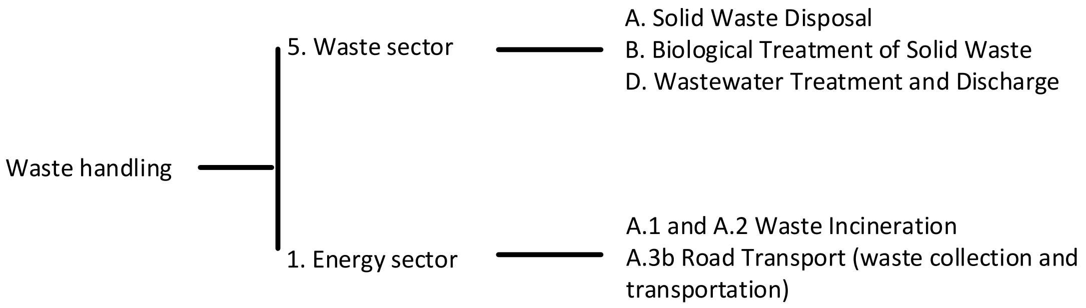


Figure 7.1-3 Reporting categories of emissions from waste handling in the national greenhouse gas inventory

7.1.1 Key categories

The key categories in the waste sector are summarised in Table 7.1-2.

Table 7.1-2 Key categories in the waste sector (CRF 5) in 1990 and 2022 (Approach 1 and Approach 2)

IPCC category	Gas	Identification criteria	Tier
5.A. Solid Waste Disposal	CH_4	L, T	Tier 2
5.B Biological Treatment of Solid Waste	CH_4	T	Tier 1
5.B. Biological Treatment of Solid Waste	N_2O	L, T	Tier 1
5.D. Wastewater Treatment and Discharge	CH_4	L	Tier 2, CS
5.D. Wastewater Treatment and Discharge	N_2O	L, T	Tier 1, CS

7.2 Solid Waste Disposal (CRF 5.A)

7.2.1 Category description

The emission source includes CH_4 emissions from solid waste disposal sites from disposal of solid municipal, industrial, construction and demolition wastes, and municipal (domestic) and industrial sludges. The amount of emissions from solid waste disposal was 1.38 Mt CO_2 eq. in 2022. The emissions have decreased 6% in a year and 71% since 1990.

Table 7.2-1 Reported emissions calculation methods and types of emission factors for the subcategory Solid Waste Disposal in the Finnish inventory (Unmanaged Waste Disposal Sites are included under Managed Waste Disposal from 1990 to 2001)

CRF	Source	Emissions reported	Methods	Emission factors
5.A.1	Managed Waste Disposal	CH_4	Tier 2	CS, D
5.A.2	Unmanaged Waste Disposal Sites	CH_4 NO CO_2 NO	NA	NA

The trend in CH_4 emissions from solid waste disposal on land is presented by subcategory in Figure 7.2-1 and Table 7.2-3.

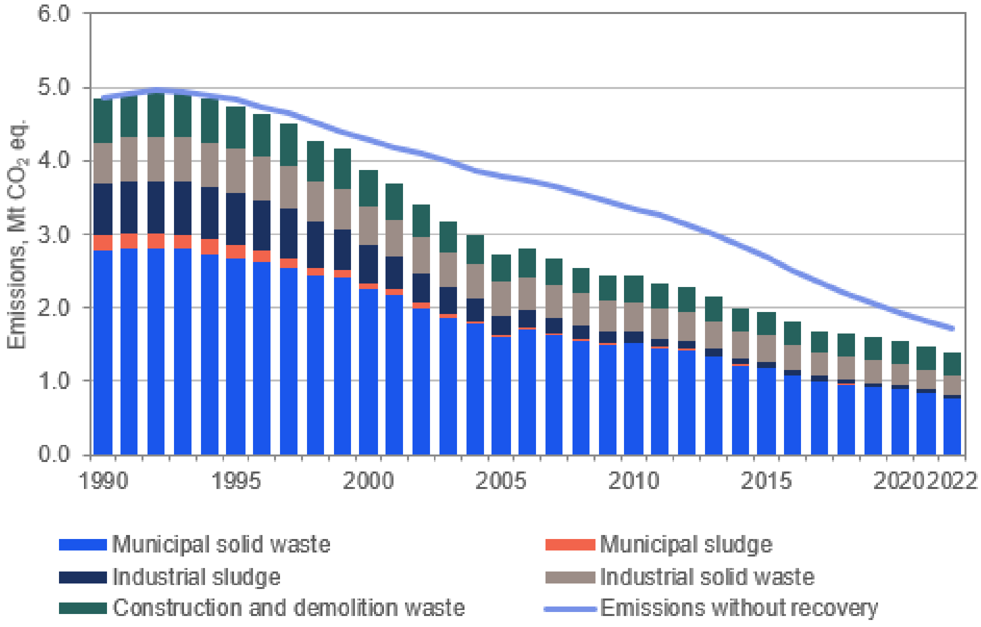


Figure 7.2-1 Methane emissions from solid waste disposal on land (Mt CO_2 eq.). The figure also shows the amount of methane generated (emission without recovery) at solid waste disposal sites

7.2.2 Methodological issues

7.2.2.1 Methods

Emissions from solid waste disposal on land have been calculated using the First Order Decay (FOD) method, which is the IPCC Tier 2 method given in the 2006 IPCC Guidelines.

The recursive FOD model calculation method in 2006 IPCC Guidelines and IPCC Equations 5.1 and 5.2 (GPG 2000) have been used as a basis for the calculations. They give the same results when the starting month is 1 in the recursive FOD model calculations. Equation 5.1 has been slightly modified, so that the term $MCF(x)$ (methane correction factor in year x) has been substituted by the term $MCF(t)$ (t = year of the inventory) in the calculation of the methane generation potential $L_0(x)$. Calculations are not made separately for each landfill but the total waste amount and the average common *MCF* value for each year have been used. The status of the SWDS (managed – unmanaged; covered or not covered) in year t defines the *MCF* to be used for the emissions caused by waste amounts landfilled in the previous years (and degraded later in year t) as well. In Finland, this is also valid for closed landfills (which were unmanaged when used) because all the closed landfills have been covered since 2002. The modified equation can be seen in Appendix_7a at the end of Chapter 7.

7.2.2.2 Emission factors and other parameters

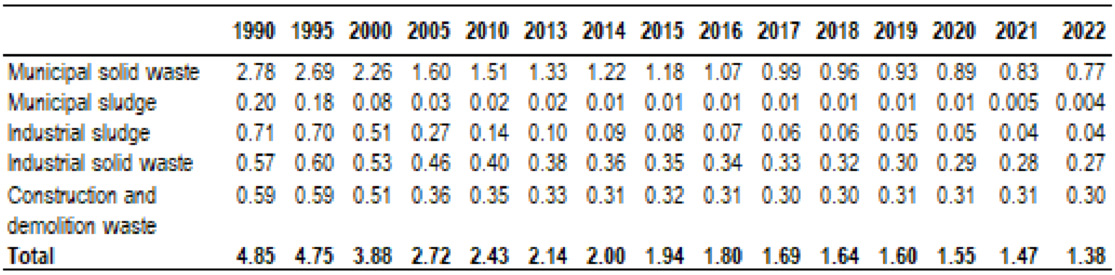
The parameters used in the calculation are mainly the 2006 IPCC Guidelines' default values. Some country-specific emission parameters (factors) are used (Table 7.2-2). The selection of parameters is in full agreement with the information and data ranges given in the 2006 IPCC Guidelines.

Table 7.2-2 Emission factors and parameters used in calculations (country-specific (CS) expert estimations or IPCC default values (D))

Factor/parameter	Value	Type of emission factor
DOC (Fraction of degradable organic carbon in municipal solid waste)	Between 0.172 and 0.186	D/CS Based on waste composition, varies in time series
DOCF (Fraction of DOC dissimilated)	0.5	D
F (Fraction of methane in landfill gas)	0.5	D
OX (Oxidation factor)	0.1	D
Methane generation rate constants; k1 = wastewater sludges, food waste k2 = wood waste, de-inking sludge k3 = paper waste, textile waste k4 = garden waste, napkins, fibre and coating sludges More detailed categories see Table 7.2-5.	k1 = 0.185 k2 = 0.03 k3 = 0.06 k4 = 0.1	D/CS 2006 IPCC Guidelines
MCF (Methane correction factor)	In 1990: 0.982 In 1991: 0.985 In 1992-1996: 0.988 In 1997-2001: 0.994 Since 2002: 1.0	D/CS; weighted mean value of the default values of 1 and of 0.4. Varies between the years, is 1 after 2002.

The historical development from 1948 to 1990 (until 1948 MCF is 0.4) of the methane correction factor is presented in Table 7.2-4. Between the years presented in the table, MCF is linearly growing. The weighted mean values of the MCF presented in Table 7.2-4 are obtained respectively (e.g. the share of the waste amount under degradation is 0.99 from managed landfills and 0.01 from unmanaged shallows resulting in the weighted value of 0.994 in 1997 to 2001).

Table 7.2-3 CH_4 emissions from solid waste disposal on land by subcategory (Mt CO_2 eq.)



	1990	1995	2000	2005	2010	2013	2014	2015	2016	2017	2018	2019	2020	2021	2022
Municipal solid waste	2.78	2.69	2.26	1.60	1.51	1.33	1.22	1.18	1.07	0.99	0.96	0.93	0.89	0.83	0.77
Municipal sludge	0.20	0.18	0.08	0.03	0.02	0.02	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.005	0.004
Industrial sludge	0.71	0.70	0.51	0.27	0.14	0.10	0.09	0.08	0.07	0.06	0.06	0.05	0.05	0.04	0.04
Industrial solid waste	0.57	0.60	0.53	0.46	0.40	0.38	0.36	0.35	0.34	0.33	0.32	0.30	0.29	0.28	0.27
Construction and demolition waste	0.59	0.59	0.51	0.36	0.35	0.33	0.31	0.32	0.31	0.30	0.30	0.31	0.31	0.31	0.30
Total	**4.85**	**4.75**	**3.88**	**2.72**	**2.43**	**2.14**	**2.00**	**1.94**	**1.80**	**1.69**	**1.64**	**1.60**	**1.55**	**1.47**	**1.38**

Table 7.2-4 The historical development of MCF

	1948	1970	1983	1986	1990
Weighted MCF	0.4	0.796	0.952	0.97	0.982
Share of managed (MCF=1) SWDS	0	0.66	0.92	0.95	0.97

The use of other values than the IPCC default values is justified by international and national research. *OX* is chosen to be 10% of the CH_4 generated at landfills based on international research (e.g. Oonk & Boom 1995).

DOC fractions of different types of waste are based on the 2006 IPCC Guidelines' default values and national research data (Isännäinen 1994) and measurements, made in industry (DOC value for de-inking sludges) (Huttunen 2008). For MSW, 2006 IPCC Guidelines' default values of DOC fractions (wood 0.43, paper 0.4, napkins and textiles 0.24, food 0.15 and garden 0.2) are used and, in addition, the waste subgroup Other organic has the DOC fraction of 0.1. The DOC value of 0.5 is used for other municipal sludges from handling plants, except for composted sludges where the DOC value of 0 is used. The waste composition of MSW is presented in Table 7.2-6. The waste compositions and DOC values of construction and demolition waste (mixed) are based on a research by VTT Technical Research Centre of Finland Ltd (Perälä & Nippala 1998) and an expert estimate by Perälä (Perälä 2001).

Table 7.2-5 The waste groups and the waste subgroups and the corresponding *DOC* and *k* values

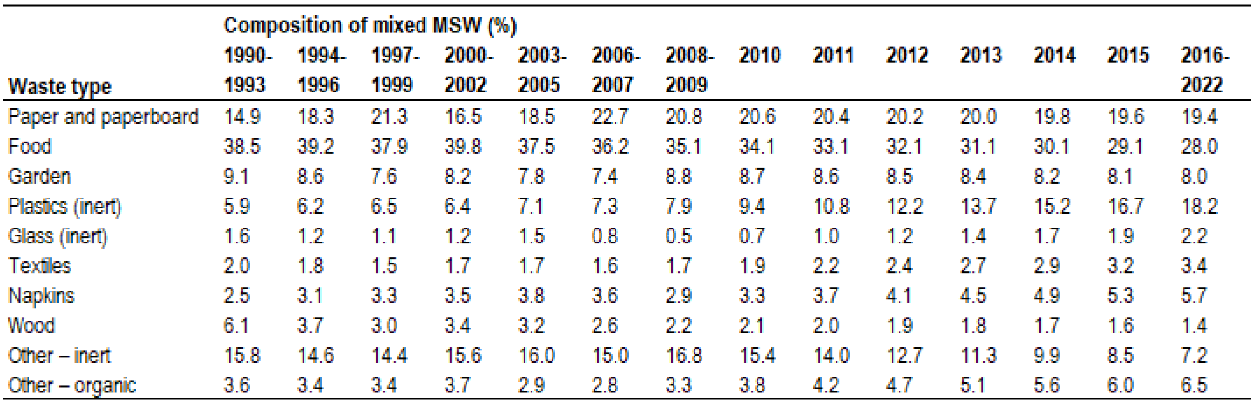
Waste group and subgroups	*DOC*	*k*	DOC Reference*
Solid municipal waste			
Textiles	0.24	0.06	2006 IPCC GLs
Food	0.15	0.185	2006 IPCC GLs
Paper	0.4	0.06	2006 IPCC GLs
Wood	0.43	0.03	2006 IPCC GLs
Garden	0.2	0.1	2006 IPCC GLs
Napkins	0.24	0.1	2006 IPCC GLs
Mixed packaging	0.1	0.06	Expert knowledge: Jouko Petäjä 2007 (DOC same as other organic, k same as paper)
Other organic	0.1	0.1	Pipatti 2001
Municipal sludge (from dry matter)			
Handling plants	0.5	0.185	Pipatti 2001
Septic tanks	0.5	0.185	Expert knowledge: Jouko Petäjä 2002 (DOC=0.5 same as for handling plants)
Sand separation	0.1	0.185	Expert knowledge: Jouko Petäjä 2002 (sludge fraction 20%; DOC=0.5 same as for handling plants)
Industrial sludge (from dry matter)			
Pulp and paper (mainly wastewater sludges)	0.45	0.185	Isännäinen, 1994
Other industry (mainly wastewater sludges)	0.45	0.185	Pipatti 2001
De-inking (pulp industry)	0.1	0.03	Huttunen 2008
Fibre and coating (paper industry)	0.1	0.1	Pipatti, 2001
Solid industrial waste			
Textile	0.24	0.06	2006 IPCC GLs
Food	0.15	0.185	2006 IPCC GLs

Waste group and subgroups	*DOC*	*k*	DOC Reference*
Paper	0.4	0.06	2006 IPCC GLs
Wood	0.43	0.03	2006 IPCC GLs
Garden	0.2	0.1	2006 IPCC GLs
De-inking reject	0.1	0.06	Pipatti 2001
Oil	0.1	0.1	Pipatti 2001
Green liquor sludge (from dry matter)	0.02	0.03	Expert knowledge: Jouko Petäjä 2003 (almost inert, only minor residues of wood)
Mixed packaging and other organic (slowly)	0.1	0.06	Expert knowledge: Jouko Petäjä 2007 (DOC same as other organic, k same as paper)
Other organic (moderately degrading)	0.1	0.1	Expert knowledge: Jouko Petäjä 2007 (same as other organic in MSW)
Construction and demolition waste			
Plastics	0		2006 IPCC GLs
Other inert	0		2006 IPCC GLs
Asphalt and tar	0.02	0.06	Expert knowledge: Jouko Petäjä 2003 (almost inert)
Wood	0.43	0.03	2006 IPCC GLs
Mixed (years 1997-1999)	0.0996	0.03	Perälä & Nippala, 1998
Mixed (years 2000-2013)	0.1384	0.03	Perälä, 2001
Total (years 1990-1996)	0.096-0.106	0.03	Calculated
Paper (packaging)	0.24	0.06	2006 IPCC GLs
Textile (packaging)	0.43	0.06	2006 IPCC GLs
Other (packaging)	0.1	0.06	Expert knowledge: Jouko Petäjä 2007 (DOC same as other organic, k same as paper)
Industrial and municipal inert waste			
Plastics	0		2006 IPCC GLs
Other combustible	0		2006 IPCC GLs
Other non-combustible	0		2006 IPCC GLs
Ash	0		2006 IPCC GLs
Other sludges (mainly from inorganic processes)	0		2006 IPCC GLs
Other inert waste			
Mine	0		2006 IPCC GLs
Soil	0		2006 IPCC GLs

** Reference for k values: 2006 IPCC Guidelines*

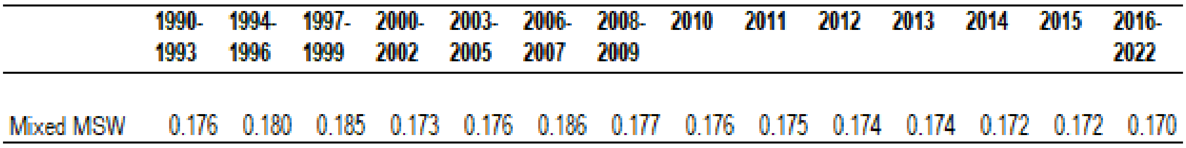
The waste composition of solid municipal waste was calculated according to the estimated composition of generated municipal waste and separately collected waste fractions (top-down approach) until 2008-2009. Especially concerning paper and paperboard, there is wide information on domestic consumption and recycling. However, in recent years there were unclear fluctuations in the paper and paperboard data and the composition of solid municipal waste was reassessed after 2009 in the 2020 submission. This estimation is based on the modelled waste composition of mixed MSW in services (Sahimaa 2017) and on the data bank of the waste composition studies in Finland on mixed MSW in households (KIVO 2019). The situation in 2016 was estimated according to the above-mentioned references and the years 2010-2015 were interpolated. After 2016 the composition is kept constant because the mixed MSW was allowed to be landfilled only by exceptional permits (the ban of organic waste to landfills).

Table 7.2-6 The estimated waste composition of solid municipal waste



	Composition of mixed MSW (%)													
Waste type	**1990-1993**	**1994-1996**	**1997-1999**	**2000-2002**	**2003-2005**	**2006-2007**	**2008-2009**	**2010**	**2011**	**2012**	**2013**	**2014**	**2015**	**2016-2022**
Paper and paperboard	14.9	18.3	21.3	16.5	18.5	22.7	20.8	20.6	20.4	20.2	20.0	19.8	19.6	19.4
Food	38.5	39.2	37.9	39.8	37.5	36.2	35.1	34.1	33.1	32.1	31.1	30.1	29.1	28.0
Garden	9.1	8.6	7.6	8.2	7.8	7.4	8.8	8.7	8.6	8.5	8.4	8.2	8.1	8.0
Plastics (inert)	5.9	6.2	6.5	6.4	7.1	7.3	7.9	9.4	10.8	12.2	13.7	15.2	16.7	18.2
Glass (inert)	1.6	1.2	1.1	1.2	1.5	0.8	0.5	0.7	1.0	1.2	1.4	1.7	1.9	2.2
Textiles	2.0	1.8	1.5	1.7	1.7	1.6	1.7	1.9	2.2	2.4	2.7	2.9	3.2	3.4
Napkins	2.5	3.1	3.3	3.5	3.8	3.6	2.9	3.3	3.7	4.1	4.5	4.9	5.3	5.7
Wood	6.1	3.7	3.0	3.4	3.2	2.6	2.2	2.1	2.0	1.9	1.8	1.7	1.6	1.4
Other – inert	15.8	14.6	14.4	15.6	16.0	15.0	16.8	15.4	14.0	12.7	11.3	9.9	8.5	7.2
Other – organic	3.6	3.4	3.4	3.7	2.9	2.8	3.3	3.8	4.2	4.7	5.1	5.6	6.0	6.5

Table 7.2-7 DOC-values of municipal solid waste



	1990-1993	1994-1996	1997-1999	2000-2002	2003-2005	2006-2007	2008-2009	2010	2011	2012	2013	2014	2015	2016-2022
Mixed MSW	0.176	0.180	0.185	0.173	0.176	0.186	0.177	0.176	0.175	0.174	0.174	0.172	0.172	0.170

7.2.2.3 Activity data

The activity data used in the calculation are taken from the YLVA (formerly VAHTI) system (see Section 1.3 and Annex 6). It includes information on all landfills in Finland excluding Åland, which is estimated according to the population. YLVA contains data on the total amounts of waste taken to landfills from 1997 onwards. In YLVA, the waste amounts are registered according to the EWC (European Waste Catalogue) classification (both EWC 1997 and EWC 2002). Sampling routines have been developed to convert the classification of the YLVA system to the classification used in the emission estimations. Corresponding data (but with volume units and a less detailed waste classification) for 1992 to 1995 were collected to the Landfill Registry of Syke. The activity data for municipal waste for 1990 are based on the estimates of the Advisory Board for Waste Management (1992) for municipal solid waste generation and treatment in Finland in 1989 with the correction of double counting in paper waste data (part of industrial paper waste was classified as municipal waste). The disposal data (amount and composition) at the beginning of the 1990s for industrial, construction and demolition waste are based on surveys and research by Statistics Finland (Isaksson 1993; Puolamaa et al. 1995), VTT (Perälä & Nippala 1998; Pipatti et al. 1996) and the National Board of Waters and the Environment (Karhu 1993). For the base year, activity data from studies by Isaksson (1993) and Pipatti et al. (1996) are used for construction and demolition waste, by Karhu (1993 for industrial sludges, and by Puolamaa et al. (1995) for solid industrial waste.

The amount of landfilled waste from 1990 to 2022 is presented in Table 7.2-8. The corresponding DOC tonnes are given in Table 7.2-9. The waste composition of landfilled industrial solid waste is presented in Appendix_7c and the DOC share of the landfilled industrial solid waste without inert industrial wastes is presented in Table 7.2-11. The industrial solid waste category consists of several hundreds of EWC -codes (EWC principal groups 02-16 and 18-19). The previous UNFCCC review encouraged Finland to provide information on clinical waste management practices and regulations, in order to improve the transparency of the inventory submission. The industrial EWC codes include, among others, the category health service activities including clinical wastes. Part of the clinical wastes are landfilled (separately or if non-hazardous among other wastes). These waste amounts are known quite well according to the exact EWC -codes. The burned or incinerated clinical waste amounts are not known so well (part of burned industrial wastes are reported by fuel codes only). The composition of industrial solid waste is presented according to the DOC and decay groups in Appendix_7c. The relatively large variation in the waste amounts of industrial solid waste is due to the diverse reporting practices of some inert waste types to the YLVA system.

The landfilled amounts of municipal solid waste have decreased clearly during recent years because of increased energy use of waste. The amount of construction and demolition waste has also decreased significantly since 1990. On the other hand, the amount of rejects from wood waste handling has increased due to the discharge of reject stocks to landfills. Also, industrial wastes have decreased significantly due to energy use of wastes in industry.

Estimated data on waste amounts before the year 1990 are based on the report of VTT (Tuhkanen 2002). In this report, GDP has a 30% weight and population has a 70% weight for generated municipal solid waste. At the beginning of 1900s, all the generated municipal solid waste was assumed to be landfilled and landfilling has a linear development to 80% of waste being landfilled in the year 1990. Other waste groups develop according to the corresponding industrial or construction economical activities. The DOC tonnes of the five waste groups starting from 1900 are presented in Figure 7.2-2.

Data on landfill gas recovery are obtained from the Finnish National Biogas Statistics (Huttunen et al. 2018) and from survey by Statistics Finland (2020, 2021a, 2021b, 2022b and 2023b) and are presented in Table 7.2-10 and in Appendix_7b (Number of landfill gas recovery plants in size categories and volume of collected gas). The great increase in the amounts of recovered methane at the beginning of 2000 comes from the regulations of landfill gas recovery (Council of State Decree 861/1997 on Landfills). The amounts of recovered methane in the recent years have decreased due to the great decrease of the waste amounts to landfills (the ban of organic wastes). Landfill gas recovery data in the Finnish Biogas Plant Register is based on information received from plants. In general, the volumes of landfill gas recovery are based on continuous measurements (Pitot tube or turbine meter) and on individual measurements (1-12 times per year) on methane content. However, these methane content values are not used in the inventory. The default value of 0.5 used in the inventory corresponds very well to the average value of these measurements. In some cases, volume metering has failed and then gas recovery was estimated, e.g. according to energy production and operating hours. If no information is available from a plant, no recovery is assumed. Some earlier estimated (2021 submission) gas recoveries for small plants in 2019 were updated by Statistics Finland (2021a). Also, gas recoveries from a small plant (Leipälä 2020) were updated. Statistics Finland has collected data from biogas facilities since 2019. The questionnaire contains information on biogas metering and estimation, also.

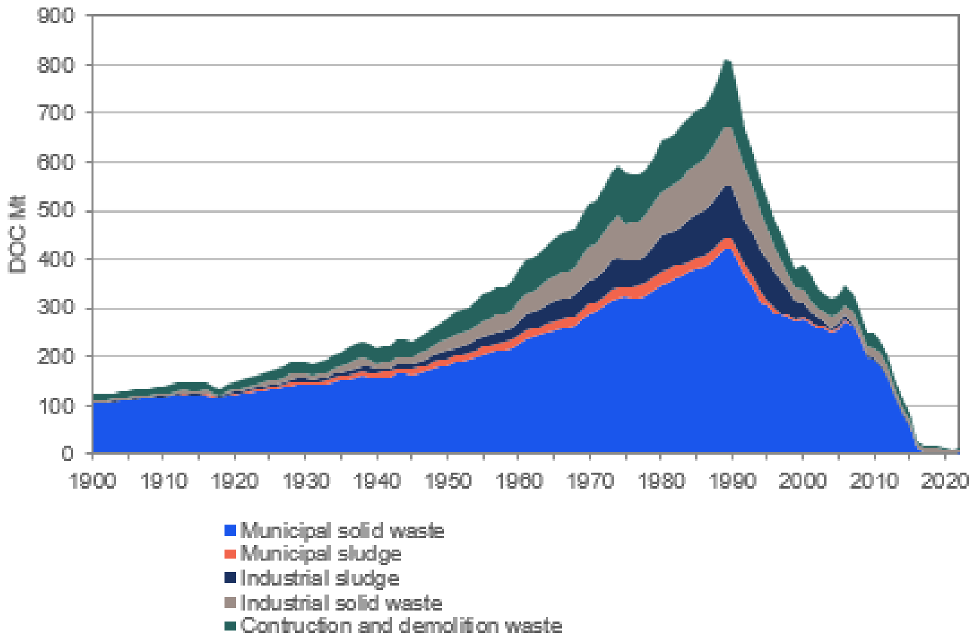


Figure 7.2-2 The DOC (Mt) of the five waste groups starting from 1900

Table 7.2-8 Landfilled waste (1,000 t). (YLVA system, Landfill Registry of Syke, Advisory Board for Waste Management 1992, Vahvelainen and Isaksson 1992, Isaksson 1993, Pipatti et al. 1996, Puolamaa et al. 1995, Perälä & Nippala 1998, Karhu 1993.

Waste group	1990	1995	2000	2005	2010	2013	2014	2015	2016	2017	2018	2019	2020	2021	2022
Municipal solid waste	2 400	1 682	1 616	1 463	1 093	679	449	316	78	19	15	25	15	13	11
Municipal sludge (d.m.)	47	25	6	6	3	3	2	2	0.9	0.2	0.1	0.1	0.1	0.1	0.1
Municipal sludge (wet m.)	498	298	70	53	23	23	17	14	7	3	2	2	3	2	3
Industrial sludge (d.m.)	337	260	120	44	26	32	19	7	3	3	3	2	4	2	2
Industrial sludge (wet m.)	1 193	881	562	151	83	94	43	21	10	10	11	11	21	9	7
Ind. solid waste (def. moist. m.)	1 985	1 382	1 917	3 771	2 839	2 705	2 629	2 600	2 517	2 336	2 300	2 160	2 093	2 496	2 196
Ind. solid waste (wet m.)	2 135	1 519	2 306	4 303	3 151	3 027	2 947	2 906	2 862	2 688	2 629	2 466	2 622	2 824	2 474
Constr. and demol. waste	1 262	637	445	388	350	192	182	163	102	112	116	132	100	97	98

Table 7.2-9 Landfilled waste (1,000 DOC t)

Waste group	1990	1995	2000	2005	2010	2013	2014	2015	2016	2017	2018	2019	2020	2021	2022
Municipal solid waste	422	303	279	255	192	118	77	54	13	3.0	2.5	3.3	2.3	2.1	1.8
Municipal sludge	24	12	3.2	2.8	1.5	1.5	1.2	1.1	0.5	0.1	0.1	0.1	0.05	0.04	0.03
Industrial sludge	103	81	26	8.8	4.5	4.2	2.4	2.1	1.1	1.3	1.1	0.7	1.8	0.6	1.0
Industrial solid waste	121	66	28	20	18	14	11	12	7.3	6.7	10	6.9	5.7	3.8	6.7
Constr. and demol. waste	134	61	55	39	35	19	17	14	6.0	4.2	4.4	4.4	2.8	2.5	3.0

Table 7.2-10 Landfill CH_4 recovery (kt) and the number of operating CH_4 recovery plants (Huttunen et. al. 2018, Biogas survey of Statistic Finland 2019, 2021a, 2021b, 2022 and 2023)

	1990	1995	2000	2005	2010	2013	2014	2015	2016	2017	2018	2019	2020	2021	2022
Recovery (kt)	0	2.84	16.24	42.51	36.61	34.18	33.89	30.04	28.42	26.08	21.96	18.36	15.25	13.89	13.2
Number	0	4	12	33	40	41	41	42	42	43	37	34	34	34	33

Table 7.2-11 DOC share in landfilled Industrial solid waste without inert industrial wastes (-)

	1990	1995	2000	2005	2010	2013	2014	2015	2016	2017	2018	2019	2020	2021	2022
DOC share (-)	0.188	0.154	0.101	0.073	0.062	0.062	0.058	0.063	0.041	0.038	0.049	0.042	0.035	0.028	0.049

7.2.3 Uncertainty assessment and time series' consistency

Quantitative estimates of uncertainty are provided in Annex 2. The annex also documents assumptions made for the analysis. A description of the uncertainty analysis is included in Section 1.6.

The uncertainty in solid waste disposal is assessed by replacing the parameters of the FOD model with probability density functions describing the uncertainty. As a result of the simulation, uncertainty in the emission estimate of CH_4 from landfills contained an uncertainty of around -33% - +33% in 2022.

In Finland, the historical waste amount is assessed starting from 1900. The uncertainties in historical activity data (estimated on the basis of different weighting of the population and GDP that are assumed to be good indicators of the amount of waste) are large but the amount of waste produced at the beginning of the 1900s was fairly small, thus reducing the significance of large uncertainties. The uncertainty estimates of the current amounts of waste are based on differences between different statistics and complemented with an expert estimate.

In the case of municipal sludge, the uncertainties in both historical and current activity data are quite large. On the other hand, the amount of industrial waste can be fairly accurately estimated based on industrial production, and, therefore, these uncertainties are the smallest in historical years.

Parameters of the FOD model contain higher uncertainties than activity data. Uncertainties are mainly due to lack of knowledge of the waste degradation process. It is also unclear if the parameters of the model are suitable for Finnish conditions. The uncertainties in other calculation parameters of the FOD model are estimated using measurement data, IPCC default uncertainties and an expert estimate.

In Finland, the amount of landfill gas recovered is obtained from the Finnish Biogas Plant Register (Huttunen et. al. until 2018, Biogas survey of Statistic Finland from 2019 on), and this figure is considered accurate. An interesting note is that methane recovery describes the reduction of emissions compared with the situation where gas is emitted. In this case, the emission reduction is accurately known, though total emissions contain higher uncertainties. In 2005, in a well-managed landfill the measured gas recovery was greater than the modelled gas generation. No faults in recovery measurements were found and it was judged that the new extension of recovery pipelines brought extra gas from gas pockets. This situation has been repeated to some extent later on, also, but not anymore in recent years. At country level the figures are reasonable through the whole time series. Since 2005 the gas recovery has been 23-30% of the generated gas.

The uncertainty estimate was performed by integrating the Monte Carlo simulation straight to the FOD model. A possible model error is also assumed to be covered by the uncertainty estimates of the model parameters. A detailed description of the uncertainty analysis has been presented in Monni & Syri (2003) and Monni (2004).

The time series' consistency of rejects from wood waste has minor inconsistencies concerning the allocation of these wastes in 2005 to 2009. These rejects have been classified according to the origin (e.g. construction and demolition waste) of the wood waste since the 2010 inventory. These EWC codes (191212 and 191211) were classified only as solid industrial waste in earlier inventories but the waste amounts were much smaller before 2010.

7.2.4 Category-specific QA/QC and verification

The quality objectives and the QA/QC plan for the Finnish greenhouse gas inventory at the national inventory level are presented in Section 1.5. The QC procedures are performed according to the QA/QC plan in order to attain these quality objectives. Bilateral quality meeting was held between the inventory unit and the sectoral expert concerning the 2022 inventory. The common principles of the archiving guidelines of the waste sector are presented in Section 1.5.

General Quality Control (QC) procedures were applied in category CRF 5.A according to the 2006 IPCC Guidelines (Vol 1, Chapter 6, Table 6.1):

- Documentation on activity data and emission factors was crosschecked with the corresponding data in MS Access tables and calculation models.
- A sample of input data from each category was crosschecked for transcription errors.
- Units and conversion factors were checked.
- Database data relationships and data fields were checked. Database and data processing steps were documented.
- Consistency of DOC values in different groups (source categories) was checked.
- Data aggregation and transcription from lower reporting levels to higher levels were checked.
- The default value of 0.5 for methane content used in the inventory was compared to the average value of plant specific measurements.

Category-specific QC

The MSW generation rate and the MSW disposal rate of the inventory were compared with the corresponding country values of the 2006 IPCC Guidelines. The MSW generation rates correspond to each other and the present values in the inventory are quite near to the value of 0.5 of the IPCC Guidelines for the year 2000. The MSW disposal rate variates much during the time series. In 1990, the inventory value corresponds to value of 0.77 of the IPCC Guidelines and the value of 0.61 of the IPCC Guidelines corresponds inventory values up to the beginning of 2000's, but after that, the values in the inventory have developed considerably lower. The decrease has been mainly due to the preparation and implementation of the new Waste Act in Finland in 1994. At the beginning of the 1990s, around 80% of the generated municipal waste was taken to solid waste disposal sites (landfills). After the implementation of the new Waste Act, minimisation of waste generation, recycling and reuse of waste material and alternative treatment methods to landfills have been endorsed. Similar developments have occurred in the treatment of industrial waste, and municipal and industrial sludges.

The YLVA data were crosschecked with the data of previous years. The errors and faults discovered were corrected and documented. The most significant of them were checked either from the Centres for Economic Development, Transport and the Environment or from the companies that manage the landfills in question.

Country-specific emission factors were crosschecked and compared with IPCC default values. Emissions were also annually estimated with the IPCC mass balance method and with the original IPCC calculation formula of the FOD method in the GPG 2000 (without the modification explained in Section 7.2.2). Also, the emissions are estimated with the starting month 13 of the equations in 2006 IPCC Guidelines. The emissions and other information are calculated in Excel sheets according to the activity data from the database.

Quality assurance and verification

The guidance in the 2006 IPCC Guidelines for activity data collection in the waste sector is based on a top-down approach starting from default data on waste generation, which are then divided into waste streams by treatment type. In Finland, the activity data for waste treatment are based on bottom-up data collected from waste management operators (main source being the YLVA system, see Annex 6). The bottom-up data are more accurate (often measured data based on requirements in environmental permits) than data on estimates on waste generation, which are based on survey data. The QA and verification measures given in Section 3.8 of the Waste-volume cannot, therefore, be applied as such.

The results from biogas survey by Statistics Finland are also pre-checked as part of the inventory work.

The corrected activity data (from the YLVA system) of the landfilled municipal solid waste used in the submission for the inventory year 2022 are delivered to Statistics Finland for comparison with their own observations on the same initial data. The results from this QA procedure were completed before the inventory is submitted to UNFCCC. The activity data of the landfilled municipal solid waste were at the same level as the waste statistics delivered to Eurostat by Statistics Finland.

For example, the total amount of municipal waste generated in Finland in 2022 was estimated to be 2.9 million tonnes and the treatment of the municipal solid waste was divided into the following categories in 2022 (Statistics Finland 2024):

- Landfilling 0.4%
- Composting and anaerobic digestion 15%
- Material recycling 29%
- Burning and incineration 56%.

The estimated amounts of landfilled municipal solid waste in the inventory are in good agreement with this figure.

Measurements of landfill gas recovery at the largest solid waste disposal site in Finland have been studied in more detail (a visit on site) in 2010. The quite large annual fluctuation in the landfill gas recovery was explained by capacity changes and by the results from quite dense leakage measurements in the SWDS (see also Section 7.2.3). Also, the landfill gas concentration measurements and modelling results by the Finnish Meteorological Institute supported the results of the recovery measurements.

7.2.5 Category-specific recalculations

Recalculations have been made for the years 2011-2021 due to a minor correction to activity data of municipal solid waste in 2011.

7.2.6 Category-specific planned improvements

There are no planned improvements.

7.3 Biological Treatment of Solid Waste (CRF 5.B)

7.3.1 Composting (CRF 5.B.1)

7.3.1.1 Category description

Emissions of greenhouse gases N_2O and CH_4 from composting were estimated and they were 0.1 Mt CO_2 eq. in 2022. The emissions increased 1% since 2021. The emission source includes emissions from composting of biowastes (municipal solid waste, municipal and industrial sludges and industrial solid waste).

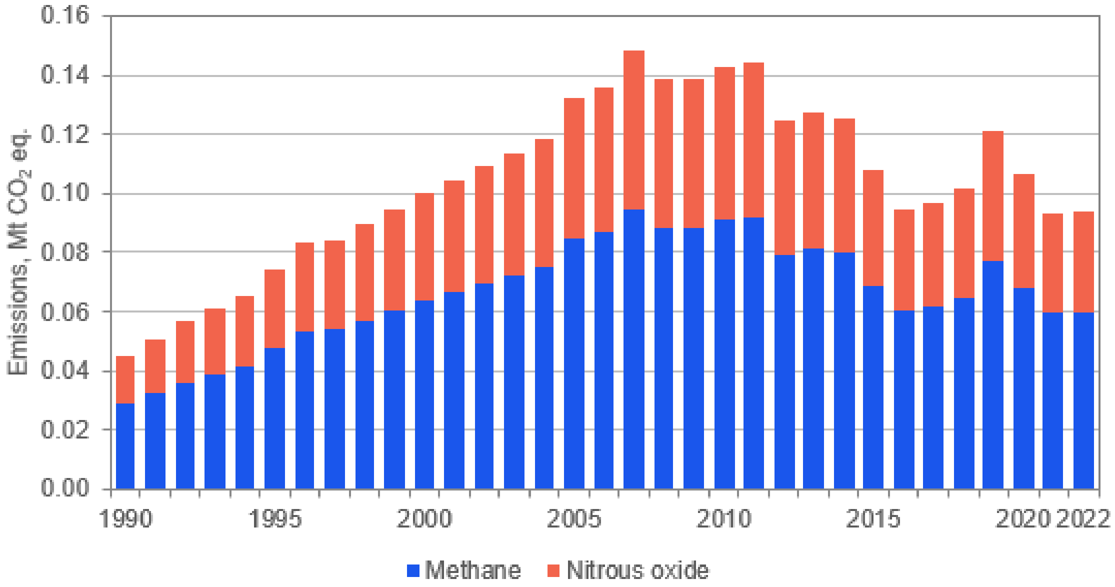


Figure 7.3-1 Greenhouse gas emissions from composting (Mt CO_2 eq.)

Table 7.3-1 Reported emissions, calculation methods and types of emission factors for the subcategory Composting in the Finnish inventory (D = default)

CRF	Source	Emissions reported	Methods	Emission factors
5.B.1	Composting			
	Municipal solid waste	CH_4, N_2O	Tier 1	D
	Municipal sludge	CH_4, N_2O	Tier 1	D
	Industrial sludge	CH_4, N_2O	Tier 1	D
	Industrial solid waste	CH_4, N_2O	Tier 1	D

Emissions from composting have more than doubled since 1990, being 5% of the waste sector's emissions in 2022. However, the emissions from composting have had a decreasing trend in recent years due to the growing share of anaerobic digestion. The emissions from composting have increased in 2019 mainly because of changes in treatment processes between composting and anaerobic digestion in a major biological treatment plant. The trend in emissions is presented by subcategory in Table 7.3-3. The waste amounts with degradable auxiliary matter (20 to 30%) in composting are presented in Table 7.3-4, correspondingly.

7.3.1.2 Methodological issues

Methods

Emissions from composting have been calculated using the method given in the 2006 IPCC Guidelines for National Greenhouse Gas Inventories.

Emissions (kt CH_4 or kt N_2O) = *AD* * *EF* / 1,000,000 where

AD = Waste amount with auxiliary matter (t)
EF = emission factor (g CH_4 or g N_2O /kg waste treated)

Emission factors

Emission factors in composting are presented in Table 7.3-2.

Table 7.3-2 Emission factors in composting (g CH_4/kg waste treated, g N_2O/kg waste treated) (2006 IPCC Guidelines)

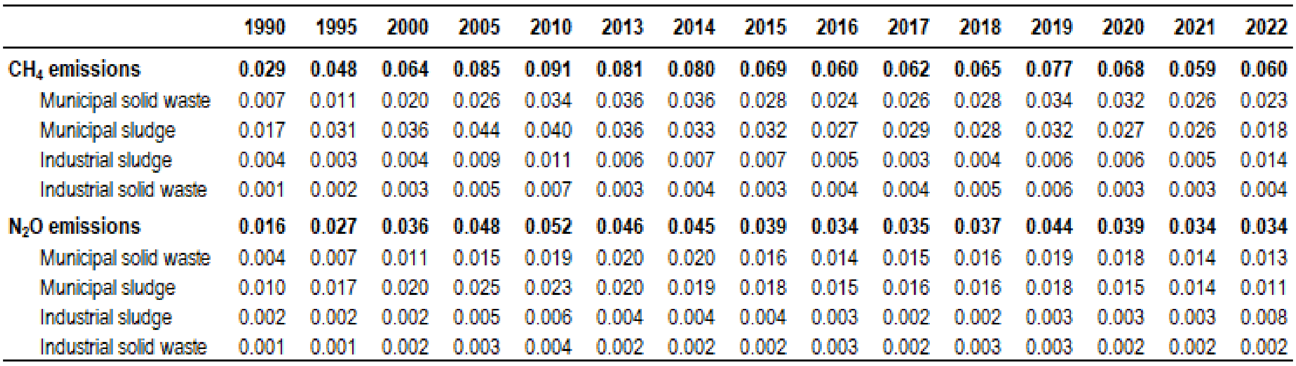
	CH_4 emission factor	N_2O emission factor
Municipal solid waste, Industrial solid waste	4	0.24
Municipal sludge, Industrial sludge (d.m.)	10	0.6

Activity data

Activity data are based on the YLVA system. The activity data for composted municipal biowaste for 1990 are based on the estimates of the Advisory Board for Waste Management (1992) for municipal solid waste generation and treatment in Finland in 1989. Data on 1997, 2004 and 2005 are from the YLVA system and the intermediate years have been interpolated. In addition, composted solid biowaste from 1991 to 1996 has been interpolated using auxiliary information from the National Waste Plan until 2005 (Ministry of the Environment 1998). The new composting treatment codes (R032, R03B and R3.2) and composting plant code in the YLVA system have been used in the data collection for 2006 to 2022. For 2021 and 2022, the composted municipal sludges are estimated either according to the removed outgoing sludges from municipal wastewater plants to composting pants or according to the incoming sludges to the on-site composting plants depending on the data available. However, some Centres for Economic Development, Transport and the Environment have failed several years also in reporting these wastewater sludges to YLVA system and copied yearly data are used in these cases. In earlier submissions the composted sludges were estimated according to the total outcoming amount of sludges and the use of sludges in anaerobic digestion and according to the estimated sludge amounts in agriculture and in landscaping. The classification to the reporting subgroups is based on the EWC codes of composted wastes (like landfilled wastes with the exception of construction wastes). The amounts of composted sludges have turned down after 2006. In recent years, anaerobic digestion plants have been built in Finland, which is probably the main reason for this development.

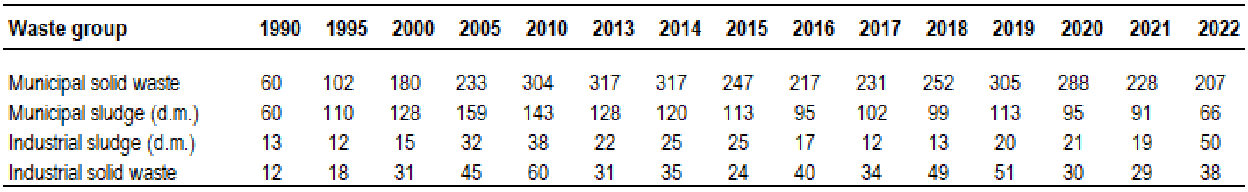
Degradable auxiliary material used in composting is included in the activity data. The shares have been estimated to be 20% (solid wastes) or 30% (sludges) for the whole time series (Petäjä 2005). In every composting plant, the share of auxiliary matter is assumed to be 20% (solid wastes) or 30% (sludges). These amounts are estimated according to plant level data from the YLVA system but the reporting practices of auxiliary matter varies considerably in the YLVA system. Also, the origin of auxiliary matter varies among composting plants: some part of the auxiliary matter is wood waste from construction and demolition waste and some part is raw material.

Table 7.3-3 Emissions from composting by subcategory (Mt CO_2 eq.)



	1990	1995	2000	2005	2010	2013	2014	2015	2016	2017	2018	2019	2020	2021	2022
CH_4 emissions	**0.029**	**0.048**	**0.064**	**0.085**	**0.091**	**0.081**	**0.080**	**0.069**	**0.060**	**0.062**	**0.065**	**0.077**	**0.068**	**0.059**	**0.060**
Municipal solid waste	0.007	0.011	0.020	0.026	0.034	0.036	0.036	0.028	0.024	0.026	0.028	0.034	0.032	0.026	0.023
Municipal sludge	0.017	0.031	0.036	0.044	0.040	0.036	0.033	0.032	0.027	0.029	0.028	0.032	0.027	0.026	0.018
Industrial sludge	0.004	0.003	0.004	0.009	0.011	0.006	0.007	0.007	0.005	0.003	0.004	0.006	0.006	0.005	0.014
Industrial solid waste	0.001	0.002	0.003	0.005	0.007	0.003	0.004	0.003	0.004	0.004	0.005	0.006	0.003	0.003	0.004
N_2O emissions	**0.016**	**0.027**	**0.036**	**0.048**	**0.052**	**0.046**	**0.045**	**0.039**	**0.034**	**0.035**	**0.037**	**0.044**	**0.039**	**0.034**	**0.034**
Municipal solid waste	0.004	0.007	0.011	0.015	0.019	0.020	0.020	0.016	0.014	0.015	0.016	0.019	0.018	0.014	0.013
Municipal sludge	0.010	0.017	0.020	0.025	0.023	0.020	0.019	0.018	0.015	0.016	0.016	0.018	0.015	0.014	0.011
Industrial sludge	0.002	0.002	0.002	0.005	0.006	0.004	0.004	0.004	0.003	0.002	0.002	0.003	0.003	0.003	0.008
Industrial solid waste	0.001	0.001	0.002	0.003	0.004	0.002	0.002	0.002	0.003	0.002	0.003	0.003	0.002	0.002	0.002

Table 7.3-4 Composted waste with degradable auxiliary matter by subcategory (1,000 t)



Waste group	1990	1995	2000	2005	2010	2013	2014	2015	2016	2017	2018	2019	2020	2021	2022
Municipal solid waste	60	102	180	233	304	317	317	247	217	231	252	305	288	228	207
Municipal sludge (d.m.)	60	110	128	159	143	128	120	113	95	102	99	113	95	91	66
Industrial sludge (d.m.)	13	12	15	32	38	22	25	25	17	12	13	20	21	19	50
Industrial solid waste	12	18	31	45	60	31	35	24	40	34	49	51	30	29	38

7.3.1.3 Uncertainty assessment and time series' consistency

Quantitative estimates of uncertainty are provided in Annex 2. The annex also documents assumptions made for the analysis. A description of the uncertainty analysis is included in Section 1.6.

The YLVA system had no treatment code solely for composting for the years 1997 to 2005 and the new code for composting was introduced in 2006 and the use of this code might still have been slightly unreliable. This has meant manual work in complementing the activity data and the uncertainties in the data (±40 in 1990, ±30% in the early 2000s to ±25 since 2017, Petäjä 2005 and Petäjä 2012) are higher than in the activity data on landfilled wastes. In addition, several wastewater handling plants do not report separately the incoming wastes to their own composting plants and the sludges are reported only in the outgoing wastes from these handling plants. Manual crosschecking of data has been necessary because there is also the option that the sludges are delivered to be composted outside the handling plant to other companies. For this reason the activity data from 2006 to 2022 were collected in the way described in the previous section. Also, the annual data from smaller composting plants, which are monitored by municipalities (and not by Centres for Economic Development, Transport and the Environment) is not available in YLVA, anymore. At least part of these waste amounts are identified by crosschecking the outgoing wastes and by utilising the report from composting plants (Merilehto 2016). This means that the uncertainties of the activity data will remain on quite a high level in future also.

The uncertainties of the emission factors are according to the range variations given in the 2006 IPCC Guidelines' default emission factors.

The calculation method for composting is the same through the whole time series. The time series for activity data are gathered in a consistent manner (e.g. waste groups) even if the origin of the activity data varies (see previous section).

7.3.1.4 Category-specific QA/QC and verification

The QC procedures are performed according to the QA/QC and verification plan in order to attain quality objectives. Bilateral quality meeting was held between the inventory unit and the sectoral expert concerning the 2022 inventory.

Composting plants (incoming waste flows) and outgoing waste flows to composting processes from the YLVA system were compared to the governmental survey from composting plants and their environmental permits by Syke and the Ministry of the Environment (Merilehto 2016). The municipal sludge amounts are consistent with the report of Finnish Water Utilities Association (2017).

General Quality Control (QC) procedures were applied in composting according to the 2006 IPCC Guidelines (Vol 1, Chapter 6, Table 6.1):

- Documentation on activity data and emission factors was crosschecked with the corresponding data in the calculation model.
- A sample of input data from each category was crosschecked for transcription errors.
- Units and conversion factors were checked.
- Data aggregation and transcription from lower reporting levels to higher levels were checked.

The data from Statistics Finland on biological treatment of municipal solid waste in 2022 (see end of Section 7.2.4) are in good agreement with the data used in the inventory.

7.3.1.5 Category-specific recalculations

No recalculations have been made.

7.3.1.6 Category-specific planned improvements

There are no planned improvements.

7.3.2 Anaerobic digestion at biogas facilities (CRF 5.B.2)

7.3.2.1 Category description

Emissions of greenhouse gas CH_4 from biogas facilities were estimated and they were 0.01 Mt CO_2 eq. in 2022. The emission source includes emissions from anaerobic digestion of biowastes (municipal solid waste, municipal and industrial sludges and industrial solid waste including construction waste).

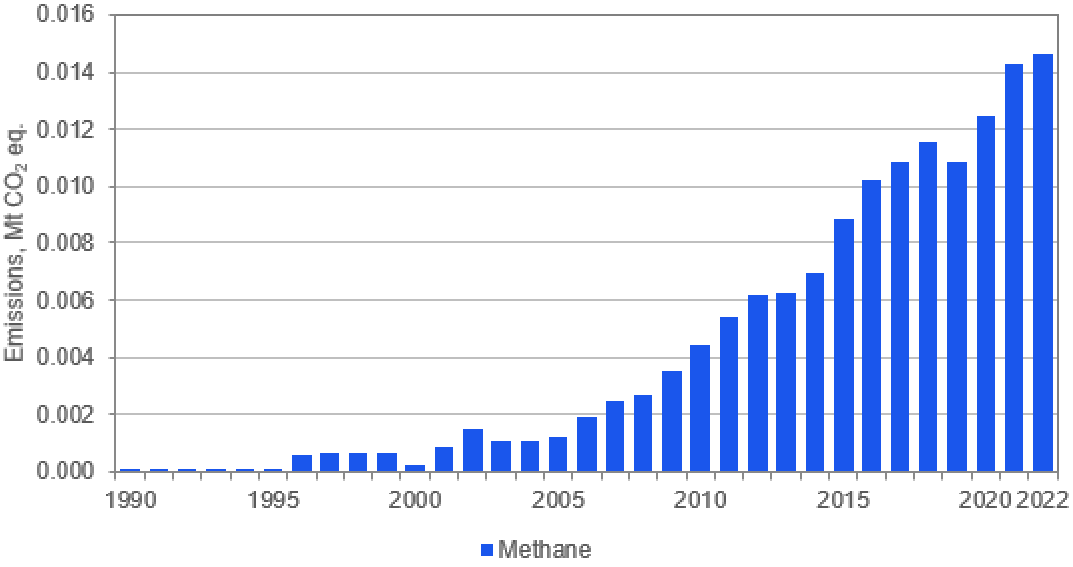


Figure 7.3-2 Methane emissions from anaerobic digestation (Mt CO_2 eq.)

Table 7.3-5 Reported emissions, calculation methods and types of emission factors for the subcategory Anaerobic digestion in the Finnish inventory (D = default)

CRF	Source	Emissions reported	Methods	Emission factors
5.B.2	Anaerobic digestion at biogas facilities			
	Municipal solid waste	CH_4	Tier 1	D
	Municipal sludge	CH_4	Tier 1	D
	Industrial sludge	CH_4	Tier 1	D
	Industrial solid waste incl. constr. waste	CH_4	Tier 1	D

Emissions from anaerobic digestion have increased significantly in recent years. Yet, this emission source is very small being 0.8% of the waste sector's total emissions in 2022. The trend in the emissions is presented by subcategory in Table 7.3-7 and the waste amounts in anaerobic digestion are presented in Table 7.3-8.

7.3.2.2 Methodological issues

Methods

Emissions from anaerobic digestion have been calculated using the method given in the 2006 IPCC Guidelines for National Greenhouse Gas Inventories.

Emissions (kt CH_4 or kt N_2O) = *AD* * *EF* / 1,000,000

where

AD = Waste amount (t)
EF = emission factor (g CH_4 /kg waste treated)

Emission factors

Emission factors in anaerobic digestion are presented in Table 7.3-6.

Table 7.3-6 Emission factors in anaerobic digestion (g CH_4/kg waste treated) (2006 IPCC Guidelines)

	CH_4 emission factor
Municipal solid waste, Industrial solid waste including construction waste	0.8
Municipal sludge, Industrial sludge (d.m.)	2

Activity data

Activity data are based on the YLVA system and extrapolated data from digestion plants operating in 1990 to 1995 (using municipal sludges). The classification to the reporting subgroups is based on the EWC codes of the treated wastes. In recent years, several anaerobic digestion plants have been built in Finland, which has multiplied the waste amounts and emissions from anaerobic digestation since 2005. The waste amounts in anaerobic digestation are presented in Table 7.3-8.

Table 7.3-7 Emissions from anaerobic digestion by subcategory (kt CO_2 eq.)

	1990	**1995**	**2000**	**2005**	**2010**	**2013**	**2014**	**2015**	**2016**	**2017**	**2018**	**2019**	**2020**	**2021**	**2022**
Methane emissions	0.10	0.10	0.23	1.25	4.41	6.23	6.93	8.81	10.25	10.88	11.56	10.88	12.50	14.28	14.66
Municipal solid waste	NO	NO	0.08	0.95	1.62	2.03	2.42	3.98	4.58	4.60	4.58	4.54	5.01	5.68	6.24
Municipal sludge	0.10	0.10	0.15	0.16	1.27	2.22	2.56	2.79	3.09	2.86	2.83	2.79	3.05	3.75	3.32
Industrial sludge	NO	NO	NO	0.03	0.05	0.28	0.20	0.25	0.16	0.75	1.20	0.94	1.05	0.81	0.64
Industrial solid and constr. waste	NO	NO	NO	0.11	1.48	1.70	1.75	1.80	2.43	2.67	2.94	2.61	3.39	4.05	4.46

Table 7.3-8 Waste amounts in anaerobic digestion by subcategory (1,000 t)

	1990	**1995**	**2000**	**2005**	**2010**	**2013**	**2014**	**2015**	**2016**	**2017**	**2018**	**2019**	**2020**	**2021**	**2022**
Municipal solid waste	NO	NO	3.8	42.4	72.2	90.4	108.0	177.6	204.6	205.6	204.6	202.7	223.6	253.5	278.4
Municipal sludge (d.m.)	1.8	1.8	2.6	2.9	22.6	39.6	45.7	49.8	55.1	51.0	50.6	49.9	54.4	66.9	59.3
Industrial sludge (d.m.)	NO	NO	NO	0.5	0.8	5.1	3.6	4.4	2.8	13.4	21.5	16.8	18.8	14.5	11.3
Industrial solid and constr. waste	NO	NO	NO	5.0	66.1	75.9	78.3	80.4	108.4	119.0	131.4	116.5	151.2	180.7	199.3

7.3.2.3 Uncertainty assessment and time series consistency

Quantitative estimates of uncertainty are provided in Annex 2. The annex also documents assumptions made for the analysis. A description of the uncertainty analysis is included in Section 1.6.

The YLVA system had no treatment code solely for anaerobic digestion for 1996 to 2005 and the new code for anaerobic digestion was introduced in 2006 and the use of this code might still have been slightly unreliable. However, the years before 2006 are not a major problem because only one digestion plant was operating in these years. Also, anaerobic digestion plants are quite large units and are all found in the YLVA system. For these reasons the uncertainties (±20% in 1990 to 1995 and after that ±10%) are smaller than in composting (Petäjä 2015).

The uncertainties of the emission factors are based on the range variations of the 2006 IPCC Guidelines' default emission factors. The calculation method for anaerobic digestion is the same through the whole time series. The time series for activity data ate gathered in a consistent manner (e.g. waste groups).

7.3.2.4 Category-specific QA/QC and verification

The QC procedures are performed according to the QA/QC and verification plan in order to attain quality objectives. In 2024 a bilateral quality meeting was held between the inventory unit and the sectoral expert concerning the 2022 inventory.

Anaerobic digestion plants from the YLVA system were compared to the governmental survey from anaerobic digestion (and composting) plants and their environmental permits by Syke and the Ministry of the Environment (Merilehto 2016). The municipal sludge amounts are consistent with the report of Finnish Water Utilities Association (2017).

General Quality Control (QC) procedures were applied in anaerobic digestion according to the 2006 IPCC Guidelines (Vol 1, Chapter 6, Table 6.1)

- Documentation on activity data and emission factors was crosschecked with the corresponding data in the calculation model.
- A sample of input data from each category was crosschecked for transcription errors.
- Units and conversion factors were checked.
- Data aggregation and transcription from lower reporting levels to higher levels were checked.

7.3.2.5 Category-specific recalculations

No recalculations have been made.

7.3.2.6 Category-specific planned improvements

No planned improvements.

7.4 Incineration and open burning of waste (CRF 5.C)

Emissions of greenhouse gases CO_2, N_2O and CH_4 from Waste Incineration (CRF 5.C) are reported in the energy sector (CRF 1.A) in the Finnish inventory. Emission factors are presented in Table 3.2-4, Table 3.2-6 and Table 3.2-7 .

There is no waste incineration on landfills in Finland and waste incineration for energy production is included in the energy sector. Waste incineration in combustion plants without energy recovery is nearly zero and it is also included in the energy sector. Waste incineration in households is quite small. In annual reporting of the recycling of wastepaper (according to the decision of the Council of State 883/1998), the incineration of wastepaper in households is estimated to be only 23,000 tonnes. The incineration of paper and paperboard in households (in boilers, stoves, fireplaces and sauna ovens) is estimated to be 31,000 tonnes of which the maximum amount of illegal open burning would be 0.1% (30 tons). Based on an expert judgement, the amount of garden waste in open burning by households (regulated by municipalities) is about 200 tonnes. As a consequence, the total amount of open burning of waste by households is only around 230 tonnes. With the exception of garden wastes of households open burning of waste is not allowed in Finland and unintentional fires are very uncommon. The emissions from open burning of waste by households is thus estimated to be insignificant (<0.1 kt CO_2 eq.) in Finland and the source is included in the list of insignificant sources in Section 1.7. Hazardous wastes are burned (with energy recovery and therefore reported under Energy) mainly in one plant in Finland and the mass of these wastes was approximately 100,000 tons in 2021.

According to the Waste decree, if the energy efficiency is over 65% waste burning is considered as energy use of waste and the corresponding treatment codes R01 and R1 can be used. If the energy efficiency is under 65% the treatment code D10 (incineration) should be used. Waste statistics are compiled according to these codes and, in Finland, 0.18% of total municipal solid waste has been incinerated (energy efficiency under 65%) and 62.3% has been burned for energy use (energy efficiency over 65%) in 2021 (Statistics Finland 2022b). Low energy efficiencies (D10 incineration) are associated with burning of poor-quality waste. In Finland, almost all poor-quality waste components have been burned with better waste components and the energy efficiency would be over 65% at boiler level.

7.5 Wastewater treatment and discharge (CRF 5.D)

7.5.1 Category description

The emission sources cover municipal (domestic) and industrial wastewater treatment plants and uncollected domestic wastewaters for CH_4 emissions. N_2O emissions are generated from nitrogen input of fish farming, as well as from domestic and industrial wastewaters. The amount of these emissions was 0.2 Mt CO_2 in 2022, being at the same level as in 2021, but it has decreased 26% since 1990.

Table 7.5-1 Reported emissions calculation methods and types of emission factors for the subcategory Wastewater Handling in the Finnish inventory

CRF	Source	Emissions reported	Methods	Emission factors
5.D.1	Domestic Wastewater	CH_4 N_2O	CS, Tier 2 CS, Tier 1	CS, D D
5.D.2	Industrial Wastewater	CH_4 N_2O	CS, Tier 2 CS	CS, D D
5.D.3	Other (Fish Farming)	N_2O	CS	D

Emission trends by sources are presented in Figure 7.5-1. The overall trend in domestic wastewaters (the most significant source) is slightly decreasing due to a downward trend of population with uncollected wastewaters (methane). Emission trends from wastewater treatment and discharge by subcategory and gas are presented in Table 7.5-2.

Finland has predominantly centralized wastewater treatment plants, which actively remove nitrogen and have typically much smaller emissions than those from effluent. However, the exact share of these nitrogen-removing plants is not known. It could be estimated that 85% of the population is connected to the advanced WWTPs, but no certainty can be reached at this time. No separate calculations for direct N_2O-emissions from nitrification and denitrification plants have been made, and all municipal wastewater plants are calculated consistently. Using the estimate of 85% of the population living within the area of an advanced plant, IPCC Guidelines Equation 6.9 gives total emissions from centralized plants of 5.0 kt CO_2-equivalent (5.5 M*0,85*1.25*3.2 g*265), which is considered insignificant. This source is listed as an insignificant source in Annex 5.

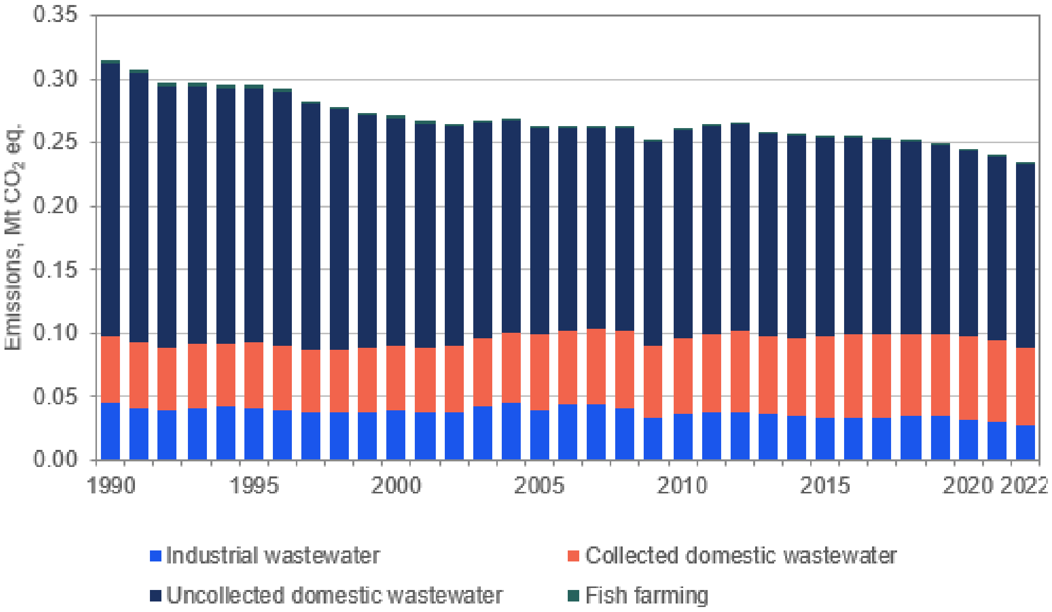


Figure 7.5-1 Emissions from wastewater handling by emission source (Mt CO_2 eq.)

7.5.2 Methodological issues

7.5.2.1 Methods

A national methodology that corresponds to the methodology given in the 2006 IPCC Guidelines is used in the estimation of CH_4 emissions. MCF parameters are defined according to total organics in wastewaters so no subtractions of removed sludges or recovered methane are taken into account. The emissions from municipal wastewater treatment are based on the BOD_7 load (Biochemical Oxygen demand, seven-day test) of the wastewaters. The BOD_7 measurements are converted to the BOD_5 load (five-day test) by dividing them with the factor 1.17 (Finnish Water and Waste Water Works Association 1995). The emissions from industrial wastewater treatment are based on the COD load (Chemical Oxygen demand).

The equations used for calculating CH_4 emissions from domestic and industrial wastewater treatment are described in Appendix_7a.

The MCF parameters for wastewater plants are based on an expert opinions (Jouttijärvi et. al. 1999) and they are within the range of the 2006 IPCC Guidelines. The applicability of this expert opinion was checked in 2018 by comparing it to measurements done by one plant in Finland. The average emission factor of this plant was 0.01 kg CH_4/ kg BOD from 2012 to 2017 (Kuokkanen 2018) which is in good agreement with the estimated MFC. All the municipal wastewater treatment plants in Finland are aerobic and 14 of them (the most significant ones) have anaerobic sludge treatment with methane recovery. The emission factors mainly illustrate exceptional operation conditions (leakages from anaerobic treatment or small anaerobic “corners” in aerobic wastewater treatment plants). There are no plant-specific measurements for the organic component of sludge in Finland. Especially for domestic wastewater, there are good measurement results for TOW of wastewaters in Finland.

In Finland, the N input from fish farming and from municipal and industrial wastewaters into the waterways is collected into the YLVA system. For municipal wastewaters, the measured values have been considered more reliable than the N input according to population data. Nitrogen removals in sludges are calculated according to the amounts of municipal sludges (Statistics Finland 2023a, 2022a and 2021c). In addition to the IPCC approach, the nitrogen load from fish farming was also taken into account. Also, a difference to the IPCC method is that co-discharged protein (factor) from industry is not taken into account but the measured N values from industry are used. Because the measures of incoming loads to wastewater treatment plants are used in the calculations, no emissions from advanced centralised wastewater treatment plants are estimated. The emission factors for industrial wastewater and for fish farming are the same as in domestic wastewater.

For uncollected wastewaters, the nitrogen load is based on population data and protein consumption (FAO 2023 and FAO 2004).

Emissions (kt N_2O) = Effluent N (kg) * EF*10^{-6}* 44/28

where

EF = Emission factor (kg N_2O-N/kg N load), IPCC default = 0.005

7.5.2.2 Emission factors and other parameters

Emission factors for collected domestic wastewaters are the IPCC default factors for the maximum methane producing capacity B_o = 0.6 kg CH_4/kg BOD and country-specific, based on expert knowledge, for the methane conversion factor MCF = 0.01 (being within the range of the 2006 IPCC Guidelines). For uncollected wastewaters the 2006 IPCC Guidelines’ default emission factors are used (BOD = 60 g/person/day, B_o = 0.6 kg CH_4/kg BOD and MCF = 0.5).

For industrial wastewaters, the emission factor is the IPCC default for the maximum methane producing capacity B_o = 0.25 kg CH_4/kg COD and a country-specific emission factor based on expert knowledge for the methane conversion factor MCF = 0.005 (being within the range of the 2006 IPCC Guidelines).

7.5.2.3 Activity data

Activity data are based on

- Domestic wastewater: Population (Uncollected wastewater); the BOD (BOD_7) values and N load values of wastewaters from the YLVA system.

- Industrial wastewater: the COD values of wastewaters from the YLVA system. Incoming COD loads are calculated from the measured outgoing COD values (YLVA system) using partly estimated efficiencies of wastewater treatment plants and partly the efficiency values from the YLVA system.

The YLVA system had some errors and shortages especially in domestic wastewaters (BOD and N values) also in 2022 and some missing values were copied from previous years.

The nitrogen load from fish farming has been taken from the mimeograph series of the Finnish Environment Institute (Repo & Hämäläinen 1996 and Repo et. al. 1999), from the summary calculations by M.-L. Hämäläinen from the Finnish Environment Institute (Hämäläinen 2009), and from the information received from Åland (Sivén 2023) and from the YLVA system (the continent of Finland). The new YLVA system has only few load values and the load values to the inventory were mainly calculated according to the growth values of fishes and to the feedstuffs used (these figures are more comprehensively stored in YLVA).

The BOD and COD load values and nitrogen load input values are presented in Table 7.5-3 and Table 7.5-4, respectively. The population having uncollected domestic wastewater handling system and the protein consumption per person are presented in Table 7.5-5.

Table 7.5-2 Emissions from wastewater treatment by subcategory (Mt CO_2 eq.)

	1990	1995	2000	2005	2010	2013	2014	2015	2016	2017	2018	2019	2020	2021	2022
Methane emissions	**0.247**	**0.234**	**0.213**	**0.201**	**0.195**	**0.193**	**0.190**	**0.189**	**0.187**	**0.186**	**0.184**	**0.183**	**0.178**	**0.175**	**0.173**
Collected domestic wastewater	0.017	0.016	0.017	0.019	0.019	0.019	0.019	0.019	0.020	0.020	0.020	0.020	0.019	0.019	0.019
Uncollected domestic wastewater	0.201	0.188	0.168	0.153	0.152	0.149	0.148	0.146	0.144	0.142	0.140	0.138	0.136	0.135	0.134
Industrial wastewater	0.030	0.030	0.028	0.029	0.025	0.025	0.024	0.024	0.024	0.024	0.024	0.025	0.023	0.022	0.020
Nitrous oxide emissions	**0.068**	**0.061**	**0.058**	**0.062**	**0.065**	**0.065**	**0.066**	**0.067**	**0.068**	**0.067**	**0.067**	**0.066**	**0.067**	**0.065**	**0.062**
Collected domestic wastewater	0.036	0.035	0.034	0.039	0.042	0.042	0.042	0.044	0.046	0.045	0.045	0.045	0.046	0.045	0.042
Uncollected domestic wastewater	0.013	0.012	0.011	0.011	0.011	0.011	0.012	0.011	0.011	0.011	0.011	0.011	0.011	0.011	0.010
Industrial wastewater	0.015	0.011	0.011	0.011	0.011	0.011	0.011	0.010	0.010	0.010	0.010	0.010	0.009	0.009	0.008
Fish farming	0.004	0.003	0.002	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001
Total wastewater	**0.315**	**0.295**	**0.271**	**0.263**	**0.260**	**0.258**	**0.256**	**0.256**	**0.255**	**0.253**	**0.252**	**0.249**	**0.245**	**0.240**	**0.234**

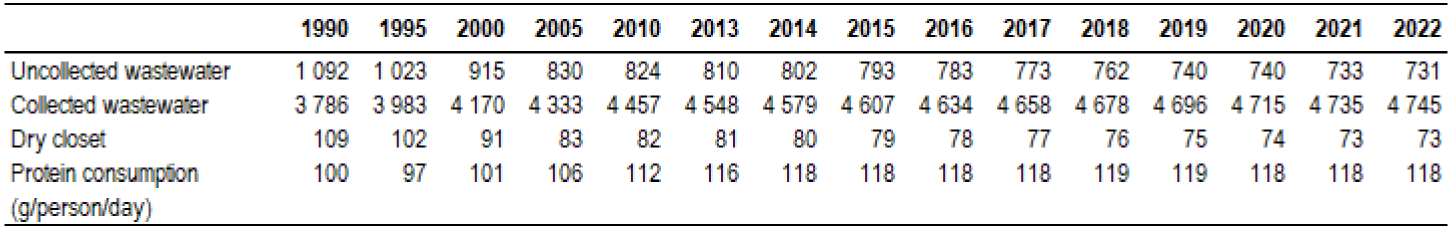
Table 7.5-3 BOD and COD loads (1,000 t)

	1990	1995	2000	2005	2010	2013	2014	2015	2016	2017	2018	2019	2020	2021	2022
Domestic wastewater															
Collected BOD_7 load	117	114	119	132	129	130	132	134	137	142	137	136	135	132	130
Collected BOD_5 load	100	97	101	113	111	111	113	115	117	121	117	117	116	113	111
Uncollected BOD_5 load	24	22	20	18	18	18	18	17	17	17	17	16	16	16	16
Industrial wastewater															
COD load	852	843	795	833	708	724	679	674	672	680	699	715	644	618	562

Table 7.5-4 N load in effluent (1,000 t)

	1990	1995	2000	2005	2010	2013	2014	2015	2016	2017	2018	2019	2020	2021	2022
Domestic wastewater															
Collected N load	17.3	17.0	16.4	18.9	20.1	20.1	20.3	21.3	21.9	21.6	21.8	21.4	21.9	21.5	20.0
Uncollected N load	6.4	5.8	5.4	5.1	5.4	5.5	5.5	5.5	5.4	5.3	5.3	5.2	5.1	5.1	5.0
N load in Industrial wastewater	7.2	5.4	5.2	5.1	5.3	5.1	5.1	4.7	4.6	4.6	4.7	4.6	4.4	4.1	3.8
N load in Fish farming	1.7	1.3	1.0	0.7	0.6	0.6	0.6	0.6	0.6	0.7	0.6	0.6	0.7	0.6	0.7

Table 7.5-5 Population (1,000 persons) having collected or uncollected wastewater treatment system and dry closets and protein consumption (g/person/day)



	1990	1995	2000	2005	2010	2013	2014	2015	2016	2017	2018	2019	2020	2021	2022
Uncollected wastewater	1 092	1 023	915	830	824	810	802	793	783	773	762	740	740	733	731
Collected wastewater	3 786	3 983	4 170	4 333	4 457	4 548	4 579	4 607	4 634	4 658	4 678	4 696	4 715	4 735	4 745
Dry closet	109	102	91	83	82	81	80	79	78	77	76	75	74	73	73
Protein consumption (g/person/day)	100	97	101	106	112	116	118	118	118	118	119	119	118	118	118

7.5.3 Uncertainty assessment and time series' consistency

Quantitative estimates of uncertainty are provided in Annex 2. The annex also documents assumptions made for the analysis. A description of the uncertainty analysis is provided in Section 1.6.

For the purposes of uncertainty estimation, emissions from wastewater management are divided into the following subgroups: Industrial Wastewater (CH_4 and N_2O separately), Domestic and Commercial Wastewater from densely populated areas (CH_4 and N_2O separately), Domestic and Commercial Wastewater from sparsely populated areas (CH_4 and N_2O separately) and N input from Fish Farming (N_2O).

Uncertainty in the emission estimates of wastewater handling arises from uncertainties in activity data and emission factors. In methane emissions from industry, activity data (COD) are based on measurements on the input into waters and partly estimated efficiencies of wastewater treatment plants. Due to the measurement data, uncertainty (±10%) is estimated lower than the default uncertainty estimate given by the IPCC.

For the uncertainty estimate, CH_4 emissions from domestic wastewaters are divided into two subcategories, i.e. densely and sparsely populated areas, because these two subcategories are calculated using different methods (type of activity data and emission factors). For densely populated areas, activity data (BOD) are fairly accurately known (±7%) due to the accurate measurement data of both incoming and outgoing wastewater flows from waste treatment plants. For $B_{0,}$ the IPCC default uncertainty (±30%) is used and the uncertainty estimate for MCF is based on expert estimation (-60% to +100%).

For sparsely populated areas, activity is based on the population and the 2006 IPCC Guidelines' default value for BOD_5 in Europe. The uncertainty in the activity data estimate (±15%) is larger than in densely populated areas, because the estimate is based on the population rather than on the measured BOD.

Uncertainty in this sector is dominated by the uncertainty in the N_2O emission factor (-94% to +380%). The methane conversion factor (MCF) is the second most important factor in terms of uncertainty.

The Monte Carlo simulation has been used to combine the uncertainties of each calculation parameter in order to get the total uncertainty of the category. A detailed description of the uncertainty analysis has been presented in Monni & Syri (2003) and Monni (2004).

7.5.4 Category-specific QA/QC and verification

General descriptions of quality objectives, QA/QC and verification procedures are presented in Section 1.5. The QC procedures are performed according to the QA/QC and verification plan in order to attain these quality objectives. Bilateral quality meeting was held between the inventory unit and the sectoral expert concerning the 2022 inventory.

General Quality Control (QC) procedures applied in category CRF 5.B. according to the 2006 IPCC Guidelines (Vol 1, Chapter 6, Table 6.1):

- Documentation on activity data and emission factors was crosschecked with the corresponding data in the calculation model.
- A sample of input data from each category was crosschecked for transcription errors.
- Units and conversion factors were checked
- Consistency of EF values of N_2O and DOC values in different source categories was checked.
- Data aggregation and transcription from lower reporting levels to higher levels were checked.

7.5.5 Category-specific recalculations

No recalculations have been made.

7.5.6 Category-specific planned improvements

There are no planned improvements.

Appendix_7a

The equations used in calculating emissions from the waste sector (CRF 5)

Solid waste disposal on land (CRF 5.A)

The modified Equation 5.1 (IPCC 2000) is as follows:

CH_4 generated in year t (kt / year) = $\sum_x [A * k * SW(x) * L_0(x) * e^{-k(t-x)}]$

for x = initial year to t,

where

t = year of inventory
x = years for which input data should be added
$A = (1 - e^{-k}) / k$; normalisation factor which corrects the summation
k = Methane generation rate constant (1 / year)
$SW(x)$ = amount of waste disposed at SWDS in year x (kt / a)
$L_0(x) = MCF(t) * DOC(x) * DOCF * F * 16 / 12$ (kt CH_4 / kt waste)
$L_0(x)$ is the methane generation potential

where

MCF (t) = Methane correction factor in year t (fraction)
DOC (x) = Degradable organic carbon (DOC) in year x (kt C / kt waste)
DOCF = Fraction of DOC dissimilated
F = Fraction by volume of CH_4 in landfill gas
16 / 12 = Conversion from C to CH_4

Emissions according to Equation 5.2 in GPG 2000 are calculated as follows:

CH_4 emitted in year t (kt / a) = [CH_4 generated in year $t - R(t)$]*$(1 - OX)$

where

$R(t)$ = Recovered CH_4 in inventory year t (kt / a)
OX = Oxidation factor (fraction)

Wastewater treatment (CRF 5.D)

Equations used in calculating CH_4 emissions from domestic wastewater and industrial wastewater treatment are as follows:

Emissions (kt CH_4) = Incoming organic load * $B_0 * MCF$ / 1,000,000

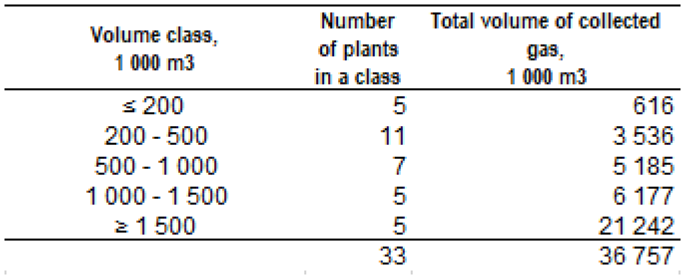
where

B_0 = Maximum methane producing capacity (kg CH_4 / kg BOD or kg COD)
MCF = Methane conversion factor (fraction)

Appendix_7b

Landfill gas recovery plants

Table 1_App_7b Number of landfill gas recovery plants in size categories and volume of collected gas in 2022 (Biogas survey of Statistic Finland 2023)



Volume class, 1 000 m3	Number of plants in a class	Total volume of collected gas, 1 000 m3
≤ 200	5	616
200 - 500	11	3 536
500 - 1 000	7	5 185
1 000 - 1 500	5	6 177
≥ 1 500	5	21 242
	33	36 757

The methane content of landfill gas is estimated to be 50% and the density of methane is 0.718 kg/m^3. Only plants operating in 2022 are included in the table (not those which were under reparation).

Appendix_7c

Industrial solid waste composition

Table 1_App_7c Landfilled wastegroups, wet

	Inert (1 000 t)					Default (1 000 t)			Fast (1 000	Slow (1 000 t)				Very slow (1 000 t)	
	Plastics	)ther comb	)ther incomb	Ash	Sludges	Garden	)ther comb	Oil	Food	Textiles	Paper	)e-inking	)ther comb	Wood	)reen l. sl.
1990	23.5	4.0	226	714	521	6.5	15.0	2.0	59.0	5.5	74	20	55	189	220
1991	23.5	4.0	227	718	521	6.5	15.0	2.0	59.0	5.5	69	20	55	177	205
1992	23.5	4.0	228	722	521	6.5	15.0	2.0	59.0	5.5	64	20	55	164	190
1993	19.1	4.5	203	709	426	6.0	13.7	1.6	52.0	4.5	53	23	54	148	176
1994	14.7	5.0	178	697	331	5.6	12.3	1.3	44.9	3.4	41	25	53	131	161
1995	10.3	5.5	153	684	237	5.1	11.0	0.9	37.9	2.4	30	28	53	115	147
1996	5.9	6.0	128	671	142	4.6	9.7	0.6	30.8	1.3	19	30	52	99	132
1997	7.1	6.5	136	787	291	4.2	12.1	0.3	27.1	0.9	7.3	33	73	84	118
1998	7.7	2.9	122	667	297	2.0	10.3	3.3	11.5	1.4	7.5	45	60	70	130
1999	4.4	4.2	373	1 191	515	0.8	8.4	2.3	16.0	1.6	3.8	29	55	59	129
2000	12.8	9.6	572	1 001	436	3.8	5.7	4.7	16.5	0.6	2.6	27	46	51	117
2001	2.9	9.3	595	1 393	402	0.7	8.0	4.9	22.1	0.3	3.0	47	44	45	124
2002	2.2	14.7	533	1 514	321	0.4	18.6	3.6	22.4	0.2	0.5	12.6	38	34	98
2003	0.2	15.4	523	1 937	304	0.2	19.8	3.4	22.5	0.1	0.5	12.3	68	16	110
2004	0.3	10.9	2 005	1 195	824	0.4	31.6	2.6	31.9	0.1	0.1	12.8	81	20	120
2005	0.2	26.7	2 098	1 072	835	0.5	4.5	2.0	32.3	0.3	1.1	10.0	83	18	119
2006	0.2	10.9	2 293	1 318	800	0.5	5.4	2.6	25.4	0.8	0.1	11.2	92	23	136
2007	0.3	10.5	1 844	1 107	890	0.2	5.1	2.5	15.6	0.7	0.1	8.5	117	16	133
2008	0.4	10.3	3 262	628	840	0.9	3.9	1.8	12.5	0.3	NO	6.0	119	11	168
2009	0.4	23.9	1 378	747	813	0.03	2.9	1.7	10.8	0.7	NO	4.5	141	8.4	128
2010	0.2	17.4	1 299	978	562	0.1	7.0	1.6	9.5	0.7	NO	15.4	126	6.5	127
2011	0.3	0.4	1 682	569	665	0.02	12.0	3.1	9.3	0.7	NO	2.8	158	4.3	111
2012	2.1	0.4	1 653	702	607	0.1	10.4	2.0	8.5	0.6	0.04	2.6	130	1.3	122
2013	3.0	0.3	1 610	571	620	NO	11.4	2.6	7.3	0.4	NO	1.4	99	1.4	99
2014	1.1	0.2	1 748	411	599	0.1	8.4	2.6	7.7	0.7	NO	0.5	70	2.3	96
2015	0.8	0.3	1 618	465	627	0.005	2.6	3.8	1.8	0.2	NO	NO	104	0.8	83
2016	0.04	0.8	1 521	491	672	0.0003	0.3	4.0	0.7	0.2	NO	0.1	57	0.03	114
2017	0.04	1.7	1 547	377	583	NO	0.7	1.9	0.7	0.1	NO	NO	49	0.5	126
2018	0.1	0.3	1 534	341	550	NO	0.2	4.7	0.7	0.2	NO	0.01	80	0.6	117
2019	0.4	0.1	1 529	246	527	NO	0.2	4.3	0.4	0.1	NO	0.01	49	0.8	108
2020	0.3	3.8	1 660	227	570	NO	0.2	4.7	1.4	0.2	NO	0.02	38	NO	117
2021	0.1	0.6	1 679	294	711	NO	0.02	3.4	0.6	0.2	NO	NO	22	NO	112
2022	0.3	6.2	1 533	240	558	NO	0.30	2.5	0.3	0.3	NO	NO	55	NO	78

Table 2_App_7c Landfilled wastegroups, in default moisture

	Inert (1 000 t)					Default (1 000 t)			Fast (1 000	Slow (1 000 t)				Very slow (1 000 t)	
	Plastics	Other comb	Other incomb	Ash	Sludges	Garden	Other comb	Oil	Food	Textiles	Paper	De-inking	Other comb	Wood	Green l. sl.
1990	23.5	4.0	226	714	521	6.5	15.0	2.0	59.0	5.5	74	6.0	55	164	110
1991	23.5	4.0	227	718	521	6.5	15.0	2.0	59.0	5.5	69	6.0	55	153	102
1992	23.5	4.0	228	722	521	6.5	15.0	2.0	59.0	5.5	64	6.0	55	142	95
1993	19.1	4.5	203	709	421	6.0	13.7	1.6	52.0	4.5	53	7.1	54	124	87
1994	14.7	5.0	178	697	321	5.6	12.3	1.3	44.9	3.4	41	8.2	53	106	79
1995	10.3	5.5	153	684	221	5.1	11.0	0.9	37.9	2.4	30	9.3	53	88	71
1996	5.9	6.0	128	671	121	4.6	9.7	0.6	30.8	1.3	19	10.4	52	70	63
1997	7.1	6.5	136	787	61	4.2	12.1	0.3	27.1	0.9	7.3	11.6	73	53	55
1998	7.7	2.9	122	667	63	2.0	10.3	3.2	11.5	1.4	7.5	12.7	60	47	60
1999	4.4	4.2	373	1 191	143	0.8	8.4	2.2	16.0	1.6	3.8	9.0	55	32	60
2000	12.8	9.6	572	1 001	138	3.8	5.7	4.5	16.5	0.6	2.6	12.8	46	35	57
2001	2.9	9.3	595	1 393	130	0.6	8.0	4.6	22.1	0.3	3.0	22.5	44	28	60
2002	2.2	14.7	533	1 514	96	0.4	18.6	3.3	22.4	0.2	0.5	4.2	38	18	45
2003	0.2	15.4	523	1 937	153	0.2	19.8	3.1	22.5	0.1	0.5	4.1	68	8.1	52
2004	0.3	10.9	2 005	1 195	363	0.4	31.6	2.4	31.9	0.1	0.1	4.3	81	10.1	55
2005	0.2	26.7	2 098	1 072	384	0.5	4.5	1.8	32.3	0.3	1.1	3.4	83	9.2	54
2006	0.2	10.9	2 293	1 318	372	0.5	5.4	2.5	25.4	0.8	0.1	4.0	92	13.4	62
2007	0.3	10.5	1 844	1 107	420	0.2	5.1	2.5	15.6	0.7	0.1	3.0	117	7.0	62
2008	0.4	10.3	3 262	628	399	0.9	3.9	1.3	12.5	0.3	NO	2.2	119	4.9	82
2009	0.4	23.9	1 378	747	374	0.03	2.9	1.1	10.8	0.7	NO	1.8	141	3.6	61
2010	0.2	17.4	1 299	978	331	0.1	7.0	1.3	9.5	0.7	NO	6.5	126	2.9	60
2011	0.3	0.4	1 682	569	384	0.02	12.0	2.8	9.3	0.7	NO	1.1	158	2.8	54
2012	2.1	0.4	1 653	702	345	0.1	10.4	2.0	8.5	0.6	0.0	1.0	130	0.8	58
2013	3.0	0.3	1 610	571	351	NO	11.4	2.6	7.3	0.4	NO	0.6	99	0.8	48
2014	1.1	0.2	1 748	411	333	0.1	8.4	2.6	7.7	0.7	NO	0.2	70	1.2	44
2015	0.8	0.3	1 618	465	365	0.005	2.6	3.7	1.8	0.2	NO	NO	104	0.4	39
2016	0.04	0.8	1 521	491	393	0.0003	0.3	4.0	0.7	0.2	NO	0.1	57	0.03	48
2017	0.04	1.7	1 547	377	296	NO	0.7	1.9	0.7	0.1	NO	NO	49	0.5	61
2018	0.1	0.3	1 534	341	280	NO	0.2	4.6	0.7	0.2	NO	0.002	80	0.6	59
2019	0.4	0.1	1 529	246	275	NO	0.2	4.2	0.4	0.1	NO	0.004	49	0.8	54
2020	0.3	3.8	1 660	227	99	NO	0.2	4.7	1.4	0.2	NO	0.005	38	NO	58
2021	0.1	0.6	1 679	294	439	NO	0.02	3.4	0.6	0.2	NO	NO	22	NO	56
2022	0.3	6.2	1 533	240	319	NO	0.30	2.5	0.3	0.3	NO	NO	55	NO	39

8 OTHER (CRF 6)

Finland does not report any emissions under the Other sector.

9 INDIRECT CO_2 AND N_2O EMISSIONS

9.1 Description of sources of indirect emissions in GHG inventory

Finland’s national total emissions include indirect CO_2 emissions but the total emissions are presented in the CRF tables with and without indirect CO_2.

Finland reports the indirect CO_2 emissions due to atmospheric oxidation of CH_4 and NMVOCs consistent with the IPCC Guidelines (Vol. 1, Chapter 7). Indirect CO_2 emissions are not calculated from non-CO_2 (CH_4, CO or NMVOCs) emissions from combustion/burning processes, as the corresponding CO_2 emissions are calculated using emission factors assuming that all carbon in the fuel emitted to the atmosphere is CO_2. Only indirect CO_2 from fossil fugitive emissions or industrial process and product use (IPPU) emissions of CH_4 and NMVOC are reported presently. The CO emission reported in the IPPU sector come from processes where the CO_2 emissions are estimated assuming full oxidation of carbon inputs to CO_2, hence no indirect CO_2 emissions are reported from CO to avoid double counting. Indirect CO_2 from biogenic sources is not considered. Information on the estimation of indirect CO_2 emissions from reported NMVOC emissions is summarised in Table 9.1-1. For general information on the estimation of the indirect CO_2 emissions see also Section 1.1.1 Greenhouse gas inventories.

Finland also reports indirect N_2O emissions from nitrogen deposition caused by NO_x emissions from other than the agriculture and LULUCF sources as a memo item. These estimates are not included in the national totals consistent with the IPCC Guidelines. Indirect N_2O emissions from NH_3 emissions are estimated to be insignificant.

Indirect CO_2 emissions totalled 51 kt in 2022. Emissions have declined by 69% compared to 1990 and have declined by 11% since 2021. In 2022, 13% of the indirect CO_2 emissions originated from the energy sector (from fugitive emissions from fuels, CRF 1.B) and 87% from the Industrial Processes and Product Use sector (CRF 2). 3% of indirect CO_2 emissions were from CH_4 and rest from NMVOCs.

Indirect N_2O emissions (except those reported in the agriculture and LULUCF sectors) totalled 114 kt in 2022. Emissions declined by 70% compared to 1990 and by 6% compared to 2021. These estimates are not included in the national totals but reported as memo items.

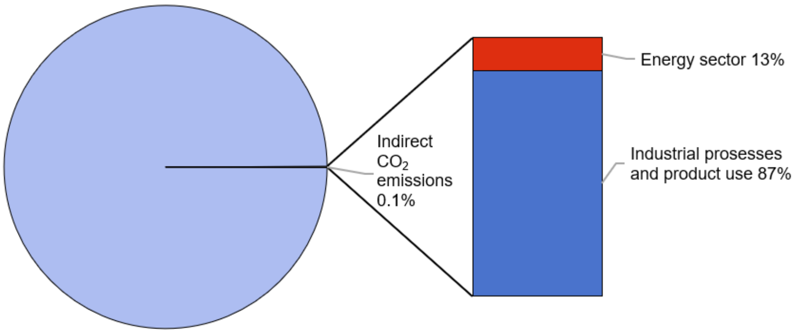


Figure 9.1-1 Indirect CO_2 emissions from the Energy sector and Industrial processes and product use compared with total emissions in 2022

Table 9.1-1 Indirect N_2O and CO_2 emissions (Mt CO_2 equivalent)

	1990	1995	2000	2005	2010	2013	2014	2015	2016	2017	2018	2019	2020	2021	2022
Indirect N_2O*	**0.37**	**0.33**	**0.30**	**0.25**	**0.22**	**0.19**	**0.18**	**0.17**	**0.16**	**0.15**	**0.15**	**0.14**	**0.12**	**0.12**	**0.11**
Indirect CO_2	**0.165**	**0.131**	**0.107**	**0.087**	**0.068**	**0.060**	**0.057**	**0.056**	**0.057**	**0.056**	**0.055**	**0.055**	**0.067**	**0.058**	**0.051**
Energy (1B)	0.019	0.027	0.019	0.016	0.016	0.013	0.010	0.011	0.011	0.010	0.010	0.009	0.008	0.007	0.006
Industrial processes and product use	0.145	0.104	0.088	0.071	0.053	0.047	0.046	0.045	0.046	0.046	0.045	0.046	0.059	0.051	0.045

* Not included in national totals. Reported as memo item.

9.1.1 Indirect CO_2 emissions from NMVOC

The inventory of indirect greenhouse gas emissions (NMVOCs) and also indirect CO_2 emissions from NMVOC emissions from fugitive emissions from fuels, as well as from the Industrial Processes and Product Use sector is prepared at Finnish Environment Institute, Syke. The NMVOC inventory is carried out to meet the obligations of the United Nations Economic Commission for Europe’s Convention on Long-Range Transboundary Air Pollution (UNECE CLRTAP) and the EU’s NEC Directive. Documentation of the calculation is presented in Finland's Informative Inventory Report under the UNECE CLRTAP and the EU NECD (Finnish Environment Institute, 2023)

NMVOC and corresponding indirect CO_2 emission sources are presented in Table 9.1-2. Indirect CO_2 emissions are calculated from NMVOC emissions as presented under Section 9.1.1.1 Methodological issues. The indirect emission are not included in the Energy and IPPU sectors, but instead in total greenhouse gas emissions reported in CRF Tables 6 and Summary 2. Indirect CO_2 emissions are not calculated from those NMVOC emissions which are considered to be of biogenic origin, or when covered in reported CO_2 emissions.

Table 9.1-2 CRF categories and description of NMVOC emissions sources

CRF category where NMVOC's reported	Description	NMVOC emissions (kt)	Average carbon content of NMVOC's (%)	Indirect CO_2 emissions (kt)	CRF Sector where aggregated indirect CO_2 reported
1.B.2a	Fugitive emissions oil; Refining / storage [1]	1.90	60	3.42	1. Energy
	Distribution of oil products; storage [1]	0.08	60	0.15	1. Energy
	Distribution of oil products; refuelling	2.36	**	**	**
1.B.2b	Fugitive emissions from natural gas transmission	0.25	60	0.55	1. Energy
1.B.2d	Road transport: Gasoline evaporation [3]	1.24	**	**	**
2.B.10	Organic chemical industry and storage of chemicals	2.10	60	4.62	2.IPPU
Chemicals production	Inorganic chemical industry and storage of chemicals	0.19	60	0.42	2.IPPU
2.C.1	Iron and steel production	0.27	60	0.60	2.IPPU
2.C.7	Non-ferrous metal production	0.04	60	0.08	2.IPPU
2.D.3,	Use of paints in industry and households (paint application)	7.00	60	15.40	2.IPPU
Solvent use	Degreasing in metal and electronics industries and dry cleaning activities	0.58	60	1.27	2.IPPU
	Chemical products, manufacture and processing	1.45	60	3.18	2.IPPU
	Pharmaceutical, textile, leather and plastic industries				
	Rubber conversion				
	Manufacture of paint, inks and glues				
	Other production	8.48	60	18.65	2.IPPU
	Printing industry				
	Domestic solvent use				
	Solvent extraction of edible oils		*	*	*
	Production of glass and mineral wool				
	Impregnation of wood				
	Use of pesticides				
	Tobacco smoking				
2.D.3,	Cement production	0.03	60	0.08	2.IPPU
Road paving with asphalt	Asphalt roofing	0.03	80	0.08	2.IPPU
	Road paving with asphalt	0.23	45	0.39	2.IPPU
2.H.1	Pulp and paper production [2]	2.30	*	*	*
2.H.2	Food and drink production	1.73	*	*	*
3.B.2	Manure management	11.74	*	*	*
3.D	Agricultural soils	3.11	*	*	*
3.F	Field burning of agricultural residues	0.00	*	*	*
5.A	Solid waste disposal	0.07	*	*	*
5.D	Wastewater treatment and discharge	0.03	*	*	*

* These emissions are biogenic and therefore indirect CO_2 emissions are not calculated.

** Included in the amount of fuel sold in the transport sector.

[1] Part of the emissions are biogenic. The biogenic part of gasoline is based on data received from Finnish Customs and Tax Administration (see also NIR Chapter 3.2.5). Diesel is estimated not to evaporate.

[2] These emissions are biogenic (as the result from handling of wood, plant or other biogenic material) and therefore the indirect CO_2 emissions are not estimated (Nilsson, 2007; Lindh, 2007 (expert estimation))

[3] NMVOC emissions from gasoline evaporation from road transport are reported in 1.B.2d since in CRF Tables these emissions can not be reported in 1.A.3.bv as in CLRTAP reporting.

9.1.1.1 Methodological issues

Indirect CO_2 emissions are calculated from NMVOC emissions for the time series 1990 to 2022 using the equation below.

$$Emissions_{CO_2} = Emissions_{NMVOC_s} * Percent\ carbon\ in\ NMVOCs\ by\ mass * 44/12$$

For 1990 to 2022 the average carbon contents of NMVOC emissions are presented by subcategory Table 9.1-2. The carbon contents are based on the 2006 IPCC Guidelines (Vol 3, Section 5.4.4 uncertainty assessment) for asphalt roofing and for road paving and for all other categories are consistent with the 2006 IPCC Guidelines (Vol 1, Section 7.2.1, Box 7.2) as described in Table 9.1-2. As in the 2006 IPCC Guidelines, the fossil carbon content fraction of NMVOC is based on limited published analyses with the speciation profile.

Indirect CO_2 emissions from NMVOC emissions are not calculated from
- refuelling and from fuel tanks in cars in order to avoid double counting, and these emissions are included in the CO_2 emissions from fuel combustion in transport which is based on the total amount of fuel sold.
- pulp and paper industry as these mainly originate from storage and handling of wood, where the major sources are production of mechanical pulp and storage of woodchips (Nilsson, 2007) and are therefore considered to be biogenic.
- emissions from fat and oil extraction (production of vegetable oils) are considered to be biogenic as well as NMVOC emissions from Agriculture and Waste sectors.

9.1.2 Indirect CO_2 emissions from CH_4

Indirect CO_2 emissions have been calculated from CH_4 emissions from oil refineries (1.B.2a), from natural gas processing, storage, transmission and distribution (1.B.2b), as well as from coke production (2.C.1f). Indirect CO_2 emissions have been calculated from CH_4 emissions for the whole time series and reported aggregated in the national totals.

9.1.2.1 Methodological issues

The method to calculate indirect CO_2 emissions from methane emissions is from the 2006 IPCC Guidelines (Vol.1, Box 7.2 in Section 7.2.1.5). Indirect CO_2 emissions from methane emissions were calculated using the equation below.

$$Emissions_{CO_2} = Emissions_{CH4} * 44/16$$

9.1.3 Indirect N_2O emissions

Nitrous oxide (N_2O) is produced in soils and surface waters through nitrification and denitrification. Increased nitrogen input to these systems enhances the production of N_2O and all anthropogenic sources of NH_3 and NO_x emissions are potential indirect sources of N_2O. Indirect N_2O emissions caused from N deposition by total NO_x emissions from other than the agriculture and LULUCF sources in Finland are reported as a memo item. The main source for NO_x emissions is fuel combustion in the Energy sector, with transportation being the most significant category. Indirect N_2O emissions from agricultural sources (mainly from NH_3 emissions) are included in the Agriculture sector. Indirect emissions from nitrogen deposition due to industrial NH_3 emissions are estimated to be of small, if not negligible, significance.

Indirect N_2O emissions from other than agriculture and LULUCF sectors are estimated based on the amount of nitrogen emitted in the country multiplied with an emission factor, assuming 1% of the nitrogen in the emissions to be converted to N_2O. The calculation method is the IPCC default method.

9.1.4 NMVOC emissions

9.1.4.1 Fugitive emissions from fuels

NMVOC emissions from oil refineries and storage and handling of petroleum products in refineries are based on emission data reported by the plants available from the YLVA (formerly VAHTI) system (detailed information in Annex 6). Evaporative emissions from cars are based on a calculation model developed at Syke (Forsberg, T. 2019) and maintained by VTT Technical Research Centre of Finland (Lauhkonen, A. 2023).

Emissions from the gasoline distribution chain and refuelling of vehicles are calculated with a calculation model which is based on information received from the Finnish Petroleum Federation (Pohjolainen 2008) and currently maintained by VTT Technical Research Centre of Finland (Lauhkonen, A. 2023). The calculation model uses sales of motor gasoline as activity data (Finnish Petroleum Federation and Statistics Finland). Fugitive emissions from natural gas transmissions are calculated using an emission factor from the EMEP/EEA Emission Inventory Guidebook 2019 and the volume of natural gas provided by Statistics Finland (2023).

9.1.4.2 Industrial processes and product use

NMVOC emissions from chemical industry, cement production and from iron and steel and non-ferrous metals production are estimated based on emission data reported by the operators (YLVA system, detailed information in Annex 6). In addition, part of emissions from iron and steel and non-ferrous metals production are calculated from production data from the Federation of Finnish Technology Industries using emission factors from the EMEP/EEA Emission Inventory Guidebook 2019.

NMVOC emissions from asphalt roofing and road paving with asphalt are calculated based on bitumen use, which is confidential data (from Nynas Oy) except for the part obtained from the foreign trade statistics (ULJAS). The method is using annual measurements by Nynas Oy (Remes, H. 2022).

Emissions from paint application have been calculated from the use of paint and varnish in industry and in households. Most Finnish paint producers and importers are members of the Association of Finnish Paint Industry, which records the annual sales of paint products in Finland. The Association calculates emissions from paint application using the amount and solvent content of sold paints and varnishes for their member companies. The rest of the emissions from the use of paints and varnishes have been estimated using a questionnaire in which companies report the solvent used sent to non-members of this association, and emission data from the YLVA system.

Emissions from degreasing and dry-cleaning are calculated using import statistics of pure chlorinated solvents, the amount of chlorinated organic solvents in products and the amounts of solvent waste processed in the hazardous waste treatment plants. NMVOCs are also emitted from the use of solvents in industrial processes: pharmaceutical industry, textile and leather industry, plastic industry, rubber conversion, manufacture of paints, inks and glues, and are mainly based on data reported by the operators to the YLVA system. Questionnaires are sent to companies in the textile, plastic and paint industries, which report either the amount of used solvent or emissions from production processes.

NMVOC emissions from the printing industry are based on emission data reported by the operators to the YLVA system and a questionnaire to those printing houses that do not report their emissions to the environmental authorities. The amount of used creosote oil is based on Kotiranta. S., 2023 and the amount of used pesticides is based on the Sales Statistics of Finnish Safety and Chemicals Agency's database (Marttila, V. 2023).

NMVOC emissions from domestic solvent use are calculated either through the sales volumes or through the use of money on products. The calculation models is presented in detail in Rantanen, N. 2016 and updated in 2023. NMVOC emissions from pharmaceuticals, adhesives and filling agents are calculated as presented in EMEP/EEA Emission Inventory Guidebook 2019. In 2022 submission the calculation of NMVOC emissions from pharmaceutical products was revised for whole timeseries. The calculation method is based on amounts of sold solvents used disinfectants based on registers provided by Finnish Safety and Chemicals Agency

(Mattila, A., 2022). Due the high amounts of used disinfectants (due the COVID-19) in 2020 also the NMVOC emissions were higher than in previous years.

NMVOC emissions from forest industries, including chemical pulping and paper production, mechanical wood industry, and from the food industry are calculated based on data reported by the plants (YLVA database), as well as from statistical data and emission factors from the EMEP/EEA Guidebook for those plants that do not report their emissions.

More information on the calculation of these NMVOC emissions can be found in Finland's Informative Inventory Report under the UNECE CLRTAP and the EU NECD (Finnish Environment Institute, 2023).

9.1.4.3 Agriculture

The emissions from CFR 3.B Manure management, CRF 3.D Agricultural soils and CRF 3.F Field burning of agricultural residues are calculated according to Tier 1 and Tier 2 methods in line with the 2019 version of the EMEP/EEA Emission Inventory Guidebook as explained in detail in the publication Grönroos et al.(2017). These emissions are considered to be of biogenic origin and indirect CO_2 emissions are therefore not calculated from these emissions.

9.1.4.4 Waste

NMVOC emissions from Solid waste disposal, from Domestic wastewater handling and from Industrial wastewater handling are included in the Finnish inventory. Detailed information on the calculation of these NMVOC emissions can be found in Finland's Informative Inventory Report under the UNECE CLRTAP and the EU NECD (Finnish Environment Institute, 2023). These emissions are considered to be of biogenic origin and indirect CO_2 emissions are therefore not calculated from these emissions.

9.2 Uncertainty assessment and time series' consistency

Quantitative estimates of uncertainty are provided in Annex 2. The annex also documents assumptions made for the analysis. A description of the uncertainty analysis is included in Section 1.6.

Uncertainty for activity data is ±100% and for emission factors ±10% is used in the following sectors: paint application, degreasing and dry cleaning, chemical products and other production. For fugitive emissions from fuels and the chemical industry, uncertainty for activity data is ±100% and for emission factors ±20% In the iron and steel industry and road paving with asphalt, uncertainty of ±85% for activity data and for emission factors ±20% is used. Uncertainty for the activity data is based on the latest uncertainty analysis for NMVOC emissions, which was carried out for the 2021 emissions in 2023 and is reported in the Finnish IIR 2023 (Informative Inventory Report) to the UNECE CLRTAP Secretariat, where the methods used for the analysis are documented. Default uncertainty values presented in the 2006 IPCC Guidelines are used for the emission factors.

The methods over the years are mainly consistent.

9.3 Category-specific QA/QC and verification

The quality objectives and the QA/QC plan for the Finnish greenhouse gas inventory at the national inventory level are presented in Section 1.5. The QC procedures are performed according to the QA/QC plan in the sector which emit indirect CO_2 emissions in order to attain these quality objectives. Bilateral quality meetings or quality desk reviews are held annually between the inventory unit and the sector experts. In 2022 a quality meeting was held between the inventory unit and the sectoral experts.

In the calculation of NMVOCs and indirect CO_2 emissions, general inventory QC procedures mentioned in the 2006 IPCC Guidelines (Chapter 1.6, Table 6) have been performed. For example, plant-specific emissions and activity data are compared between the years. The data reported by the plants according to the monitoring requirements in their environmental permits are checked and approved by the environmental competent authority before recording it into the YLVA system. In annual meetings between the Nordic countries emission factors and methods used by the Nordic countries are compared and the suitability of EMEP/EEA Emission Inventory Guidebook EFs to Nordic circumstances is evaluated.

9.4 Category-specific recalculations

In the indirect CO_2 emissions for the year 2023 submission, activity data have been corrected from natural gas transmissions (year 2021). Also, activity data used for NMVOC emissions in paint application (year 2021) and chemical products (years 2008-2021) have been corrected and activity data for other domestic solvent use (years 1990-2021) have been updated.

9.5 Category-specific planned improvements

There are no planned improvements.

10 RECALCULATIONS AND IMPROVEMENTS

10.1 Explanations and justifications for recalculations, including in response to the review process

The inventory is improved continuously taking into account new data and science available, assessments by the inventory experts and results of external reviews. The recommendations from the previous UNFCCC inventory reviews have been taken into account. The significance of the sources based on the results of the key category and uncertainty analyses are considered when prioritising improvements to be made in the inventory calculations. When planning and implementing improvements, time-series consistency is ensured, guided by the IPCC guidelines. Effects of recalculations, i.e. improvements, activity data updates and corrections, on the time-series are discussed and summarized in the sectoral chapters of the National Inventory Document and quantified for years 1990, 2005 and 2021 in Table 10.1-1.

The recalculations made since the previous inventory submission are described also in the sector Chapters 3-9. Improvements carried out for the first time in this submission are included in the description of recalculations under each sector here below.

Energy (CRF 1)

In **the Energy sector (1.A)** For 1990, 2005 and 2021 there were few recalculations:

- Total fuel use of biomass and peat has been changed in the energy statistics resulting changes in 1A1a Biomass and Peat as the non-specified fuel use is allocated here (+ 19 kt CO_2 eq. in 2021).
- Gasoil used for agricultural dryers and plant residues used for heating were updated resulting recalculations in 1.A.4.ci (-50 kt CO_2 eq. in 2021). This also results allocation changes between 1.A.4 and 1.A.5 subcategory.
- Total use of liquid fuels, mainly gasoil was updated to correspond data in energy statistics. This change reflected as a recalculation in category 1.A.5, which include residuals of liquid fuels (-107 kt CO_2 eq. in 2021)
- Emission factors of biogenic CO_2 from MSW and other waste-derived fuels were updated for the whole timeseries due to new information received. Biogenic CO_2 emissions in 1.A.1a and 1.A.2 increased 8 kt in 1990, 41 kt in 2005 and 446 kt in 2021.

Compared to 2023 submission no recalculations for 1990 nor 2005 were done for reference approach. Recalculations in the sectoral approach also reflects to the RA-SA difference. The largest recalculation concerning reference approach was revised methodology for correcting (taking into account) the effect of transport biofuels in RA emission data. In addition, wrong export data of natural gas was corrected for 2012 to 2021 and data of peat, bitumen and residual fuel were updated to correspond energy statistics data for 2021. The total difference between RA-SA changed from -4.7% to 0.4% in 2021 from the previous submission.
In **Fugitive emissions from fuels (CRF 1.B),** point source emissions in 1.B.2a were corrected for 2021 (- 2.5 kt CO_2 eq.). In 1.B.2b CH_4 emissions of a plant was included for years 2017 to 2021 (0.6 kt CO_2 eq. in 2021).

Industrial Processes and Product use (CRF 2)

In **Industrial Processes and Product use,** for the 1990, 2005 and 2021 there were few recalculations:

- The use amount of $LiCO_3$ were corrected for 2021, emissions increased 1.0 t CO_2.
- Preliminary data on imported soda ash were corrected for 2021, emissions decreased 0.06 kt CO_2.
- CO_2 emissions from formalin production were included to the inventory for the whole time series, annual emissions have fluctuated 2 kt to 16 kt. Some small corrections were done for the 2021 data of hydrogen production, emissions decreased 14 kt.
- The activity data of urea used in NOx control were corrected for 2021, emissions increased 0.09 kt CO_2.

- HFC emissions in category 2.F.1.a were recalculated for 2021 due to update of activity data (the number of professional kitchens in operation in 2021). HFC emissions from category 2.F.1.f were recalculated for 2020 to 2021 due to update of activity data of large heat pumps for these years.
- In category 2.G.1, SF_6 emissions were recalculated for 2013 to 2021 due to addition of activity data previously missing from the inventory.

Agriculture (CRF 3)

In **the Agriculture sector**, the implementation of a new method for national cattle excretion has influenced the sector's emissions for the entire time series from 1990 to 2021. Furthermore, a revision of the methane emission factor (EF) value for calves was made, assuming that calves do not emit methane during the period when fed with milk. These updates reduced the total emissions from enteric fermentation (CRF 3.A) almost throughout the entire time series but in the case of manure management (CRF 3.B) and agricultural soils (CRF 3D), emissions increased particularly during the beginning of the time series and decreased towards the end. However, the impact of these updates remained small, as total agriculture emissions decreased slightly 85 kt CO_2 eq (circa 1.3 %) over the entire time series.

LULUCF (CRF 4)

In **the LULUCF sector,** the areas of all land-use categories were recalculated and hence also all carbon stock changes and non-CO_2 emissions for which activity data are areas and are computed from the NFI data.

Gains in tree biomass were recalculated due to a change of method. For the 2023 submission, the estimation method for the gains in living tree biomass was modified to conform to the methodology the Finnish NFI applies to volume increment estimation. During the 12th and 13th inventory rounds NFI moved from the increment core based method to a method based on the remeasured trees on permanent sample plots. The aim was to estimate the tree biomass growth using the remeasured trees and give up applying BECFs to new NFI data. Thereafter the development work continued, and the new method was discovered problematical for biomass estimation. For the 2024 submission, we returned to use the BECFs for trees of NFI12 and NFI13 data. The NFI13 tree data measured in 2022 and corrected NFI13 sample tree data for the years 2020 and 2021 (remodelled upper diameter of some sample trees and regions) were adopted.

Losses in tree biomass were recalculated due to natural drain and waste wood, which are components of total drain, being recalculated based on the 12th NFI measured in 2014 to 2018. Thus, the statistics on total drain has changed. Also, data for 2017 to 2021 were revised. These changes reduced total drain on average by 0.4% during the period. NFI13 data for 2022 was adopted to estimate losses due to fellings on lands converted to forest land. Recalculations in the biomass affect the litter input to the soil and thus carbon stock changes in soils were also recalculated.

Manure production of livestock was updated for the whole time series resulting in the need for recalculation of emissions of cropland soils. The fraction of leached N and the emission factor for N_2O emissions per N lost through leaching for conversion to cropland categories were updated to correspond to the ones used in the Agriculture sector.

An error was found in the calculation of SOC stock change from settlements to cropland. The calculation did not take into account the emissions of the whole 20-year conversion period. The error is now corrected in this submission.

Activity data for HWP were updated according to the latest statistics. An error in the production of chemical wood pulp for the year 2012 was corrected, resulting in recalculation of the time series since 2012.

Waste (CRF 5)

Recalculations have been made for the years 2011-2021 due to a minor correction to activity data of municipal solid waste in 2011.

Indirect CO_2 emissions

In the indirect CO_2 emissions for the year 2023 submission, activity data have been corrected from natural gas transmissions (year 2021). Also, activity data used for NMVOC emissions in paint application (year 2021) and chemical products (years 2008-2021) have been corrected and calculation of other domestic solvent use (years 1990-2021) have been updated.

Table 10.1-1 Recalculations made for the 2022 inventory submission by CRF category and their implications to the emission level in 1990, 2005 and 2021

CRF Category	**Recalculation**	**Reason for the recalculation**	**Implication to the CRF category level (kt CO_2 eq.)**			**Implication to the Total emission level without LULUCF (%)**		
			1990	**2005**	**2021**	**1990**	**2005**	**2021**
1. Energy			**0.00**	**0.00**	**-139.05**	**0.00**	**0.00**	**-0.29**
1.A. Fuel combustion activities			0.00	0.00	-137.16			-0.29
1. Energy industries	Total fuel use of biomass and peat was updated to correspond data in the energy statistics.	Updates in the activity data	0.00	0.00	19.10			0.04
2. Manufacturing industries and construction					0.06			<0.01
3. Transport			0.00	0.00	0.00			
4. Other sectors	Gasoil used for agricultural dryers and plant residues used for heating were updated.	Updates in the activity data	0.00	0.00	-49.57			-0.10
5. Other	Total use of liquid fuels, mainly gasoil was updated to correspond data in energy statistics.	Updates in the activity data	0.00	0.00	-106.75			-0.22
1.B Fugitive emissions from fuels			0.00	0.00	-1.89			<0.01
2.Oil and natural gas	Inclusion of a plant and correction of activity data	Updates in the activity data	0.00	0.00	-1.89			<0.01
2. Industrial Processes and Product Use			**6.71**	**16.42**	**-7.17**	**0.01**	**0.02**	**-0.02**
A. Mineral industry	An amount of imported soda ash was updated	Updates in the activity data	0.00	0.00	-0.05			<0.01
B. Chemical industry	Emissions from formalin plant were included for the whole timeseries. Activity data of hydrogen production were updated in three plants.	Inclusion of a plant Updates in the activity data	6.71	16.42	-11.72	0.01	0.02	-0.02
C. Metal industry			0.00	0.00	0.00			0.00
D. Non-energy products from fuels and solvent use	Urea used for NOx control was updated for 2021.	Updates in the activity data	0.00	0.00	0.09			0.00
F. Product uses as substitutes for ODS	Activity data correction in categories 2.F.1a and 2.F.1f	Updates in the activity data	0.00	0.00	-0.50			<0.01
G. Other product manufacture and use	Activity data correction in category 2.G.1	Updates in the activity data	0.00	0.00	5.01			0.01

CRF Category	Recalculation	Reason for the recalculation	Implication to the CRF category level (kt CO_2 eq.)			Implication to the Total emission level without LULUCF (%)		
			1990	2005	2021	1990	2005	2021
H. Other			0.00	0.00	0.00			0.00
3. Agriculture			**71.46**	**-95.58**	**-106.85**	**0.10**	**-0.14**	**-0.22**
A. Enteric fermentation	Implementation of a new country-specific method to calculate gross energy intake and N excretion of cattle, revision of the methane emission factor for calves	New data, methodological change.	3.74	-81.31	-78.69	0.01	-0.12	-0.17
B. Manure management	Implementation of a new method for gross energy intake and N excretion of cattle	New data, methodological change.	27.04	-22.43	-13.70	0.04	-0.03	-0.03
D. Agricultural soils	Implementation of a new method for gross energy intake and N excretion of cattle, recalculation of direct N_2O emissions from the cultivation of organic soils and mineralisation of nitrogen in mineral soils due to new area estimates for cropland and grassland	New cattle excretion data. New area estimates due to the updating of NFI data (see Section 6.2).	40.68	8.16	-14.47	0.06	0.01	-0.03
G. Liming			0.00	0.00	0.00			
H. Urea application			0.00	0.00	0.00			
4. Land use, land-use change and forestry			**2 631.99**	**3 597.42**	**2 987.63**			
A. Forest land	CSC, drainage and rewetting, mineralization, biomass burning	AD update, methodological change, error corrections	2 659.20	3 518.11	3 338.73			
B. Cropland	CSC, mineralisation	AD update, error correction	-27.26	79.16	-246.35			
C. Grassland	CSC, mineralisation, biomass burning	AD update	-0.03	0.16	60.05			
D. Wetlands	CSC, drainage and rewetting	AD update	0.00	0.00	22.31			
E Settlements	CSC, mineralisation	AD update	0.50	0.39	-114.58			
G. HWP	CSC	AD update, error correction	0.00	0.00	-72.16			
5. Waste			**0.00**	**0.00**	**-0.51**	**0.00**	**0.00**	**<0.01**
A. Solid waste disposal	Minor correction to the municipal solid waste emissions	Correction of activity data in 2011			-0.51			<0.01
B. Biological treatment of solid waste					0.00			

CRF Category	Recalculation	Reason for the recalculation	Implication to the CRF category level (kt CO_2 eq.)			Implication to the Total emission level without LULUCF (%)		
			1990	2005	2021	1990	2005	2021
D. Wastewater treatment and discharge					0.00			
Indirect CO_2 emissions	Correction of AD in paint application, chemicals products and natural gas transmission and updating calculation of other domestic solvent use	AD update, error correction	**-1.67**	**-0.62**	**1.19**	**<0.01**	**<0.01**	**<0.01**

10.1.1 Recalculations between the January 2024 and March 2024 submissions for the year 2022

Emissions in the 15 January and 15 March 2024 EU submissions are presented in the table below for the year 2024. The main recalculations are described below by sector.

Table 10.1-2. Emissions in 2022 in the 15 January and 15 March 2024 EU submissions and difference between them.

		Submission		
		15th January 2024	15th March 2024	difference
Energy	Mt CO2e	33.0	32.9	-0.16
Transport	*Mt CO2e*	*9.8*	*9.8*	*0.00*
IPPU	Mt CO2e	5.0	5.0	-0.02
F gases	*Mt CO2e*	*0.8*	*0.8*	*0.00*
Agriculture	Mt CO2e	6.2	6.1	-0.16
Waste	Mt CO2e	1.7	1.7	0.00
LULUCF	Mt CO2e	4.5	4.4	-0.02
Indirect CO_2	Mt CO2e	0.1	0.1	0.00
Total (without LULUCF)	**Mt CO2e**	46.0	45.7	-0.34
Total (with LULUCF)	**Mt CO2e**	50.5	50.1	-0.36

Energy

In general, in the 15th January submission energy statistics data used for the inventory is preliminary and more updated data is available for the 15th March submission. Due to this, the total consumption of biomass, natural gas and liquid fuels, mainly gasoil was updated resulting 162 kt CO_2 eq. lower emissions in the energy sector in 2022. Also, emissions from the small scale combustion were recalculated due to information received from energy statistics resulting allocation changes between 1.A.4 and 1.A.1a/1.A.5 subcategories in the March submission. Emission factors of biogenic CO_2 from MSW and other waste-derived fuels were updated for the whole timeseries due to new information received and technical error in the calculations of biomass from 1A1a was corrected for years 2004 to 2016. The largest recalculation concerning reference approach was revised methodology for correcting (taking into account) the effect of transport biofuels in RA emission data.

Industrial Processes and Product Use

Emissions from lubricant use were recalculated due to new activity data received from energy statistics (in 15th January submission data from 2021 was used). This resulted 18 kt CO_2 eq. lower emissions in the IPPU sector in 2022.

Agriculture

The delay in the availability of data affected the synthetic fertilisers, lime and urea activity data for 2022. For March 2024 submission, the estimates were calculated based on the change between 2021 and 2022 in the quantities of those companies for which the fertiliser, lime and urea data has already been obtained for 2022. For a more detailed description of the reason for the delay and the calculation of the estimates, see Sections 5.4.2.2, 5.6.1 and 5.7.1. The fertiliser data updates decreased synthetic fertiliser emissions by 214 kt CO_2 eq. and organic fertilisers by 15 kt CO_2 eq. Liming emissions increased by approximately 6.6 kt CO_2 eq., while urea emissions increased by approximately 6 kt CO_2 eq.

This year, a mismatch in cover crop areas between the LULUCF and Agriculture sectors was noticed during the check. However, it was too late to correct emissions related to crop residues, mineralisation in mineral soils and pertinent indirect emissions for January 2024 submission, the error was corrected for March 2024 submission.

LULUCF

The activity data for fertilisers applied to Forest land and related emissions for the year 2022 were updated according to the latest available statistics, reducing the emissions in 2022 by 21 kt CO_2 eq. Allocation of wildfire area to Forest land remaining Forest land and lands converted to Forest land in 2009 was corrected and emissions calculated accordingly, with minimal effects on the emission levels.

Waste

No recalculations between the January 2024 and March 2024 submissions.

10.2 Implications for emission and removal levels

See Section 10.1.

10.3 Implications for emission and removal trends, including time series’ consistency

See Section 10.1.

10.4 Areas of improvement and/or capacity-building in response to the review process

Statistics Finland coordinates the development of the inventory's different sectors. Each organisation participating in the inventory preparation bears the primary responsibility for the development of its own sector. The advisory board of the inventory evaluates the need for significant improvements, horizontal development projects, and discusses and gives advice on how to find resources for significant development projects. The significance of the sources based on the results of the key category and uncertainty analyses are considered when prioritising improvements to be made in the inventory calculations.

The development of the greenhouse gas inventory aims to improve the calculation of the emissions/removals and the reporting of the inventory so that the inventory fulfils the quality objectives set for it and produces accurate estimates for the total emissions of greenhouse gases in different emission categories.

Statistics Finland collects the different horizontal development needs and those detected in the different sectors. The planned or proposed improvement measures are compiled in an annual inventory improvement plan. The inventory improvement plan is discussed by the advisory board before starting the next calculation round.

Table 10.4-1 summarises planned sectoral improvements for the forthcoming inventories identified by the Finnish experts responsible for the calculations and/or brought out in the review processes. The table also includes a tentative timeline for the implementation of the improvement in future submissions. More information about planned improvements can be found under the sectoral chapters.

Table 10.4-1 Sector-specific improvement needs of Finland's national greenhouse gas inventory

CRF category	Planned improvement	Tentative submission
CRF 3.B	Update on the distribution of manure management systems based on the detailed farm survey that was carried out during 2022-2023.	2025
CRF 3.B / 3.D	Implementation of the revised Nitrogen flow model along with new manure management data.	2025
CRF 4	Estimation and/or improvement of estimation of emissions and removals for Cropland, Grasslands, Wetlands and Settlements..	2025–2027
CRF 4.A, 4.B	Preparations to implement a newer Yasso soil model for mineral soils on forest land and cropland.	
CRF 5.B	Updating the time series of the sludge amounts to composting plants according to the new approach to get more accurate activity data.	2025

Table 10.4-2 summarises Finland's responses to the UNFCCC review of the 2022 inventory submission. Only issues that were not resolved during the review, are addressed in the table.

Table 10.4-2 Response to the review of the 2022 UNFCCC inventory submission and recommendations from previous reviews which have not been resolved. Note: There was no UNFCCC review for the 2023 submission.

CRF category / issue	Review recommendation	Review report / paragraph	MS response / status of implementation	Reason for non- implementation	Chapter/Section in the NID
1.A / E.5	The ERT recommends that the Party find the solution to use appropriate notation keys for subcategories 1.A.3.e (CRF table 1.A(a)s3) and 1.A.5.b (CRF table 1.A(a)s4) in line with paragraph 37 in the UNFCCC Annex I inventory reporting guidelines.		Checked but not implemented	It was checked that problem with the CRF Reporter still exists and notation key was not changed for the 2023 nor 2024 submission. Notation key C prevents the aggregation in parent cells resulting in incorrect emission figures. Finland does not consider manual input of emissions to these “pink cells” with the incorrect sums as a solution because it is time consuming and may result calculation or transfer errors easily. Therefore, notation key IE is used instead of C for confidential data in subcategories 1.A.5b and 1.A.3e.	Section 3.1.1.
4.C.1 / L.1 (L.8, 2020)	4.C.1 - Losses from living biomass on grassland remaining grassland: The ERT recommends that the Party either provide a justification of how the currently applied approach improves upon the Tier 1 approach or go back to the Tier 1 approach detailed in the 2006 IPCC Guidelines (vol. 4, chap. 6.2.1.1).		The description was updated, but we plan to further examine the ERT’s recommendation when preparing the 2025 submission.	The aim is to use at least Tier 2 methods, also for categories which are not key categories. Therefore, methods are developed to estimate CSCs more accurately for all LU and LUC categories including tree biomass on grasslands.	Section 6.6.2.1
4.E.2 / L.7	The ERT recommends that the Party either better justify the method used and provide clarification on why conversions of settlements with tree cover to cropland, grassland or wetlands are rare in Finland or use a method that takes into account the initial change in living biomass for conversions of settlements with tree cover to cropland, grassland or wetlands.		We plan to examine the possibilities by 2025 submission.	The examination of data and possible development of methodology was not possible in this time frame. The aim is to use at least Tier 2 methods, also for categories which are not key categories. Therefore, methods are developed to estimate CSCs more accurately for all LU and LUC categories.	
4.B / L.4	The ERT recommends that the Party improve the method for estimating carbon stock change in living biomass for cropland converted to other land use or land converted to cropland so that it takes into account the annual carbon stock change in living biomass of apple trees and currants to maintain the consistency with the method of estimating carbon stock change in living biomass in cropland remaining cropland.		This is planned to be implemented for the 2024 submission if conversion areas with apple trees and currants exist.	The examination of data and possible development of methodology was not possible in this time frame. The aim is to use at least Tier 2 methods, also for categories which are not key categories. Therefore, methods are developed to estimate CSCs more accurately for all LU and LUC categories.	Section 6.5.6

11 INFORMATION ON CHANGES IN THE NATIONAL SYSTEM

No changes have been made in national systems since the previous submission.

12 INFORMATION ON CHANGES TO THE NATIONAL REGISTRY

The following changes to the national registry of Finland have occurred in 2023.

Reporting Item	Description
15/CMP.1 annex II.E paragraph 32.(a) Change of name or contact	No change of name or contact occurred during the reported period.
15/CMP.1 annex II.E paragraph 32.(b) Change regarding cooperation arrangement	No change regarding cooperation arrangement occurred during the reported period.
15/CMP.1 annex II.E paragraph 32.(c) Change to database structure or the capacity of national registry	There have been five new EUCR releases in production (versions 13.10, 13.10.2, 13.10.3, 13.10.4 and 13.11.2) after version 13.8.2 (the production version at the time of the last submission). No changes were applied to the database, whose model is provided in Annex A. No change was required to the application backup plan or to the disaster recovery plan. No change to the capacity of the national registry occurred during the reported period.
15/CMP.1 annex II.E paragraph 32.(d) Change regarding conformance to technical standards	The changes that have been introduced with versions 13.10, 13.10.2, 13.10.3, 13.10.4 and 13.11.2 compared with version 13.8.2 of the national registry are presented in Annex B. It is to be noted that each release of the registry is subject to both regression testing and tests related to new functionality. These tests also include thorough testing against the DES and are carried out prior to the relevant major release of the version to Production (see Annex B). No other change in the registry's conformance to the technical standards occurred for the reported period.
15/CMP.1 annex II.E paragraph 32.(e) Change to discrepancies procedures	No change of discrepancies procedures occurred during the reported period.
15/CMP.1 annex II.E paragraph 32.(f) Change regarding security	No changes regarding security were introduced.
15/CMP.1 annex II.E paragraph 32.(g) Change to list of publicly available information	The true-up period report of Finland concerning the second commitment period (2013-2020) of the Kyoto Protocol was added to the list of publicly available information in the webpage of the Energy Authority (https://energiavirasto.fi:8443/en/emissions-trading-registry#public_information). No other changes to the list of publicly available information occurred during the reported period.

Reporting Item	Description
15/CMP.1 annex II.E paragraph 32.(h) Change of Internet address	No change to the registry internet address during the reported period.
15/CMP.1 annex II.E paragraph 32.(i) Change regarding data integrity measures	No change of data integrity measures occurred during the reported period.
15/CMP.1 annex II.E paragraph 32.(j) Change regarding test results	No change during the reported period.

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ANNEXES TO THE NATIONAL INVENTORY DOCUMENT

ANNEX 1. Key categories

This Annex describes the methodology used to identify key categories. Key categories identified automatically by the CRF Reporter Software according to the Approach 1 method are presented in the CRF Table 7. Nationally calculated analysis tables with numerical results are presented below in Tables 1 to 12, more detailed supplementary information can be found in attachment file 2022_FIN_UA-KCA_5v282.xlsx.

The methods of the 2006 IPCC Guidelines have been coded into a SAS programme. This programme reads input information directly from a simple XML-file imported from the CRF Reporter Software and outputs uncertainty and key category tables to result Excel file. The process is fast and all errors can be traced back into either the data or the programme, because manual operations (such as copy-paste) do not take place. Uncertainties used in key category analysis are from the Approach 2 uncertainty analysis (UA). The reported key categories are a combination of all keys identified either with Approach 1 or Approach 2 key category analysis (KCA). Both Approaches of KCA also include calculation alternatives, where LULUCF emissions are excluded and included. Results from al calculation alternatives are presented below, and the summary of a results can be found in Section 1.5.

The aggregation level of subcategories used in the analysis is based on the suggested aggregation level in the 2006 IPCC Guidelines (Vol. 1, Table 4.1) with following disaggregations:

i) The category *1.A.3b Road Transportation* is subdivided to main fuel types,
ii) The category *2.B.10 Other* is subdivided to the 4th CRF category level,
iii) The category *2.D Non-energy Products from Fuels and Solvent Use* is subdivided to the 3rd CRF category level.

These subcategories have clearly distinguishable activity data and cross correlation between them is minimal.

The categories *4.D.1 Wetlands remaining wetlands* and *4.D.2 Land converted to wetlands* are kept in the 3rd CRF category level. Here, the peat extraction area is the main activity area and the other subcategories have minor role. Subdivision of this category would increase uncertainties since cross correlations between the subcategories are poorly known.

And the category list also has one addition, the *Indirect* CO_2 emissions are also included in the key category analysis.

Table 1. Key category analysis, base year level assessment (Approach 1) excluding LULUCF sector

CRF	CRF name	Fuel / Fuel group	Gas	Emissions/ removals 1990	Level assess-ment	Contri-bution to level	Cumu-lative sum of contri-bution	Key in level analysis
				Gg CO2-eq				
1A1	Energy industries	Solid	CO2	9 640.1	0.135	0.135	0.135	yes
1A4	Other sectors	Liquid	CO2	7 230.4	0.101	0.101	0.237	yes
1A3b	Road transportation	Motor gasoline	CO2	5 880.5	0.082	0.082	0.319	yes
1A3b	Road transportation	Diesel oil	CO2	4 923.5	0.069	0.069	0.388	yes
5A	Waste disposal		CH4	4 847.1	0.068	0.068	0.456	yes
1A2	Manufacturing industries and construction	Solid	CO2	4 841.6	0.068	0.068	0.524	yes
1A2	Manufacturing industries and construction	Liquid	CO2	4 575.7	0.064	0.064	0.588	yes
1A1	Energy industries	Peat	CO2	3 949.5	0.055	0.055	0.643	yes
3D1	Direct N2O emissions from managed soils		N2O	2 940.3	0.041	0.041	0.685	yes
3A	Enteric fermentation		CH4	2 715.5	0.038	0.038	0.723	yes
1A1	Energy industries	Gaseous	CO2	2 636.2	0.037	0.037	0.760	yes
1A1	Energy industries	Liquid	CO2	2 616.2	0.037	0.037	0.796	yes
1A2	Manufacturing industries and construction	Gaseous	CO2	2 198.6	0.031	0.031	0.827	yes
2C1	Iron and steel production		CO2	1 967.2	0.028	0.028	0.855	yes
1A2	Manufacturing industries and construction	Peat	CO2	1 475.9	0.021	0.021	0.875	yes
2B2	Nitric acid production		N2O	1 415.4	0.020	0.020	0.895	yes
1A5	Other energy	Liquid	CO2	1 035.6	0.015	0.015	0.910	yes
2A1	Cement production		CO2	729.2	0.010	0.010	0.920	yes
3G	Liming		CO2	642.0	0.009	0.009	0.929	yes
1A3d	Domestic navigation	Liquid	CO2	441.3	0.006	0.006	0.935	yes
3B	Manure management		CH4	421.9	0.006	0.006	0.941	yes
2A2	Lime production		CO2	400.6	0.006	0.006	0.947	yes
1A3a	Domestic aviation	Liquid	CO2	385.1	0.005	0.005	0.952	yes

Table 2. Key category analysis, base year level assessment (Approach 1) including LULUCF sector

CRF	CRF name	Fuel / Fuel group	Gas	Emissions/ removals 1990	Level assess-ment	Contri-bution to level	Cumu-lative sum of contri-bution	Key in level analysis
				Gg CO2-eq				
4A1	Forest land remaining forest land		CO2	-31 945.3	0.271	0.271	0.271	yes
1A1	Energy industries	Solid	CO2	9 640.1	0.082	0.082	0.352	yes
1A4	Other sectors	Liquid	CO2	7 230.4	0.061	0.061	0.413	yes
1A3b	Road transportation	Motor gasoline	CO2	5 880.5	0.050	0.050	0.463	yes
1A3b	Road transportation	Diesel oil	CO2	4 923.5	0.042	0.042	0.505	yes
5A	Waste disposal		CH4	4 847.1	0.041	0.041	0.546	yes
1A2	Manufacturing industries and construction	Solid	CO2	4 841.6	0.041	0.041	0.587	yes
1A2	Manufacturing industries and construction	Liquid	CO2	4 575.7	0.039	0.039	0.626	yes
4B1	Cropland remaining cropland		CO2	4 521.6	0.038	0.038	0.664	yes
1A1	Energy industries	Peat	CO2	3 949.5	0.033	0.033	0.697	yes
4G	Harvested wood products		CO2	-2 951.6	0.025	0.025	0.722	yes
3D1	Direct N2O emissions from managed soils		N2O	2 940.3	0.025	0.025	0.747	yes
3A	Enteric fermentation		CH4	2 715.5	0.023	0.023	0.770	yes
1A1	Energy industries	Gaseous	CO2	2 636.2	0.022	0.022	0.793	yes
1A1	Energy industries	Liquid	CO2	2 616.2	0.022	0.022	0.815	yes
1A2	Manufacturing industries and construction	Gaseous	CO2	2 198.6	0.019	0.019	0.833	yes
2C1	Iron and steel production		CO2	1 967.2	0.017	0.017	0.850	yes
4(ii)	Emissions and removals from drainage and rewetting and other management of soils		CH4	1 690.2	0.014	0.014	0.864	yes
1A2	Manufacturing industries and construction	Peat	CO2	1 475.9	0.012	0.012	0.877	yes
4(ii)	Emissions and removals from drainage and rewetting and other management of soils		N2O	1 451.2	0.012	0.012	0.889	yes
2B2	Nitric acid production		N2O	1 415.4	0.012	0.012	0.901	yes
4D1	Wetlands remaining wetlands		CO2	1 269.2	0.011	0.011	0.912	yes
1A5	Other energy	Liquid	CO2	1 035.6	0.009	0.009	0.921	yes
4B2	Land converted to cropland		CO2	859.3	0.007	0.007	0.928	yes
4E2	Land converted to settlements		CO2	857.8	0.007	0.007	0.935	yes
4C1	Grassland remaining grassland		CO2	852.2	0.007	0.007	0.943	yes
2A1	Cement production		CO2	729.2	0.006	0.006	0.949	yes
3G	Liming		CO2	642.0	0.005	0.005	0.954	yes

Table 3. Key category analysis, base year level assessment (Approach 2) excluding LULUCF sector

CRF	CRF name	Fuel / Fuel group	Gas	Emissions/ removals 1990	Level assess-ment	Contri-bution to level	Cumu-lative sum of contri-bution	Key in level analysis
				Gg CO2-eq				
3D1	Direct N2O emissions from managed soils		N2O	2 940.3	0.029	0.149	0.149	yes
2B2	Nitric acid production		N2O	1 415.4	0.020	0.101	0.251	yes
5A	Waste disposal		CH4	4 847.1	0.017	0.087	0.337	yes
3D2	Indirect N2O emissions from managed soils		N2O	315.7	0.013	0.064	0.401	yes
1A4	Other sectors	Liquid	CO2	7 230.4	0.009	0.047	0.503	yes
3G	Liming		CO2	642.0	0.009	0.045	0.549	yes
2C1	Iron and steel production		CO2	1 967.2	0.008	0.040	0.589	yes
3A	Enteric fermentation		CH4	2 715.5	0.008	0.039	0.628	yes
1A1	Energy industries	Solid	CO2	9 640.1	0.006	0.030	0.658	yes
5B	Biological treatment of waste		N2O	16.3	0.006	0.029	0.687	yes
3B	Manure management		N2O	270.2	0.005	0.026	0.713	yes
1A5	Other energy	Liquid	CO2	1 035.6	0.005	0.023	0.736	yes
5D	Wastewater treatment and discharge		N2O	67.9	0.004	0.021	0.757	yes
1A1	Energy industries	Peat	CO2	3 949.5	0.004	0.020	0.777	yes
2C7	Other metal industry		CO2	8.9	0.004	0.018	0.795	yes
5D	Wastewater treatment and discharge		CH4	247.5	0.003	0.018	0.813	yes
1A4	Other sectors	Biomass	CH4	148.1	0.003	0.016	0.829	yes
2D1	Lubricant use		CO2	207.5	0.003	0.015	0.844	yes
1A2	Manufacturing industries and construction	Solid	CO2	4 841.6	0.003	0.014	0.858	yes
1A3b	Road transportation	Motor gasoline	CO2	5 880.5	0.002	0.012	0.870	yes
3B	Manure management		CH4	421.9	0.002	0.011	0.881	yes
1A1	Energy industries	Liquid	CO2	2 616.2	0.002	0.011	0.892	yes
1A2	Manufacturing industries and construction	Peat	CO2	1 475.9	0.002	0.009	0.901	yes

Notes: In addition, category 3F Field burning of agricultural residues was identified as a key category on the basis of the base year but is not included in this table because field burning of agricultural residues was banned in the beginning of 2021 and emissions do not occur anymore (see Section 5.5.1). 3F has represented a minor source (0,8 Gg CO2-eq), some 0.05% of the emissions of the agriculture sector.

Table 4. Key category analysis, base year level assessment (Approach 2) including LULUCF sector

CRF	CRF name	Fuel / Fuel group	Gas	Emissions/ removals 1990	Level assess- ment	Contri- bution to level	Cumu- lative sum of contri- bution	Key in level analysis
				Gg CO2-eq				
4A1	Forest land remaining forest land		CO2	-31 945.3	0.046	0.180	0.180	yes
3D1	Direct N2O emissions from managed soils		N2O	2 940.3	0.018	0.070	0.250	yes
4D1	Wetlands remaining wetlands		CO2	1 269.2	0.017	0.068	0.318	yes
4(ii)	Emissions and removals from drainage and rewetting and other management of soils		CH4	1 690.2	0.015	0.057	0.375	yes
4B1	Cropland remaining cropland		CO2	4 521.6	0.013	0.052	0.427	yes
4(ii)	Emissions and removals from drainage and rewetting and other management of soils		N2O	1 451.2	0.012	0.049	0.476	yes
2B2	Nitric acid production		N2O	1 415.4	0.012	0.047	0.523	yes
5A	Waste disposal		CH4	4 847.1	0.010	0.040	0.563	yes
4G	Harvested wood products		CO2	-2 951.6	0.009	0.035	0.598	yes
3D2	Indirect N2O emissions from managed soils		N2O	315.7	0.008	0.030	0.628	yes
4E2	Land converted to settlements		CO2	857.8	0.007	0.028	0.657	yes
4C1	Grassland remaining grassland		CO2	852.2	0.006	0.023	0.705	yes
1A4	Other sectors	Liquid	CO2	7 230.4	0.006	0.022	0.727	yes
3G	Liming		CO2	642.0	0.005	0.021	0.749	yes
4A2	Land converted to forest land		CO2	-62.4	0.005	0.021	0.769	yes
2C1	Iron and steel production		CO2	1 967.2	0.005	0.019	0.788	yes
3A	Enteric fermentation		CH4	2 715.5	0.005	0.018	0.806	yes
1A1	Energy industries	Solid	CO2	9 640.1	0.004	0.014	0.820	yes
5B	Biological treatment of waste		N2O	16.3	0.003	0.014	0.834	yes
3B	Manure management		N2O	270.2	0.003	0.012	0.846	yes
1A5	Other energy	Liquid	CO2	1035.6	0.003	0.011	0.857	yes
5D	Wastewater treatment and discharge		N2O	67.9	0.002	0.01	0.867	yes
1A1	Energy industries	Peat	CO2	3949.5	0.002	0.009	0.876	yes
4B2	Land converted to cropland		CO2	859.3	0.002	0.009	0.885	yes
2C7	Other metal industry		CO2	8.9	0.002	0.008	0.893	yes
5D	Wastewater treatment and discharge		CH4	247.5	0.002	0.008	0.901	yes

Notes: In addition, category 3F Field burning of agricultural residues was identified as a key category on the basis of the base year but is not included in this table because field burning of agricultural residues was banned in the beginning of 2021 and emissions do not occur anymore (see Section 5.5.1). 3F has represented a minor source (0,8 Gg CO2-eq), some 0.05% of the emissions of the agriculture sector.

Table 5. Key category analysis, year 2022 level assessment (Approach 1) excluding LULUCF sector

CRF	CRF name	Fuel / Fuel group	Gas	Emissions/ removals 2022	Level assess-ment	Contri-bution to level	Cumu-lative sum of contri-bution	Key in level analysis
				Gg CO2-eq				
1A3b	Road transportation	Diesel oil	CO2	5 993.4	0.131	0.131	0.131	yes
1A1	Energy industries	Solid	CO2	5 531.1	0.121	0.121	0.252	yes
1A1	Energy industries	Peat	CO2	3 309.7	0.072	0.072	0.325	yes
1A3b	Road transportation	Motor gasoline	CO2	3 161.6	0.069	0.069	0.394	yes
1A4	Other sectors	Liquid	CO2	2 884.2	0.063	0.063	0.457	yes
3D1	Direct N2O emissions from managed soils		N2O	2 733.5	0.060	0.060	0.517	yes
1A2	Manufacturing industries and construction	Liquid	CO2	2 681.5	0.059	0.059	0.575	yes
1A1	Energy industries	Liquid	CO2	2 560.6	0.056	0.056	0.631	yes
3A	Enteric fermentation		CH4	2 175.2	0.048	0.048	0.679	yes
2C1	Iron and steel production		CO2	1 956.6	0.043	0.043	0.722	yes
5A	Waste disposal		CH4	1 383.9	0.030	0.030	0.752	yes
1A2	Manufacturing industries and construction	Gaseous	CO2	1 262.9	0.028	0.028	0.780	yes
1A2	Manufacturing industries and construction	Solid	CO2	891.7	0.020	0.020	0.799	yes
2B10b	Hydrogen production		CO2	870.9	0.019	0.019	0.818	yes
2F1	Refrigeration and air conditioning		HFCs	738.5	0.016	0.016	0.834	yes
1A5	Other energy	Liquid	CO2	707.7	0.015	0.015	0.850	yes
1A1	Energy industries	Gaseous	CO2	631.1	0.014	0.014	0.864	yes
1A1	Energy industries	Other fossil	CO2	612.3	0.013	0.013	0.877	yes
2A1	Cement production		CO2	597.1	0.013	0.013	0.890	yes
1A2	Manufacturing industries and construction	Other fossil	CO2	483.3	0.011	0.011	0.901	yes
3B	Manure management		CH4	453.2	0.010	0.010	0.911	yes
1A2	Manufacturing industries and construction	Peat	CO2	403.4	0.009	0.009	0.920	yes
1A3d	Domestic navigation	Liquid	CO2	332.4	0.007	0.007	0.927	yes
2A2	Lime production		CO2	259.6	0.006	0.006	0.933	yes
3G	Liming		CO2	249.8	0.005	0.005	0.938	yes
3D2	Indirect N2O emissions from managed soils		N2O	231.5	0.005	0.005	0.943	yes
3B	Manure management		N2O	223.8	0.005	0.005	0.948	yes
1A4	Other sectors	Biomass	CH4	178.4	0.004	0.004	0.952	yes

Table 6. Key category analysis, year 2022 level assessment (Approach 1) including LULUCF sector

CRF	CRF name	Fuel / Fuel group	Gas	Emissions/ removals 2022	Level assess-ment	Contri-bution to level	Cumu-lative sum of contri-bution	Key in level analysis
				Gg CO2-eq				
4A1	Forest land remaining forest land		CO2	-7 045.5	0.099	0.099	0.099	yes
4B1	Cropland remaining cropland		CO2	6 438.9	0.091	0.091	0.190	yes
1A3b	Road transportation	Diesel oil	CO2	5 993.4	0.084	0.084	0.274	yes
1A1	Energy industries	Solid	CO2	5 531.1	0.078	0.078	0.352	yes
1A1	Energy industries	Peat	CO2	3 309.7	0.047	0.047	0.399	yes
4G	Harvested wood products		CO2	-3 250.9	0.046	0.046	0.444	yes
1A3b	Road transportation	Motor gasoline	CO2	3 161.6	0.044	0.044	0.489	yes
1A4	Other sectors	Liquid	CO2	2 884.2	0.041	0.041	0.529	yes
3D1	Direct N2O emissions from managed soils		N2O	2 733.5	0.038	0.038	0.568	yes
1A2	Manufacturing industries and construction	Liquid	CO2	2 681.5	0.038	0.038	0.606	yes
1A1	Energy industries	Liquid	CO2	2 560.6	0.036	0.036	0.642	yes
4B2	Land converted to cropland		CO2	2 381.9	0.034	0.034	0.675	yes
3A	Enteric fermentation		CH4	2 175.2	0.031	0.031	0.706	yes
2C1	Iron and steel production		CO2	1 956.6	0.028	0.028	0.733	yes
4D1	Wetlands remaining wetlands		CO2	1 853.9	0.026	0.026	0.759	yes
4(ii)	Emissions and removals from drainage and rewetting and other management of soils		N2O	1 728.4	0.024	0.024	0.784	yes
5A	Waste disposal		CH4	1 383.9	0.019	0.019	0.803	yes
1A2	Manufacturing industries and construction	Gaseous	CO2	1 262.9	0.018	0.018	0.821	yes
1A2	Manufacturing industries and construction	Solid	CO2	891.7	0.013	0.013	0.834	yes
2B10b	Hydrogen production		CO2	870.9	0.012	0.012	0.846	yes
4(ii)	Emissions and removals from drainage and rewetting and other management of soils		CH4	847.6	0.012	0.012	0.858	yes
4E2	Land converted to settlements		CO2	762.2	0.011	0.011	0.868	yes
2F1	Refrigeration and air conditioning		HFCs	738.5	0.010	0.010	0.879	yes
1A5	Other energy	Liquid	CO2	707.7	0.010	0.010	0.889	yes
1A1	Energy industries	Gaseous	CO2	631.1	0.009	0.009	0.898	yes
1A1	Energy industries	Other fossil	CO2	612.3	0.009	0.009	0.906	yes
2A1	Cement production		CO2	597.1	0.008	0.008	0.915	yes
4C1	Grassland remaining grassland		CO2	517.7	0.007	0.007	0.922	yes
1A2	Manufacturing industries and construction	Other fossil	CO2	483.3	0.007	0.007	0.929	yes
3B	Manure management		CH4	453.2	0.006	0.006	0.935	yes
1A2	Manufacturing industries and construction	Peat	CO2	403.4	0.006	0.006	0.941	yes
1A3d	Domestic navigation	Liquid	CO2	332.4	0.005	0.005	0.946	yes
2A2	Lime production		CO2	259.6	0.004	0.004	0.949	yes
3G	Liming		CO2	249.8	0.004	0.004	0.953	yes

Table 7. Key category analysis, year 2022 level assessment (Approach 2) excluding LULUCF sector

CRF	CRF name	Fuel / Fuel group	Gas	Emissions/ removals 2022	Level assess-ment	Contri-bution to level	Cumu-lative sum of contri-bution	Key in level analysis
				Gg CO2-eq				
3D1	Direct N2O emissions from managed soils		N2O	2 733.5	0.034	0.237	0.237	yes
3D2	Indirect N2O emissions from managed soils		N2O	231.5	0.014	0.097	0.334	yes
5A	Waste disposal		CH4	1 383.9	0.010	0.071	0.405	yes
3A	Enteric fermentation		CH4	2 175.2	0.009	0.063	0.468	yes
2F1	Refrigeration and air conditioning		HFCs	738.5	0.007	0.051	0.518	yes
3B	Manure management		N2O	223.8	0.006	0.043	0.561	yes
1A4	Other sectors	Biomass	CH4	178.4	0.006	0.041	0.602	yes
5D	Wastewater treatment and discharge		N2O	61.5	0.005	0.036	0.638	yes
1A4	Other sectors	Liquid	CO2	2 884.2	0.004	0.028	0.667	yes
1A3b	Road transportation	Diesel oil	CO2	5 993.4	0.004	0.027	0.694	yes
3B	Manure management		CH4	453.2	0.004	0.026	0.720	yes
1A1	Energy industries	Other fossil	CO2	612.3	0.002	0.017	0.737	yes
5D	Wastewater treatment and discharge		CH4	172.8	0.002	0.016	0.753	yes
1A5	Other energy	Liquid	CO2	707.7	0.002	0.016	0.768	yes
1A1	Energy industries	Solid	CO2	5 531.1	0.002	0.015	0.784	yes
1A1	Energy industries	Peat	CO2	3 309.7	0.002	0.015	0.798	yes
1A3b	Road transportation	Motor gasoline	CO2	3 161.6	0.002	0.014	0.812	yes
1A1	Energy industries	Liquid	CO2	2 560.6	0.002	0.014	0.826	yes
1A1	Energy industries	Biomass	N2O	137.8	0.002	0.012	0.837	yes
1A3b	Road transportation	Diesel oil	N2O	50.1	0.002	0.011	0.849	yes
2C1	Iron and steel production		CO2	1 956.6	0.002	0.011	0.860	yes
1A2	Manufacturing industries and construction	Liquid	CO2	2 681.5	0.002	0.011	0.871	yes
2B10b	Hydrogen production		CO2	870.9	0.001	0.008	0.879	yes
3G	Liming		CO2	249.8	0.001	0.008	0.886	yes
1A2	Manufacturing industries and construction	Other fossil	CO2	483.3	0.001	0.008	0.894	yes
1A4	Other sectors	Biomass	N2O	32.1	0.001	0.006	0.900	yes

Table 8. Key category analysis, year 2022 level assessment (Approach 2) including LULUCF sector

CRF	CRF name	Fuel / Fuel group	Gas	Emissions/ removals 2022	Level assess-ment	Contri-bution to level	Cumu-lative sum of contri-bution	Key in level analysis
				Gg CO2-eq				
4A1	Forest land remaining forest land		CO2	-7 045.5	0.211	0.449	0.449	yes
4D1	Wetlands remaining wetlands		CO2	1 853.9	0.039	0.083	0.531	yes
4B1	Cropland remaining cropland		CO2	6 438.9	0.036	0.078	0.609	yes
4(ii)	Emissions and removals from drainage and rewetting and other management of soils		N2O	1 728.4	0.028	0.059	0.668	yes
3D1	Direct N2O emissions from managed soils		N2O	2 733.5	0.022	0.046	0.714	yes
4G	Harvested wood products		CO2	-3 250.9	0.021	0.045	0.759	yes
4(ii)	Emissions and removals from drainage and rewetting and other management of soils		CH4	847.6	0.014	0.029	0.788	yes
4B2	Land converted to cropland		CO2	2 381.9	0.010	0.021	0.809	yes
3D2	Indirect N2O emissions from managed soils		N2O	231.5	0.009	0.019	0.827	yes
4C1	Grassland remaining grassland		CO2	517.7	0.007	0.015	0.843	yes
5A	Waste disposal		CH4	1 383.9	0.006	0.014	0.856	yes
3A	Enteric fermentation		CH4	2 175.2	0.006	0.012	0.869	yes
4E2	Land converted to settlements		CO2	762.2	0.005	0.010	0.879	yes
2F1	Refrigeration and air conditioning		HFCs	738.5	0.005	0.010	0.889	yes
3B	Manure management		N2O	223.8	0.004	0.008	0.897	yes
1A4	Other sectors	Biomass	CH4	178.4	0.004	0.008	0.905	yes

Table 9. Key category analysis, trend assessment (Approach 1) excluding LULUCF sector

CRF	CRF name	Fuel / Fuel group	Gas	Trend assess-ment	Contri-bution to trend	Cumu-lative sum of contri-bution	Key in trend analysis
1A3b	Road transportation	Diesel oil	CO2	0.040	0.137	0.137	yes
1A2	Manufacturing industries and construction	Solid	CO2	0.031	0.106	0.243	yes
1A4	Other sectors	Liquid	CO2	0.025	0.084	0.327	yes
5A	Waste disposal		CH4	0.024	0.083	0.410	yes
1A1	Energy industries	Gaseous	CO2	0.015	0.051	0.461	yes
1A1	Energy industries	Liquid	CO2	0.012	0.043	0.503	yes
3D1	Direct N2O emissions from managed soils		N2O	0.012	0.041	0.544	yes
2B10b	Hydrogen production		CO2	0.011	0.038	0.582	yes
1A1	Energy industries	Peat	CO2	0.011	0.037	0.620	yes
2B2	Nitric acid production		N2O	0.011	0.037	0.657	yes
2F1	Refrigeration and air conditioning		HFCs	0.010	0.036	0.692	yes
2C1	Iron and steel production		CO2	0.010	0.033	0.726	yes
1A1	Energy industries	Solid	CO2	0.009	0.031	0.757	yes
1A1	Energy industries	Other fossil	CO2	0.009	0.029	0.786	yes
1A3b	Road transportation	Motor gasoline	CO2	0.008	0.029	0.815	yes
1A2	Manufacturing industries and construction	Peat	CO2	0.008	0.026	0.841	yes
3A	Enteric fermentation		CH4	0.006	0.021	0.862	yes
1A2	Manufacturing industries and construction	Other fossil	CO2	0.006	0.020	0.882	yes
1A2	Manufacturing industries and construction	Liquid	CO2	0.004	0.012	0.894	yes
3B	Manure management		CH4	0.003	0.009	0.903	yes
3G	Liming		CO2	0.002	0.008	0.911	yes
1A2	Manufacturing industries and construction	Gaseous	CO2	0.002	0.007	0.918	yes
1A1	Energy industries	Biomass	N2O	0.002	0.007	0.924	yes
2A1	Cement production		CO2	0.002	0.006	0.931	yes
1A3a	Domestic aviation	Liquid	CO2	0.002	0.005	0.936	yes
1A4	Other sectors	Biomass	CH4	0.001	0.004	0.940	yes
1A5	Other energy	Gaseous	CO2	0.001	0.004	0.944	yes
1A3c	Railways	Liquid	CO2	0.001	0.003	0.947	yes
1A4	Other sectors	Peat	CO2	0.001	0.003	0.950	yes

Table 10. Key category analysis, trend assessment (Approach 1) including LULUCF sector

CRF	CRF name	Fuel / Fuel group	Gas	Trend assess-ment	Contri-bution to trend	Cumu-lative sum of contri-bution	Key in trend analysis
4A1	Forest land remaining forest land		CO2	0.200	0.358	0.358	yes
1A4	Other sectors	Liquid	CO2	0.039	0.071	0.429	yes
1A1	Energy industries	Solid	CO2	0.038	0.068	0.497	yes
1A2	Manufacturing industries and construction	Solid	CO2	0.035	0.063	0.560	yes
5A	Waste disposal		CH4	0.031	0.056	0.616	yes
1A3b	Road transportation	Motor gasoline	CO2	0.025	0.045	0.661	yes
1A1	Energy industries	Gaseous	CO2	0.018	0.032	0.693	yes
1A2	Manufacturing industries and construction	Liquid	CO2	0.018	0.032	0.725	yes
4B1	Cropland remaining cropland		CO2	0.015	0.026	0.751	yes
4B2	Land converted to cropland		CO2	0.013	0.023	0.774	yes
2B2	Nitric acid production		N2O	0.011	0.020	0.794	yes
1A2	Manufacturing industries and construction	Peat	CO2	0.010	0.017	0.811	yes
1A2	Manufacturing industries and construction	Gaseous	CO2	0.009	0.016	0.827	yes
4(ii)	Emissions and removals from drainage and rewetting and other management of soils		CH4	0.008	0.014	0.840	yes
1A3b	Road transportation	Diesel oil	CO2	0.007	0.013	0.854	yes
1A1	Energy industries	Peat	CO2	0.007	0.012	0.866	yes
2B10b	Hydrogen production		CO2	0.006	0.011	0.877	yes
2F1	Refrigeration and air conditioning		HFCs	0.006	0.011	0.888	yes
3A	Enteric fermentation		CH4	0.006	0.010	0.898	yes
1A1	Energy industries	Other fossil	CO2	0.005	0.009	0.908	yes
4D1	Wetlands remaining wetlands		CO2	0.005	0.008	0.916	yes
4G	Harvested wood products		CO2	0.004	0.006	0.922	yes
3G	Liming		CO2	0.004	0.006	0.928	yes
1A2	Manufacturing industries and construction	Other fossil	CO2	0.003	0.006	0.934	yes
1A5	Other energy	Liquid	CO2	0.003	0.006	0.940	yes
4C1	Grassland remaining grassland		CO2	0.003	0.006	0.945	yes
3D1	Direct N2O emissions from managed soils		N2O	0.003	0.005	0.950	yes

Table 11. Key category analysis, trend assessment (Approach 2) excluding LULUCF sector

CRF	CRF name	Fuel / Fuel group	Gas	Trend assess-ment	Contri-bution to trend	Cumu-lative sum of contri-bution	Key in trend analysis
5A	Waste disposal		CH4	0.008	0.183	0.183	yes
3D1	Direct N2O emissions from managed soils		N2O	0.007	0.152	0.335	yes
2F1	Refrigeration and air conditioning		HFCs	0.005	0.104	0.439	yes
1A4	Other sectors	Biomass	CH4	0.002	0.039	0.478	yes
2B2	Nitric acid production		N2O	0.002	0.037	0.516	yes
1A4	Other sectors	Liquid	CO2	0.002	0.036	0.551	yes
1A1	Energy industries	Other fossil	CO2	0.002	0.035	0.586	yes
1A3b	Road transportation	Diesel oil	CO2	0.001	0.026	0.613	yes
3A	Enteric fermentation		CH4	0.001	0.026	0.639	yes
3D2	Indirect N2O emissions from managed soils		N2O	0.001	0.025	0.664	yes
1A1	Energy industries	Biomass	N2O	0.001	0.024	0.688	yes
3B	Manure management		CH4	0.001	0.022	0.710	yes
5D	Wastewater treatment and discharge		N2O	0.001	0.022	0.732	yes
3B	Manure management		N2O	0.001	0.020	0.752	yes
1A3b	Road transportation	Motor gasoline	N2O	0.001	0.020	0.771	yes
1A2	Manufacturing industries and construction	Solid	CO2	0.001	0.018	0.789	yes
2B10b	Hydrogen production		CO2	0.001	0.015	0.804	yes
1A2	Manufacturing industries and construction	Other fossil	CO2	0.001	0.014	0.817	yes
1A3b	Road transportation	Motor gasoline	CH4	0.001	0.012	0.829	yes
3G	Liming		CO2	0.000	0.010	0.839	yes
1A1	Energy industries	Liquid	CO2	0.000	0.010	0.849	yes
5B	Biological treatment of waste		N2O	0.000	0.009	0.858	yes
5B	Biological treatment of waste		CH4	0.000	0.008	0.866	yes
2C1	Iron and steel production		CO2	0.000	0.008	0.874	yes
1A1	Energy industries	Peat	CO2	0.000	0.007	0.881	yes
1A4	Other sectors	Biomass	N2O	0.000	0.007	0.888	yes
1B2	Oil and Natural gas and other emissions from energy production		CH4	0.000	0.006	0.894	yes
1A3b	Road transportation	Diesel oil	N2O	0.000	0.006	0.900	yes

Table 12. Key category analysis, trend assessment (Approach 2) including LULUCF sector

CRF	CRF name	Fuel / Fuel group	Gas	Trend assess-ment	Contri-bution to trend	Cumu-lative sum of contri-bution	Key in trend analysis
4A1	Forest land remaining forest land		CO2	0.425	0.857	0.857	yes
5A	Waste disposal		CH4	0.010	0.021	0.878	yes
4(ii)	Emissions and removals from drainage and rewetting and other management of soils		CH4	0.009	0.018	0.896	yes
4D1	Wetlands remaining wetlands		CO2	0.007	0.014	0.910	yes

ANNEX 2. Uncertainty assessment

Annex 2 provides the mandatory reporting table for uncertainty analysis. Finland reports annually both Approach 1 and Approach 2 uncertainty analyses (UA). The Approach 2 analysis is based on the Monte Carlo simulation, and it is prepared in accordance with IPCC methodology (2006 IPCC Guidelines). Disaggregation of subcategories is at a more detailed level in the Approach 2 calculation than in Approach 1, where relevant. Disaggregation concerns mostly the energy sector, where detailed fuel type levels (heavy fuel oil, light fuel oil, etc.) are used. Approach 2 UA results are aggregated to desired levels in the Monte Carlo simulation to be in a usable format for Approach 1 UA. The results of Approach 2 and Approach 1 analysis are reported according to Tables 3.3. and 3.2. of the 2006 IPCC Guidelines. Analysis tables with numerical results are shown below, more detailed supplementary information can be found in 2022_FIN_UA-KCA_5v282.xlsx.. The results of the uncertainty analysis are presented and discussed in Section 1.6 and in the sectoral chapters.

The uncertainty of wetlands remaining wetlands constitutes that of peat extraction, while uncertainties of other subcategories were excluded due to their minor role.

Finland checks annually the UA parameterisation of the Approach 2 subcategories with expert organisations.

Table 1. Approach 2 uncertainty assessment

CRF	CRF name	Fuel / Fuel group	Gas	Emissions/ removals 1990	Emissions/ removals 2022	Activity data uncertainty 2022		Emission factor/ implied EF uncertainty 2022		Uncertainty in emissions 2022		Share of total uc in emissions 2022	Category trend 1990-2022	Uncertainty in trend	
				Gg CO2-eq	Gg CO2-eq	(-) %	(+) %	(-) %	(+) %	(-) %	(+) %	%	%	(-) %	(+) %
0I	Indirect emissions		CO2	164.7	51.2	.	.	.	.	18	18	0.013	-69	7.0	9.1
1A1	Energy Industries	Liquid	CO2	2 616.2	2 560.6	3	3	2	2	3	3	0.111	-2	6	6
1A1	Energy Industries	Liquid	CH4	1.2	1.4	3	3	33	32	33	32	6.E-04	9	30	48
1A1	Energy Industries	Liquid	N2O	20.7	20.7	3	3	35	35	35	36	0.010	0	28	42
1A1	Energy Industries	Solid	CO2	9 640.1	5 531.1	1	1	2	2	2	2	0.140	-43	3	3
1A1	Energy Industries	Solid	CH4	3.1	1.6	1	1	49	49	49	49	0.001	-49	5	14
1A1	Energy Industries	Solid	N2O	37.1	17.8	1	1	49	48	49	48	0.012	-52	5	15
1A1	Energy Industries	Gaseous	CO2	2 636.2	631.1	1	1	0	0	1	1	0.009	-76	0	0
1A1	Energy Industries	Gaseous	CH4	1.4	0.5	1	1	53	54	53	54	0.000	-66	6	5
1A1	Energy Industries	Gaseous	N2O	13.4	3.6	1	1	48	48	48	48	0.002	-73	3	4
1A1	Energy Industries	Other fossil	CO2	1.0	612.3	10	10	15	15	18	18	0.158	61065	17044	26048
1A1	Energy Industries	Other fossil	CH4	0.001	0.6	9	9	59	58	59	59	5.E-04	69456	44003	124336
1A1	Energy Industries	Other fossil	N2O	0.005	7.4	9	9	58	57	59	59	0.006	155905	98711	277053
1A1	Energy Industries	Peat	CO2	3 949.5	3 309.7	2	2	2	2	3	3	0.133	-16	6	7
1A1	Energy Industries	Peat	CH4	3.3	5.3	2	2	60	60	60	60	0.004	57	8	9
1A1	Energy Industries	Peat	N2O	29.7	42.9	2	2	60	60	60	60	0.036	44	8	8
1A1	Energy Industries	Biomass	CH4	2.0	27.1	5	4	56	55	56	56	0.021	1 284	148	233
1A1	Energy Industries	Biomass	N2O	2.6	137.8	5	4	55	55	55	56	0.108	5171	583	953

CRF	CRF name	Fuel / Fuel group	Gas	Emissions/ removals 1990	Emissions/ removals 2022	Activity data uncertainty 2022		Emission factor/ implied EF uncertainty 2022		Uncertainty in emissions 2022		Share of total uc in emissions 2022	Category trend 1990-2022	Uncertainty in trend	
				Gg CO2-eq	Gg CO2-eq	(-) %	(+) %	(-) %	(+) %	(-) %	(+) %	%	%	(-) %	(+) %
1A2	Manufacturing industries and construction	Liquid	CO2	4 575.7	2 681.5	2	2	1	1	3	3	0.098	-41	2	2
1A2	Manufacturing industries and construction	Liquid	CH4	4.0	3.3	2	2	36	36	36	36	0.002	-19	31	39
1A2	Manufacturing industries and construction	Liquid	N2O	32.3	17.9	2	2	29	43	30	43	0.011	-45	19	30
1A2	Manufacturing industries and construction	Solid	CO2	4 841.6	891.7	2	2	2	2	2	2	0.030	-82	1	1
1A2	Manufacturing industries and construction	Solid	CH4	1.8	0.3	2	2	27	27	27	27	1.E-04	-83	3	4
1A2	Manufacturing industries and construction	Solid	N2O	40.0	21.0	2	2	52	53	52	53	0.016	-47	23	23
1A2	Manufacturing industries and construction	Gaseous	CO2	2 198.6	1 262.9	2	2	0	0	2	2	0.028	-43	2	2
1A2	Manufacturing industries and construction	Gaseous	CH4	1.3	0.9	2	2	32	32	32	32	0.000	-35	14	30
1A2	Manufacturing industries and construction	Gaseous	N2O	13.0	7.9	2	2	35	35	35	35	0.004	-39	8	17
1A2	Manufacturing industries and construction	Other fossil	CO2	100.6	483.3	6	6	8	8	10	10	0.069	380	97	135
1A2	Manufacturing industries and construction	Other fossil	CH4	0.1	0.5	6	6	39	40	40	41	3.E-04	241	164	446
1A2	Manufacturing industries and construction	Other fossil	N2O	0.6	3.6	6	6	31	31	31	32	0.002	539	237	445
1A2	Manufacturing industries and construction	Peat	CO2	1 475.9	403.4	2	2	2	2	3	3	0.016	-73	2	3
1A2	Manufacturing industries and construction	Peat	CH4	1.2	0.3	2	2	53	53	53	53	2.E-04	-75	8	7
1A2	Manufacturing industries and construction	Peat	N2O	13.7	2.6	2	2	56	56	56	56	0.002	-81	6	5
1A2	Manufacturing industries and construction	Biomass	CH4	9.2	16.6	2	2	29	29	29	29	0.007	80	34	51
1A2	Manufacturing industries and construction	Biomass	N2O	48.6	70.7	2	2	38	39	39	39	0.039	45	12	11

CRF	CRF name	Fuel / Fuel group	Gas	Emissions/ removals 1990	Emissions/ removals 2022	Activity data uncertainty 2022		Emission factor/ implied EF uncertainty 2022		Uncertainty in emissions 2022		Share of total uc in emissions 2022	Category trend 1990-2022	Uncertainty in trend	
				Gg CO2-eq	Gg CO2-eq	(-) %	(+) %	(-) %	(+) %	(-) %	(+) %	%	%	(-) %	(+) %
1A3a	Civil aviation	Liquid	CO2	385.1	135.2	5	5	2	2	5	5	0.010	-65	4	4
1A3a	Civil aviation	Liquid	CH4	0.2	0.06	5	5	59	60	59	60	5.E-05	-58	4	5
1A3a	Civil aviation	Liquid	N2O	2.8	1.0	5	5	70	146	71	146	0.002	-65	5	4
1A3b	Road transportation	Diesel oil	CO2	4 923.5	5 993.4	2	2	1	1	3	3	0.247	22	5	5
1A3b	Road transportation	Diesel oil	CH4	15.3	0.8	2	2	60	59	60	59	0.001	-95	3	9
1A3b	Road transportation	Diesel oil	N2O	58.2	50.1	2	2	70	149	71	148	0.105	-14	75	203
1A3b	Road transportation	Motor gasoline	CO2	5 880.5	3 161.6	2	2	2	2	3	3	0.126	-46	2	2
1A3b	Road transportation	Motor gasoline	CH4	104.3	5.6	2	2	60	60	60	60	0.005	-95	3	9
1A3b	Road transportation	Motor gasoline	N2O	78.5	8.3	2	2	70	148	70	148	0.017	-89	9	25
1A3b	Road transportation	Gaseous	CO2	.	1.4	3	3	2	2	2	2	4.E-05	.	.	.
1A3b	Road transportation	Gaseous	CH4	.	0.3	3	3	58	59	58	59	3.E-04	.	.	.
1A3b	Road transportation	Gaseous	N2O	.	0.1	3	3	68	147	68	147	3.E-04	.	.	.
1A3b	Road transportation	Biomass	CH4	.	1.4	1	1	38	38	38	38	8.E-04	.	.	.
1A3b	Road transportation	Biomass	N2O	.	12.0	1	1	68	145	68	145	0.024	.	.	.
1A3c	Railways	Liquid	CO2	191.1	58.8	2	2	1	2	3	3	0.002	-69	1	1
1A3c	Railways	Liquid	CH4	0.3	0.1	2	2	60	60	60	60	8.E-05	-70	1	1
1A3c	Railways	Liquid	N2O	1.3	0.2	2	2	70	150	70	150	5.E-04	-81	1	1
1A3c	Railways	Biomass	CH4	.	0.004	15	15	60	60	60	64	3.E-06	.	.	.
1A3c	Railways	Biomass	N2O	.	0.01	15	15	70	147	70	150	2.E-05	.	.	.
1A3d	Domestic navigation	Liquid	CO2	441.3	332.4	10	10	1	1	10	10	0.047	-25	10	12
1A3d	Domestic navigation	Liquid	CH4	6.1	3.8	10	10	53	55	54	57	0.003	-38	37	92
1A3d	Domestic navigation	Liquid	N2O	2.5	2.1	10	10	56	103	56	104	0.003	-16	51	248
1A3d	Domestic navigation	Gaseous	CO2	.	7.4	20	20	1	1	20	20	0.002	.	.	.
1A3d	Domestic navigation	Gaseous	CH4	.	0.1	20	20	59	60	61	66	8.E-05	.	.	.
1A3d	Domestic navigation	Gaseous	N2O	.	0.01	20	20	70	148	71	150	2.E-05	.	.	.
1A3d	Domestic navigation	Biomass	CH4	.	0.4	9	9	57	58	57	60	3.E-04	.	.	.
1A3d	Domestic navigation	Biomass	N2O	.	0.1	9	9	51	86	52	87	2.E-04	.	.	.

CRF	CRF name	Fuel / Fuel group	Gas	Emissions/ removals 1990	Emissions/ removals 2022	Activity data uncertainty 2022		Emission factor/ implied EF uncertainty 2022		Uncertainty in emissions 2022		Share of total uc in emissions 2022	Category trend 1990-2022	Uncertainty in trend	
				Gg CO2-eq	Gg CO2-eq	(-) %	(+) %	(-) %	(+) %	(-) %	(+) %	%	%	(-) %	(+) %
1A4	Other sectors	Liquid	CO2	7 230.4	2 884.2	6	6	1	1	6	6	0.259	-60	-60	60
1A4	Other sectors	Liquid	CH4	29.8	13.8	6	6	25	26	25	26	0.005	-54	-54	54
1A4	Other sectors	Liquid	N2O	50.6	16.4	6	6	29	35	29	36	0.008	-68	-68	68
1A4	Other sectors	Solid	CO2	46.5	7.3	20	20	1	1	20	20	0.002	-84	-84	84
1A4	Other sectors	Solid	CH4	3.1	0.01	20	20	59	61	60	67	8.E-06	-100	-100	100
1A4	Other sectors	Solid	N2O	0.5	0.1	20	20	60	60	61	66	6.E-05	-88	-88	88
1A4	Other sectors	Gaseous	CO2	94.7	105.5	7	7	0	0	7	7	0.010	11	11	-11
1A4	Other sectors	Gaseous	CH4	0.3	0.2	7	7	41	41	41	42	9.E-05	-44	-44	44
1A4	Other sectors	Gaseous	N2O	0.5	0.5	7	7	40	40	40	41	3.E-04	9	9	-9
1A4	Other sectors	Other fossil	CO2	0.2	.	.	.	.	.	.	.		-100	.	.
1A4	Other sectors	Other fossil	CH4	9.E-05	.	.	.	.	.	.	.		-100	.	.
1A4	Other sectors	Other fossil	N2O	8.E-04	.	.	.	.	.	.	.		-100	.	.
1A4	Other sectors	Peat	CO2	118.1	138.8	8	8	2	2	9	9	0.017	17	21	29
1A4	Other sectors	Peat	CH4	1.6	1.9	8	8	60	122	60	123	0.003	18	64	91
1A4	Other sectors	Peat	N2O	1.2	1.4	8	8	64	132	64	132	0.003	15	66	90
1A4	Other sectors	Biomass	CH4	148.1	178.4	16	16	69	147	70	152	0.382	20	35	59
1A4	Other sectors	Biomass	N2O	24.8	32.1	16	16	60	127	61	132	0.060	29	32	74
1A5	Other energy	Liquid	CO2	1 035.6	707.7	14	14	3	3	14	14	0.140	-32	18	33
1A5	Other energy	Liquid	CH4	3.3	1.3	14	14	41	43	42	47	0.001	-61	15	29
1A5	Other energy	Liquid	N2O	7.0	3.9	14	14	38	45	39	47	0.003	-44	22	45
1A5	Other energy	Solid	CO2	1.2	.	.	.	.	.	.	.		-100	.	.
1A5	Other energy	Solid	CH4	0.001	.	.	.	.	.	.	.		-100	.	.
1A5	Other energy	Solid	N2O	0.01	.	.	.	.	.	.	.		-100	.	.
1A5	Other energy	Gaseous	CO2	65.7	125.0	20	20	1	1	20	20	0.036	90	1 407	1 481
1A5	Other energy	Gaseous	CH4	0.1	0.2	20	20	59	60	60	66	2.E-04	92	1 422	1 503
1A5	Other energy	Gaseous	N2O	0.3	0.6	20	20	60	60	61	66	6.E-04	89	1 398	1 478
1A5	Other energy	Peat	CO2	24.0	.	.	.	.	.	.	.		-100	.	.
1A5	Other energy	Peat	CH4	0.3	.	.	.	.	.	.	.		-100	.	.
1A5	Other energy	Peat	N2O	0.1	.	.	.	.	.	.	.		-100	.	.
1A5	Other energy	Biomass	CH4	0.4	0.6	11	11	58	58	58	59	5.E-04	48	94	282
1A5	Other energy	Biomass	N2O	0.2	0.1	11	11	44	43	45	46	9.E-05	-35	36	116

CRF	CRF name	Fuel / Fuel group	Gas	Emissions/ removals 1990	Emissions/ removals 2022	Activity data uncertainty 2022		Emission factor/ implied EF uncertainty 2022		Uncertainty in emissions 2022		Share of total uc in emissions 2022	Category trend 1990-2022	Uncertainty in trend	
				Gg CO2-eq	Gg CO2-eq	(-) %	(+) %	(-) %	(+) %	(-) %	(+) %	%	%	(-) %	(+) %
1B2	Oil and Natural gas and other emissions from energy production	Non-fuel	CO2	111.5	65.0	50	50	20	20	52	57	0.052	-42	33	76
1B2	Oil and Natural gas and other emissions from energy production	Non-fuel	CH4	12.2	25.9	49	50	41	105	29	29	0.011	113	33	102
1B2	Oil and Natural gas and other emissions from energy production	Non-fuel	N2O	1.1	0.7	50	50	60	60	69	90	0.001	-37	46	164
2A1	Cement production		CO2	729.2	597.1	2	2	5	5	5	5	0.045	-18	2	2
2A2	Lime production		CO2	400.6	259.6	2	2	3	3	4	4	0.013	-35	3	3
2A3	Limestone and dolomite use		CO2	21.0	2.0	5	5	3	3	6	6	2.E-04	-90	1	1
2A4	Other process uses of carbonates		CO2	67.5	81.5	4	4	2	2	4	4	0.005	21	10	12
2B1	Ammonia production		CO2	93.0	.	.	.	.	.	.	.		-100	.	.
2B2	Nitric acid production		N2O	1 415.4	144.8	3	3	15	15	15	15	0.031	-90	26	54
2B8	Petrochemical and carbon black production		CH4	5.2	1.4	.	.	.	.	40	40	0.001	-72	14	45
2B10a	Phosphoric acid production		CO2	24.5	32.1	.	.	.	.	7	7	0.003	31	19	25
2B10b	Hydrogen production		CO2	116.2	870.9	5	5	3	3	6	6	0.072	649	82	97
2B10c	Limestone and dolomite use		CO2	36.5	65.1	5	5	3	3	6	6	0.005	78	14	16
2B10d	Chemicals production		CO2	6.7	2.2	.	.	.	.	100	100	0.003	-68	-68	68
2C1	Iron and steel production		CO2	1 967.2	1 956.6	.	.	.	.	4	4	0.101	-1	22	41
2C1	Iron and steel production		CH4	0.001	0.002	3	3	20	20	20	20	6.E-07	66	7	7
2C7	Other Metal Industry		CO2	8.9	17.4	.	.	.	.	3	3	0.001	96	0	0
2D1	Lubricant use		CO2	207.5	89.8	20	20	7	7	21	21	0.027	-57	11	14
2D1	Lubricant use		CH4	0.3	0.1	20	20	60	60	61	66	1.E-04	-57	11	14
2D1	Lubricant use		N2O	1.5	0.6	20	20	60	60	61	66	0.001	-57	11	14
2D2	Paraffin wax use		CO2	10.2	24.3	10	10	101	99	101	101	0.034	139	45	66
2D3	Other non energy products		CO2	.	19.4	20	20	2	2	20	20	0.006	.	.	.
2F1	Refrigeration and air conditioning		HFCs	0.01	738.5	12	12	29	31	30	32	3.E-01	6285532	3158325	11962934
2F1	Refrigeration and air conditioning		PFCs	.	0.6	25	25	50	50	53	60	0.001	.	.	.
2F2	Foam blowing agents		HFCs	.	4.3	20	20	50	50	51	57	0.003	.	.	.
2F4	Aerosols		HFCs	.	17.0	.	.	.	.	50	50	0.012	.	.	.
2G1	Electrical equipment		SF6	46.4	23.0	20	20	40	40	43	47	0.015	-51	27	76
2G3	N2O from product uses		N2O	57.3	21.4	.	.	.	.	10	10	0.003	-63	6	11
2H3	Other Industrial process and product se		HFCs	0.01	3.5	.	.	.	.	60	60	0.003	40 651	26 820	97 160
2H3	Other Industrial process and product se		PFCs	0.2	0.9	.	.	.	.	60	60	0.001	364	309	1 120
2H3	Other Industrial process and product se		SF6	7.7	5.0	.	.	.	.	64	64	0.005	-35	69	360

CRF	CRF name	Fuel / Fuel group	Gas	Emissions/ removals 1990	Emissions/ removals 2022	Activity data uncertainty 2022		Emission factor/ implied EF uncertainty 2022		Uncertainty in emissions 2022		Share of total uc in emissions 2022	Category trend 1990-2022	Uncertainty in trend	
				Gg CO2-eq	Gg CO2-eq	(-) %	(+) %	(-) %	(+) %	(-) %	(+) %	%	%	(-) %	(+) %
3A	Enteric fermentation		CH4	2 715.5	2 175.2	.	.	.	.	14	19	0.573	-20	21	9
3B	Manure management		CH4	421.9	453.2	.	.	.	.	23	38	0.241	7	27	36
3B	Manure management		N2O	270.2	223.8	.	.	.	.	37	124	0.392	-17.2	44	92
3D1	Direct soil emissions		N2O	2 940.3	2 733.5	.	.	.	.	33	56	2.162	-7	35	54
3D2	Indirect emissions		N2O	315.7	231.5	.	.	.	.	98	270	0.880	-27	70	282
3F	Field burning of agricultural residues		CH4	3.4	.	.	.	.	.	.	.		-100	.	.
3F	Field burning of agricultural residues		N2O	0.8	.	.	.	.	.	.	.		-100	.	.
3G	Liming		CO2	642.0	249.8	.	.	.	.	20	20	0.070	-61	0	0
3H	Urea Application		CO2	5.4	7.8	.	.	.	.	30	30	3.E-03	44	0	0
4A1	Forest Land remaining Forest Land		CO2	-31 945.3	-7 045.5	.	.	.	.	107	213	21.108	-78	48	25
4A2	Land converted to Forest Land		CO2	- 62.4	- 158.0	.	.	.	.	144	139	0.320	153	1 047	568
4B1	Cropland remaining Cropland		CO2	4 521.6	6 438.9	.	.	.	.	40	35	3.650	42	65	92
4B2	Land converted to Cropland		CO2	859.3	2 381.9	.	.	.	.	29	29	0.971	177	97	137
4C1	Grassland remaining Grassland		CO2	852.2	517.7	.	.	.	.	97	97	0.710	-39	64	231
4C2	Land converted to Grassland		CO2	167.5	249.3	.	.	.	.	71	72	0.252	49	128	590
4D1	Wetlands remaining Wetlands		CO2	1 269.2	1 853.9	.	.	.	.	70	149	3.885	46	103	986
4D2	Land converted to Wetlands		CO2	65.5	86.3	.	.	.	.	70	150	0.182	32	102	450
4E1	Settlements remaining Settlements		CO2	.	.	.	.	.	.	.	.		.	.	.
4E2	Land converted to Settlements		CO2	857.8	762.2	.	.	.	.	31	46	0.489	-11	34	58
4G	Harvested Wood Products		CO2	-2 951.6	-3 250.9	.	.	.	.	46	46	2.107	10	54	88
4(i)	N fertilization		N2O	18.3	5.3	10	10	70	203	70	203	0.015	-71	4	4
4(ii)	Drainage. rewetting and other management soils		CH4	1 690.2	847.6	10	10	80	80	79	81	0.972	-50	78	271
4(ii)	Drainage. rewetting and other management soils		N2O	1 451.2	1 728.4	10	10	80	80	81	82	1.986	19	182	661
4(iii)	Mineralization		N2O	25.6	23.7	10	10	70	204	70	205	0.069	-7	12	14
4(iv)	Indirect N2O emissions		N2O	1.1	1.2	.	.	.	.	41	187	0.003	12	168	171
4A(v)	FL. biomass burning		CH4	3.2	0.6	10	10	76	19	76	18	0.001	-82	11	26
4A(v)	FL. biomass burning		N2O	1.7	0.3	100	100	100	100	100	100	4.E-04	-82	-82	82
4C(v)	GL. biomass burning		CO2	0.01	0.002	10	10	12	12	15	16	5.E-07	-74	5	6
4C(v)	GL. biomass burning		CH4	0.1	0.01	10	10	78	78	78	80	2.E-05	-81	16	62
4C(v)	GL. biomass burning		N2O	0.1	0.01	10	10	95	94	95	95	2.E-05	-81	23	103
5A	Solid Waste Disposal		CH4	4 847.1	1 383.9	.	.	.	.	33	33	0.649	-71	6	6
5B	Biological Treatment of Solid Waste		CH4	28.8	74.5	7	7	46	46	46	48	0.050	158	87	245

5B	Biological Treatment of Solid Waste	N2O	16.3	34.0	16	16	73	116	73	118	0.056	108	131	108
5D	Wastewater Treatment and Discharge	CH4	247.5	172.8	12	12	34	58	33	56	0.136	-30	11	14
5D	Wastewater Treatment and Discharge	N2O	67.9	61.5	9	8	93	382	93	384	0.333	-9	37	467

Notes: When uncertainties are estimated for emissions/removals directly (not for AD and EF). the columns for AD and EF/IEF uncertainty are left blank. When year 2022 emissions/removals are zero. all uncertainty columns are left blank. When either 1990 or 2022 emissions are zero. trend uncertainty columns are left blank.

Table 2. Approach 1 uncertainty analysis with and without the LULUCF sector

CRF	CRF name	Fuel / Fuel group	Gas	Emissions/ removals 1990	Emissions/ removals 2022	AD uncertainty 2022	EF / IEF uncertainty 2022	Combined level uncertainty 2022	Share of level uncertainty *excl. LULUCF*	Share of trend uncertainty *excl. LULUCF*	Share of level uncertainty *incl. LULUCF*	Share of trend uncertainty *incl. LULUCF*
				Gg CO2-eq	Gg CO2-eq	± %	± %	± %	%	± %	%	± %
0I	Indirect emissions		CO2	164.7	51.2	18	.	18	0.020	0.018	0.018	0.027
1A1	Energy Industries	Liquid	CO2	2 616.2	2 560.6	3	2	3	0.194	0.175	0.176	0.260
1A1	Energy Industries	Liquid	CH4	1.2	1.4	3	33	33	0.001	3.E-04	0.001	1.E-04
1A1	Energy Industries	Liquid	N2O	20.7	20.7	3	35	36	0.016	0.004	0.015	0.002
1A1	Energy Industries	Solid	CO2	9 640.1	5 531.1	1	2	2	0.215	0.194	0.195	0.288
1A1	Energy Industries	Solid	CH4	3.1	1.6	1	49	49	0.002	3.E-04	0.002	0.002
1A1	Energy Industries	Solid	N2O	37.1	17.8	1	49	49	0.019	0.004	0.017	0.021
1A1	Energy Industries	Gaseous	CO2	2 636.2	631.1	1	0	1	0.014	0.013	0.013	0.026
1A1	Energy Industries	Gaseous	CH4	1.4	0.5	1	54	54	0.001	3.E-04	0.001	1.E-03
1A1	Energy Industries	Gaseous	N2O	13.4	3.6	1	48	48	0.004	0.003	0.003	0.010
1A1	Energy Industries	Other fossil	CO2	1.0	612.3	10	15	18	0.242	0.219	0.221	0.325
1A1	Energy Industries	Other fossil	CH4	0.001	0.6	9	59	59	0.001	0.001	0.001	0.001
1A1	Energy Industries	Other fossil	N2O	0.005	7.4	9	58	59	0.010	0.006	0.009	0.009
1A1	Energy Industries	Peat	CO2	3 949.5	3 309.7	2	2	3	0.206	0.186	0.187	0.276
1A1	Energy Industries	Peat	CH4	3.3	5.3	2	60	60	0.007	0.003	0.006	0.002
1A1	Energy Industries	Peat	N2O	29.7	42.9	2	60	60	0.056	0.020	0.051	0.015
1A1	Energy Industries	Biomass	CH4	2.0	27.1	5	56	56	0.033	0.020	0.030	0.029
1A1	Energy Industries	Biomass	N2O	2.6	137.8	5	55	55	0.167	0.106	0.152	0.155

CRF	CRF name	Fuel / Fuel group	Gas	Emissions/ removals 1990	Emissions/ removals 2022	AD uncertainty 2022	EF / IEF uncertainty 2022	Combined level uncertainty 2022	Share of level uncertainty *excl. LULUCF*	Share of trend uncertainty *excl. LULUCF*	Share of level uncertainty *incl. LULUCF*	Share of trend uncertainty *incl. LULUCF*
				Gg CO2-eq	Gg CO2-eq	± %	± %	± %	%	± %	%	± %
1A2	Manufacturing industries and construction	Liquid	CO2	4 575.7	2 681.5	2	1	3	0.156	0.141	0.142	0.210
1A2	Manufacturing industries and construction	Liquid	CH4	4.0	3.3	2	36	36	0.003	0.002	0.002	0.003
1A2	Manufacturing industries and construction	Liquid	N2O	32.3	17.9	2	43	43	0.017	0.015	0.015	0.023
1A2	Manufacturing industries and construction	Solid	CO2	4 841.6	891.7	2	2	3	0.049	0.045	0.045	0.066
1A2	Manufacturing industries and construction	Solid	CH4	1.8	0.3	2	27	27	2E-04	3E-04	2E-04	0.001
1A2	Manufacturing industries and construction	Solid	N2O	40.0	21.0	2	53	53	0.024	0.003	0.022	0.023
1A2	Manufacturing industries and construction	Gaseous	CO2	2 198.6	1 262.9	2	0	2	0.043	0.038	0.039	0.057
1A2	Manufacturing industries and construction	Gaseous	CH4	1.3	0.9	2	32	32	0.001	3.E-05	0.001	4.E-04
1A2	Manufacturing industries and construction	Gaseous	N2O	13.0	7.9	2	35	35	0.006	0.000	0.006	0.004
1A2	Manufacturing industries and construction	Other fossil	CO2	100.6	483.3	6	8	10	0.107	0.097	0.098	0.144
1A2	Manufacturing industries and construction	Other fossil	CH4	0.1	0.5	6	40	40	4.E-04	2.E-04	4.E-04	3.E-04
1A2	Manufacturing industries and construction	Other fossil	N2O	0.6	3.6	6	31	32	0.002	0.001	0.002	0.002
1A2	Manufacturing industries and construction	Peat	CO2	1 475.9	403.4	2	2	3	0.024	0.021	0.022	0.051
1A2	Manufacturing industries and construction	Peat	CH4	1.2	0.3	2	53	53	3.E-04	3.E-04	3.E-04	0.001
1A2	Manufacturing industries and construction	Peat	N2O	13.7	2.6	2	56	56	0.003	0.005	0.003	0.014
1A2	Manufacturing industries and construction	Biomass	CH4	9.2	16.6	2	29	29	0.011	0.004	0.010	0.004
1A2	Manufacturing industries and construction	Biomass	N2O	48.6	70.7	2	39	39	0.060	0.022	0.055	0.017

CRF	CRF name	Fuel / Fuel group	Gas	Emissions/ removals 1990	Emissions/ removals 2022	AD uncertainty 2022	EF / IEF uncertainty 2022	Combined level uncertainty 2022	Share of level uncertainty *excl. LULUCF*	Share of trend uncertainty *excl. LULUCF*	Share of level uncertainty *incl. LULUCF*	Share of trend uncertainty *incl. LULUCF*
				Gg CO2-eq	Gg CO2-eq	± %	± %	± %	%	± %	%	± %
1A3a	Civil aviation	Liquid	CO2	385.1	135.2	5	2	5	0.016	0.014	0.014	0.023
1A3a	Civil aviation	Liquid	CH4	0.2	0.06	5	60	60	8.E-05	3.E-05	8.E-05	1.E-04
1A3a	Civil aviation	Liquid	N2O	2.8	1.0	5	146	146	0.003	0.002	0.003	0.006
1A3b	Road transportation	Diesel oil	CO2	4 923.5	5 993.4	2	1	3	0.382	0.346	0.348	0.513
1A3b	Road transportation	Diesel oil	CH4	15.3	0.8	2	60	60	0.001	0.001	0.001	0.001
1A3b	Road transportation	Diesel oil	N2O	58.2	50.1	2	149	149	0.163	0.148	0.149	0.219
1A3b	Road transportation	Motor gasoline	CO2	5 880.5	3 161.6	2	2	3	0.195	0.177	0.178	0.262
1A3b	Road transportation	Motor gasoline	CH4	104.3	5.6	2	60	60	0.007	0.007	0.007	0.010
1A3b	Road transportation	Motor gasoline	N2O	78.5	8.3	2	148	148	0.027	0.024	0.024	0.036
1A3b	Road transportation	Gaseous	CO2		1.4	3	2	3	0.000	0.000	0.000	0.000
1A3b	Road transportation	Gaseous	CH4		0.3	3	59	59	4.E-04	4.E-04	4.E-04	6.E-04
1A3b	Road transportation	Gaseous	N2O		0.1	3	147	147	4.E-04	4.E-04	4.E-04	6.E-04
1A3b	Road transportation	Biomass	CH4		1.4	1	38	38	0.001	0.001	0.001	0.002
1A3b	Road transportation	Biomass	N2O		12.0	1	145	145	0.038	0.034	0.035	0.051
1A3c	Railways	Liquid	CO2	191.1	58.8	2	2	3	0.003	0.003	0.003	0.006
1A3c	Railways	Liquid	CH4	0.3	0.1	2	60	60	1.E-04	9.E-05	1.E-04	3.E-04
1A3c	Railways	Liquid	N2O	1.3	0.2	2	150	150	0.001	0.001	0.001	0.003
1A3c	Railways	Biomass	CH4		0.004	15	60	62	5.E-06	3.E-06	5.E-06	5.E-06
1A3c	Railways	Biomass	N2O		0.01	15	147	148	3.E-05	2.E-05	3.E-05	3.E-05
1A3d	Domestic navigation	Liquid	CO2	441.3	332.4	10	1	10	0.073	0.067	0.067	0.099
1A3d	Domestic navigation	Liquid	CH4	6.1	3.8	10	55	56	0.005	0.004	0.004	0.006
1A3d	Domestic navigation	Liquid	N2O	2.5	2.1	10	103	103	0.005	0.004	0.004	0.006
1A3d	Domestic navigation	Gaseous	CO2		7.4	20	1	20	0.003	0.003	0.003	0.004
1A3d	Domestic navigation	Gaseous	CH4		0.1	20	60	63	1.E-04	1.E-04	1.E-04	2.E-04
1A3d	Domestic navigation	Gaseous	N2O		0.01	20	148	149	4.E-05	3.E-05	3.E-05	5.E-05
1A3d	Domestic navigation	Biomass	CH4		0.4	9	58	59	5.E-04	4.E-04	5.E-04	7.E-04
1A3d	Domestic navigation	Biomass	N2O		0.1	9	86	86	3.E-04	2.E-04	2.E-04	4.E-04

CRF	CRF name	Fuel / Fuel group	Gas	Emissions/ removals 1990	Emissions/ removals 2022	AD uncertainty 2022	EF / IEF uncertainty 2022	Combined level uncertainty 2022	Share of level uncertainty *excl. LULUCF*	Share of trend uncertainty *excl. LULUCF*	Share of level uncertainty *incl. LULUCF*	Share of trend uncertainty *incl. LULUCF*
				Gg CO2-eq	Gg CO2-eq	± %	± %	± %	%	± %	%	± %
1A4	Other sectors	Liquid	CO2	7 230.4	2 884.2	6	1	6	0.403	0.365	0.367	0.540
1A4	Other sectors	Liquid	CH4	29.8	13.8	6	26	26	0.008	0.007	0.007	0.011
1A4	Other sectors	Liquid	N2O	50.6	16.4	6	35	35	0.013	0.012	0.012	0.017
1A4	Other sectors	Solid	CO2	46.5	7.3	20	1	20	0.003	0.003	0.003	0.004
1A4	Other sectors	Solid	CH4	3.1	0.01	20	61	64	1.E-05	0.002	1.E-05	0.004
1A4	Other sectors	Solid	N2O	0.5	0.1	20	60	64	9.E-05	2.E-04	8.E-05	6.E-04
1A4	Other sectors	Gaseous	CO2	94.7	105.5	7	0	7	0.015	0.014	0.014	0.021
1A4	Other sectors	Gaseous	CH4	0.3	0.2	7	41	42	1.E-04	2.E-05	1.E-04	1.E-04
1A4	Other sectors	Gaseous	N2O	0.5	0.5	7	40	41	0.000	1.E-04	0.000	1.E-04
1A4	Other sectors	Other fossil	CO2	0.2		.	.	.	.	.	.	.
1A4	Other sectors	Other fossil	CH4	9.E-05		.	.	.	.	.	.	.
1A4	Other sectors	Other fossil	N2O	8.E-04		.	.	.	.	.	.	.
1A4	Other sectors	Peat	CO2	118.1	138.8	8	2	9	0.026	0.024	0.024	0.035
1A4	Other sectors	Peat	CH4	1.6	1.9	8	122	122	0.005	0.002	0.005	0.001
1A4	Other sectors	Peat	N2O	1.2	1.4	8	132	132	0.004	0.001	0.004	0.001
1A4	Other sectors	Biomass	CH4	148.1	178.4	16	147	148	0.578	0.182	0.527	0.114
1A4	Other sectors	Biomass	N2O	24.8	32.1	16	127	128	0.090	0.031	0.082	0.023
1A5	Other energy	Liquid	CO2	1 035.6	707.7	14	3	14	0.221	0.200	0.201	0.296
1A5	Other energy	Liquid	CH4	3.3	1.3	14	43	45	0.001	0.001	0.001	0.002
1A5	Other energy	Liquid	N2O	7.0	3.9	14	45	47	0.004	0.001	0.004	0.004
1A5	Other energy	Solid	CO2	1.2		.	.	.	.	.	.	.
1A5	Other energy	Solid	CH4	0.001		.	.	.	.	.	.	.
1A5	Other energy	Solid	N2O	0.01		.	.	.	.	.	.	.
1A5	Other energy	Gaseous	CO2	65.7	125.0	20	1	20	0.056	0.050	0.051	0.075
1A5	Other energy	Gaseous	CH4	0.1	0.2	20	60	63	3.E-04	1.E-04	2.E-04	2.E-04
1A5	Other energy	Gaseous	N2O	0.3	0.6	20	60	63	0.001	4.E-04	0.001	0.000
1A5	Other energy	Peat	CO2	24.0		.	.	.	.	.	.	.
1A5	Other energy	Peat	CH4	0.3		.	.	.	.	.	.	.
1A5	Other energy	Peat	N2O	0.1		.	.	.	.	.	.	.
1A5	Other energy	Biomass	CH4	0.4	0.6	11	58	59	0.001	3.E-04	0.001	0.000
1A5	Other energy	Biomass	N2O	0.2	0.1	11	44	45	1.E-04	3.E-05	1.E-04	9.E-05

CRF	CRF name	Fuel / Fuel group	Gas	Emissions/ removals 1990	Emissions/ removals 2022	AD uncertainty 2022	EF / IEF uncertainty 2022	Combined level uncertainty 2022	Share of level uncertainty *excl. LULUCF*	Share of trend uncertainty *excl. LULUCF*	Share of level uncertainty *incl. LULUCF*	Share of trend uncertainty *incl. LULUCF*
				Gg CO2-eq	Gg CO2-eq	± %	± %	± %	%	± %	%	± %
1B2	Oil and Natural gas and other emissions from energy production	Non-fuel	CO2	111.5	65.0	57	20	61	0.086	0.078	0.079	0.116
1B2	Oil and Natural gas and other emissions from energy production	Non-fuel	CH4	12.2	25.9	29	105	110	0.062	0.056	0.057	0.083
1B2	Oil and Natural gas and other emissions from energy production	Non-fuel	N2O	1.1	0.7	90	60	108	0.002	0.001	0.001	0.002
2A1	Cement production		CO2	729.2	597.1	2	5	5	0.070	0.025	0.064	0.039
2A2	Lime production		CO2	400.6	259.6	2	3	4	0.021	0.019	0.019	0.028
2A3	Limestone and dolomite use		CO2	21.0	2.0	5	3	6	3.E-04	0.001	2.E-04	0.001
2A4	Other process uses of carbonates		CO2	67.5	81.5	4	2	5	0.008	0.007	0.007	0.009
2B1	Ammonia production		CO2	93.0		.	.	.	.	.	.	.
2B2	Nitric acid production		N2O	1 415.4	144.8	3	15	15	0.049	0.044	0.044	0.065
2B8	Petrochemical and carbon black production		CH4	5.2	1.4	40	.	40	0.001	0.001	0.001	0.002
2B10a	Phosphoric acid production		CO2	24.5	32.1	7	.	7	0.005	0.004	0.005	0.007
2B10b	Hydrogen production		CO2	116.2	870.9	5	3	6	0.111	0.101	0.102	0.150
2B10c	Limestone and dolomite use		CO2	36.5	65.1	5	3	6	0.008	0.007	0.008	0.010
2B10d	Chemicals production		CO2	6.7	2.2	.	.	.	.	.	.	.
2C1	Iron and steel production		CO2	1967.2	1 956.6	4	.	4	0.157	0.142	0.143	0.211
2C1	Iron and steel production		CH4	0.001	0.002	3	20	20	1.E-06	4.E-07	9.E-07	4.E-07
2C7	Other Metal Industry		CO2	8.9	17.4	3	.	3	0.001	0.001	0.001	0.002
2D1	Lubricant use		CO2	207.5	89.8	20	7	21	0.042	0.036	0.038	0.056
2D1	Lubricant use		CH4	0.3	0.1	20	60	64	2.E-04	8.E-05	2.E-04	3.E-04
2D1	Lubricant use		N2O	1.5	0.6	20	60	64	0.001	4.E-04	0.001	0.001
2D2	Paraffin wax use		CO2	10.2	24.3	10	101	101	0.054	0.025	0.049	0.029
2D3	Other non energy products		CO2	0	19.4	20	2	20	0.009	0.008	0.008	0.012
2F1	Refrigeration and air conditioning		HFCs	0.01	738.5	32	31	44	0.717	0.649	0.653	0.962
2F1	Refrigeration and air conditioning		PFCs		0.6	60	50	78	0.001	0.001	0.001	0.001
2F2	Foam blowing agents		HFCs		4.3	57	50	76	0.007	0.007	0.007	0.010
2F4	Aerosols		HFCs		17.0	50	.	50	0.019	0.017	0.017	0.025
2G1	Electrical equipment		SF6	46.4	23.0	47	40	62	0.031	0.028	0.028	0.042
2G3	N2O from product uses		N2O	57.3	21.4	10	.	10	0.005	0.004	0.004	0.006
2H3	Other Industrial process and product se		HFCs	0.01	3.5	60	.	60	0.005	0.004	0.004	0.006
2H3	Other Industrial process and product se		PFCs	0.2	0.9	60	.	60	0.001	0.001	0.001	0.002
2H3	Other Industrial process and product se		SF6	7.7	5.0	64	.	64	0.007	0.006	0.006	0.009

CRF	CRF name	Fuel / Fuel group	Gas	Emissions/ removals 1990	Emissions/ removals 2022	AD uncertainty 2022	EF / IEF uncertainty 2022	Combined level uncertainty 2022	Share of level uncertainty *excl. LULUCF*	Share of trend uncertainty *excl. LULUCF*	Share of level uncertainty *incl. LULUCF*	Share of trend uncertainty *incl. LULUCF*
				Gg CO2-eq	Gg CO2-eq	± %	± %	± %	%	± %	%	± %
3A	Enteric fermentation		CH4	2 715.5	2 175.2	19	.	19	0.891	0.807	0.812	1.196
3B	Manure management		CH4	421.9	453.2	38	.	38	0.374	0.339	0.341	0.502
3B	Manure management		N2O	270.2	223.8	124	.	124	0.610	0.552	0.555	0.818
3D1	Direct soil emissions		N2O	2 940.3	2 733.5	56	.	56	3.361	3.045	3.063	4.511
3D2	Indirect emissions		N2O	315.7	231.5	270	.	270	1.368	1.240	1.247	1.836
3F	Field burning of agricultural residues		CH4	3.4		.	.	.	.	.	.	.
3F	Field burning of agricultural residues		N2O	0.8		.	.	.	.	.	.	.
3G	Liming		CO2	642.0	249.8	.	20	20	0.109	0.045	0.099	0.173
3H	Urea Application		CO2	5.4	7.8	.	30	30	0.005	0.002	0.005	0.001
4A1	Forest Land remaining Forest Land		CO2	-31 945.3	-7 045.5	213	.	213	-32.813	29.730	-29.905	44.038
4A2	Land converted to Forest Land		CO2	- 62.4	- 158.0	144	.	144	-0.497	0.450	-0.453	0.667
4B1	Cropland remaining Cropland		CO2	4 521.6	6 438.9	40	.	40	5.674	5.141	5.171	7.615
4B2	Land converted to Cropland		CO2	859.3	2 381.9	29	.	29	1.509	1.367	1.376	2.026
4C1	Grassland remaining Grassland		CO2	852.2	517.7	97	.	97	1.104	1.000	1.006	1.481
4C2	Land converted to Grassland		CO2	167.5	249.3	72	.	72	0.391	0.354	0.356	0.525
4D1	Wetlands remaining Wetlands		CO2	1 269.2	1 853.9	149	.	149	6.039	5.472	5.504	8.106
4D2	Land converted to Wetlands		CO2	65.5	86.3	150	.	150	0.282	0.256	0.257	0.379
4E2	Land converted to Settlements		CO2	857.8	762.2	46	.	46	0.760	0.688	0.692	1.019
4G	Harvested Wood Products		CO2	-2 951.6	-3 250.9	46	.	46	-3.276	2.968	-2.985	4.396
4(i)	N fertilization		N2O	18.3	5.3	10	203	203	0.024	0.018	0.021	0.058
4(ii)	Drainage. rewetting and other management soils		CH4	1 690.2	847.6	81	80	114	2.120	1.921	1.932	2.845
4(ii)	Drainage. rewetting and other management soils		N2O	1 451.2	1 728.4	82	80	115	4.334	3.927	3.950	5.817
4(iii)	Mineralization		N2O	25.6	23.7	10	205	206	0.107	0.022	0.097	0.014
4(iv)	Indirect N2O emissions		N2O	1.1	1.2	187	.	187	0.005	0.005	0.005	0.007
4A(v)	FL. biomass burning		CH4	3.2	0.6	10	76	76	0.001	0.001	0.001	0.001
4A(v)	FL. biomass burning		N2O	1.7	0.3	100	100	141	0.001	0.001	0.001	0.001
4C(v)	GL. biomass burning		CO2	0.009	0.002	10	12	16	8.E-07	7.E-07	7.E-07	1.E-06
4C(v)	GL. biomass burning		CH4	0.1	0.01	10	78	79	2.E-05	2.E-05	2.E-05	3.E-05
4C(v)	GL. biomass burning		N2O	0.1	0.01	10	95	95	3.E-05	2.E-05	2.E-05	3.E-05
5A	Solid Waste Disposal		CH4	4 847.1	1 383.9	33	.	33	1.010	0.915	0.920	1.355
5B	Biological Treatment of Solid Waste		CH4	28.8	74.5	7	46	47	0.077	0.069	0.070	0.103
5B	Biological Treatment of Solid Waste		N2O	16.3	34.0	16	116	117	0.087	0.079	0.079	0.117
5D	Wastewater Treatment and Discharge		CH4	247.5	172.8	12	58	59	0.223	0.202	0.203	0.299
5D	Wastewater Treatment and Discharge		N2O	67.9	61.5	9	382	383	0.515	0.097	0.469	0.075

Notes: When uncertainties are estimated for emissions/removals directly (not for AD and EF), the columns for AD and EF/IEF uncertainty are left blank. When year 2022 emissions/removals are zero, all uncertainty columns are left blank. When either 1990 or 2022 emissions are zero, trend uncertainty columns are left blank.

ANNEX 3. Detailed description of the reference approach (including inputs to the reference approach such as the national energy balance) and the results of the comparison of national estimates of emissions with those obtained using the reference approach

The national energy balance for the most recent inventory year.

Table 1. Energy Balance Sheet 2022, ktoe

Finland **ktoe** **2022**	Total	Solid fossil fuels	Manufac-tured gases	Peat and peat products	Oil shale and oil sands	Oil and petroleum products	Natural gas	Renewables and biofuels	Non-renewable waste	Nuclear heat	Heat	Electricity
+ Primary production	18 814.5	0.0	Z	320.9	0.0	0.0	0.0	11 926.9	317.9	6 115.2	133.5	Z
+ Recovered & recycled products	65.3	0.0	Z	0.0	0.0	65.3	Z	0.0	Z	Z	Z	Z
+ Imports	22 211.6	2 774.4	0.0	8.9	0.0	16 231.8	1 133.0	395.6	0.0	Z	0.0	1 667.8
- Exports	8 788.7	55.9	0.0	0.0	0.0	7 953.0	0.0	188.2	0.0	Z	0.0	591.6
+ Change in stock	-260.7	-565.5	0.0	546.0	0.0	-206.1	-34.1	-0.9	0.0	Z	Z	Z
= Gross available energy	**32 042.1**	**2 153.0**	**0.0**	**875.8**	**0.0**	**8 138.1**	**1 098.9**	**12 133.4**	**317.9**	**6 115.2**	**133.5**	**1 076.3**
- International maritime bunkers	337.3	0.0	0.0	0.0	0.0	335.6	1.7	0.0	Z	Z	Z	Z
= Gross inland consumption	**31 704.8**	**2 153.0**	**0.0**	**875.8**	**0.0**	**7 802.5**	**1 097.2**	**12 133.4**	**317.9**	**6 115.2**	**133.5**	**1 076.3**
- International aviation	531.6	Z	Z	Z	Z	531.6	Z	0.0	Z	Z	Z	Z
= Total energy supply	**31 173.2**	**2 153.0**	**0.0**	**875.8**	**0.0**	**7 270.9**	**1 097.2**	**12 133.4**	**317.9**	**6 115.2**	**133.5**	**1 076.3**
Transformation input	**33 121.3**	**2 579.2**	**147.5**	**774.0**	**0.0**	**15 576.6**	**400.8**	**7 039.7**	**260.9**	**6 115.2**	**166.6**	**60.8**
+ Electricity & heat generation	15 674.2	1 003.6	147.5	774.0	0.0	427.8	303.0	6 414.7	260.9	6 115.2	166.6	60.8
+ Coke ovens	797.1	797.1	0.0	0.0	0.0	0.0	0.0	0.0	Z	Z	Z	Z
+ Blast furnaces	638.3	638.3	0.0	0.0	0.0	0.0	0.0	0.0	Z	Z	Z	Z
+ Gas works	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	Z	Z	Z	Z
+ Refineries & petrochemical industry	15 148.7	Z	Z	Z	Z	15 148.7	Z	0.0	Z	Z	Z	Z
+ Patent fuel plants	0.0	0.0	0.0	0.0	0.0	0.0	Z	0.0	0.0	Z	Z	Z
+ BKB & PB plants	0.0	0.0	0.0	0.0	0.0	Z	Z	0.0	0.0	Z	Z	Z
+ Coal liquefaction plants	0.0	0.0	0.0	0.0	0.0	Z	Z	Z	Z	Z	Z	Z
+ For blended natural gas	12.1	Z	0.0	Z	Z	0.0	Z	12.1	Z	Z	Z	Z
+ Liquid biofuels blended	612.9	Z	Z	Z	Z	Z	Z	612.9	Z	Z	Z	Z
+ Charcoal production plants	0.0	Z	Z	Z	Z	Z	Z	0.0	Z	Z	Z	Z
+ Gas-to-liquids plants	0.0	Z	Z	Z	Z	Z	0.0	Z	Z	Z	Z	Z
+ Not elsewhere specified	238.0	140.2	0.0	0.0	0.0	0.0	97.9	0.0	0.0	Z	Z	Z
Transformation output	**27 388.8**	**596.4**	**459.8**	**0.0**	**Z**	**15 155.5**	**12.1**	**612.9**	**Z**	**Z**	**4 342.3**	**6 209.9**
+ Electricity & heat generation	10 552.1	Z	Z	Z	Z	Z	Z	Z	Z	Z	4 342.3	6 209.9
+ Coke ovens	757.6	596.4	161.2	Z	Z	Z	Z	Z	Z	Z	Z	Z
+ Blast furnaces	298.6	0.0	298.6	Z	Z	Z	Z	Z	Z	Z	Z	Z
+ Gas works	0.0	0.0	0.0	Z	Z	Z	Z	Z	Z	Z	Z	Z
+ Refineries & petrochemical industry	15 034.4	Z	Z	Z	Z	15 034.4	Z	0.0	Z	Z	Z	Z
+ Patent fuel plants	0.0	0.0	Z	Z	Z	Z	Z	Z	Z	Z	Z	Z
+ BKB & PB plants	0.0	0.0	Z	0.0	Z	Z	Z	Z	Z	Z	Z	Z
+ Coal liquefaction plants	0.0	Z	Z	Z	Z	0.0	Z	Z	Z	Z	Z	Z
+ Blended in natural gas	12.1	Z	Z	Z	Z	Z	12.1	Z	Z	Z	Z	Z
+ Liquid biofuels blended	612.9	Z	Z	Z	Z	Z	Z	612.9	Z	Z	Z	Z
+ Charcoal production plants	0.0	Z	Z	Z	Z	Z	Z	0.0	Z	Z	Z	Z
+ Gas-to-liquids plants	121.1	Z	Z	Z	Z	121.1	Z	Z	Z	Z	Z	Z
+ Not elsewhere specified	0.0	0.0	0.0	0.0	Z	0.0	Z	Z	Z	Z	Z	Z

Finland **ktoe 2022**	Total	Solid fossil fuels	Manufac-tured gases	Peat and peat products	Oil shale and oil sands	Oil and petroleum products	Natural gas	Renewables and biofuels	Non-renewable waste	Nuclear heat	Heat	Electricity
Energy sector	**1 253.6**	**0.0**	**179.0**	**0.0**	**0.0**	**498.4**	**39.0**	**45.0**	**0.0**	**Z**	**116.0**	**376.3**
+ Own use in electricity & heat generation	260.2	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	Z	0.0	260.2
+ Coal mines	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	Z	0.0	0.0
+ Oil & natural gas extraction plants	0.0	Z	Z	Z	Z	0.0	0.0	0.0	Z	Z	0.0	0.0
+ Patent fuel plants	0.0	0.0	0.0	0.0	0.0	Z	Z	0.0	0.0	Z	0.0	0.0
+ Coke ovens	81.5	0.0	81.5	0.0	0.0	0.0	0.0	0.0	0.0	Z	0.0	0.0
+ BKB & PB plants	0.0	0.0	0.0	0.0	0.0	Z	Z	0.0	0.0	Z	0.0	0.0
+ Gas works	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	Z	0.0	0.0
+ Blast furnaces	85.5	0.0	85.5	0.0	0.0	0.0	0.0	0.0	0.0	Z	0.0	0.0
+ Petroleum refineries (oil refineries)	813.7	0.0	0.0	0.0	0.0	498.4	38.3	45.0	0.0	Z	116.0	116.1
+ Nuclear industry	0.0	Z	Z	Z	Z	Z	Z	Z	Z	Z	0.0	0.0
+ Coal liquefaction plants	0.0	0.0	0.0	0.0	0.0	Z	Z	Z	Z	Z	0.0	0.0
+ Liquefaction & regasification plants (LNG	0.7	Z	Z	Z	Z	Z	0.7	Z	Z	Z	0.0	0.0
+ Gasification plants for biogas	0.0	Z	Z	Z	Z	Z	Z	0.0	0.0	Z	0.0	0.0
+ Gas-to-liquids (GTL) plants	0.0	Z	Z	Z	Z	Z	0.0	Z	Z	Z	0.0	0.0
+ Charcoal production plants	0.0	Z	Z	Z	Z	Z	Z	0.0	0.0	Z	0.0	0.0
+ Not elsewhere specified (energy)	11.9	0.0	11.9	0.0	0.0	0.0	0.0	0.0	0.0	Z	0.0	0.0
Distribution losses	**597.7**	**0.0**	**7.9**	**0.0**	**0.0**	**5.6**	**10.3**	**0.0**	**0.0**	**Z**	**334.4**	**239.6**
Available for final consumption	**23 589.4**	**170.2**	**125.4**	**101.8**	**0.0**	**6 345.8**	**659.3**	**5 661.5**	**57.1**	**0.0**	**3 858.8**	**6 609.5**
Final non-energy consumption	**1 375.7**	**0.0**	**0.0**	**0.0**	**0.0**	**1 327.9**	**47.8**	**0.0**	**Z**	**Z**	**Z**	**Z**
Final energy consumption	**23 172.7**	**108.7**	**125.5**	**101.8**	**0.0**	**5 249.6**	**610.5**	**6 451.4**	**57.1**	**Z**	**3 858.7**	**6 609.4**
+ Industry	9 751.5	106.9	125.5	69.3	0.0	1 026.0	551.1	3 645.5	46.9	Z	1 191.0	2 989.3
+ Iron & steel	738.3	26.6	102.4	0.0	0.0	6.5	142.3	0.0	0.0	Z	91.9	368.5
+ Chemical & petrochemical	909.4	0.0	0.0	0.0	0.0	241.7	51.5	2.0	11.8	Z	217.7	384.8
+ Non-ferrous metals	239.5	4.4	0.0	0.0	0.0	25.7	1.1	0.9	0.1	Z	43.3	164.0
+ Non-metallic minerals	283.5	31.4	23.2	0.2	0.0	81.9	29.7	23.9	17.1	Z	13.7	62.3
+ Transport equipment	55.7	0.0	0.0	0.0	0.0	4.0	1.8	0.3	0.0	Z	27.0	22.5
+ Machinery	316.4	0.0	0.0	0.0	0.0	24.0	5.4	3.0	0.0	Z	97.4	186.5
+ Mining & quarrying	170.9	0.0	0.0	0.0	0.0	22.2	0.1	4.5	0.0	Z	6.8	137.4
+ Food, beverages & tobacco	414.6	3.0	0.0	0.0	0.0	34.7	11.1	11.2	0.0	Z	172.6	182.0
+ Paper, pulp & printing	5 341.0	41.5	0.0	56.2	0.0	117.2	303.2	3 356.0	17.8	Z	255.9	1 193.1
+ Wood & wood products	604.7	0.0	0.0	12.8	0.0	6.1	0.0	227.3	0.0	Z	207.2	151.2
+ Construction	417.3	0.0	0.0	0.0	0.0	358.5	0.0	14.2	0.0	Z	0.0	44.5
+ Textile & leather	24.9	0.0	0.0	0.0	0.0	3.0	1.6	0.2	0.0	Z	8.2	12.0
+ Not elsewhere specified (industry)	235.2	0.0	0.0	0.0	0.0	100.4	3.4	1.8	0.0	Z	49.3	80.3
+ Transport	3 856.9	0.0	0.0	0.0	0.0	3 185.2	14.2	563.6	0.0	Z	Z	93.9
+ Rail	78.9	0.0	0.0	0.0	0.0	18.8	Z	0.7	0.0	Z	Z	59.4
+ Road	3 616.0	Z	Z	Z	Z	3 014.5	10.2	556.8	0.0	Z	Z	34.5
+ Domestic aviation	44.5	Z	Z	Z	Z	44.5	Z	0.0	Z	Z	Z	Z
+ Domestic navigation	113.5	0.0	0.0	0.0	0.0	107.5	Z	6.0	0.0	Z	Z	Z
+ Pipeline transport	0.8	Z	Z	Z	Z	0.0	0.8	0.0	Z	Z	Z	0.0
+ Not elsewhere specified (transport)	3.2	0.0	0.0	0.0	0.0	0.0	3.2	0.0	0.0	Z	Z	0.0
+ Other	9 564.3	1.8	0.0	32.5	0.0	1 038.4	45.2	2 242.3	10.2	Z	2 667.7	3 526.1
+ Commercial & public services	2 971.9	0.0	0.0	2.5	0.0	252.6	24.1	180.6	10.2	Z	1 036.2	1 465.7
+ Households	5 642.9	0.0	0.0	3.5	0.0	218.4	19.1	1 868.0	0.0	Z	1 580.9	1 953.0
+ Agriculture & forestry	699.8	1.8	0.0	26.6	0.0	383.9	1.9	162.8	0.0	Z	15.3	107.5
+ Fishing	32.9	0.0	0.0	0.0	0.0	31.6	0.0	1.3	0.0	Z	0.0	0.0
+ Not elsewhere specified (other)	216.8	0.0	0.0	0.0	0.0	151.8	0.1	29.6	0.0	Z	35.3	0.0
Statistical differences	**-959.0**	**61.5**	**-0.2**	**0.0**	**0.0**	**-231.7**	**1.0**	**-789.9**	**0.0**	**0.0**	**0.1**	**0.2**

Gross electricity production	6 209.9	296.0	50.9	185.7	0.0	21.4	82.3	3 324.7	45.8	2 178.5	0.0	Z
Gross heat production	4 342.3	515.6	28.1	388.1	0.0	359.8	173.9	2 302.8	151.5	0.0	Z	11.7

Symbol Z means data are not applicable

Table 2. Energy Balance Sheet 2022, TJ

Finland **TJ 2022**	Total	Solid fossil fuels	Manufac-tured gases	Peat and peat products	Oil shale and oil sands	Oil and petroleum products	Natural gas	Renewables and biofuels	Non-renewable waste	Nuclear heat	Heat	Electricity
+ Primary production	787 726	0	0	13 437	0	0	0	499 356	13 311	256 031	5 591	0
+ Recovered & recycled products	2 736	0	0	0	0	2 736	0	0	0	0	0	0
+ Imports	929 954	116 160	0	372	0	679 595	47 437	16 562	0	0	0	69 829
- Exports	367 966	2 342	0	0	0	332 974	0	7 881	0	0	0	24 768
+ Change in stock	-10 913	-23 676	0	22 859	0	-8 630	-1 429	-37	0	0	0	0
= Gross available energy	**1 341 538**	**90 142**	**0**	**36 667**	**0**	**340 727**	**46 008**	**508 000**	**13 311**	**256 031**	**5 591**	**45 061**
- International maritime bunkers	14 121	0	0	0	0	14 051	70	0	0	0	0	0
= Gross inland consumption	**1 327 417**	**90 142**	**0**	**36 667**	**0**	**326 676**	**45 938**	**508 000**	**13 311**	**256 031**	**5 591**	**45 061**
- International aviation	22 256	0	0	0	0	22 256	0	0	0	0	0	0
= Total energy supply	**1 305 160**	**90 142**	**0**	**36 667**	**0**	**304 420**	**45 938**	**508 000**	**13 311**	**256 031**	**5 591**	**45 061**
Transformation input	**1 386 723**	**107 985**	**6 177**	**32 405**	**0**	**652 160**	**16 781**	**294 740**	**10 922**	**256 031**	**6 977**	**2 545**
+ Electricity & heat generation	656 247	42 020	6 177	32 405	0	17 913	12 684	268 573	10 922	256 031	6 977	2 545
+ Coke ovens	33 373	33 373	0	0	0	0	0	0	0	0	0	0
+ Blast furnaces	26 724	26 724	0	0	0	0	0	0	0	0	0	0
+ Gas works	0	0	0	0	0	0	0	0	0	0	0	0
+ Refineries & petrochemical industry	634 247	0	0	0	0	634 247	0	0	0	0	0	0
+ Patent fuel plants	0	0	0	0	0	0	0	0	0	0	0	0
+ BKB & PB plants	0	0	0	0	0	0	0	0	0	0	0	0
+ Coal liquefaction plants	0	0	0	0	0	0	0	0	0	0	0	0
+ For blended natural gas	507	0	0	0	0	0	0	507	0	0	0	0
+ Liquid biofuels blended	25 660	0	0	0	0	0	0	25 660	0	0	0	0
+ Charcoal production plants	0	0	0	0	0	0	0	0	0	0	0	0
+ Gas-to-liquids plants	0	0	0	0	0	0	0	0	0	0	0	0
+ Not elsewhere specified	9 966	5 869	0	0	0	0	4 097	0	0	0	0	0
Transformation output	**1 146 713**	**24 969**	**19 251**	**0**	**0**	**634 529**	**507**	**25 660**	**0**	**0**	**181 802**	**259 995**
+ Electricity & heat generation	441 797	0	0	0	0	0	0	0	0	0	181 802	259 995
+ Coke ovens	31 718	24 969	6 748	0	0	0	0	0	0	0	0	0
+ Blast furnaces	12 503	0	12 503	0	0	0	0	0	0	0	0	0
+ Gas works	0	0	0	0	0	0	0	0	0	0	0	0
+ Refineries & petrochemical industry	629 460	0	0	0	0	629 460	0	0	0	0	0	0
+ Patent fuel plants	0	0	0	0	0	0	0	0	0	0	0	0
+ BKB & PB plants	0	0	0	0	0	0	0	0	0	0	0	0
+ Coal liquefaction plants	0	0	0	0	0	0	0	0	0	0	0	0
+ Blended in natural gas	507	0	0	0	0	0	507	0	0	0	0	0
+ Liquid biofuels blended	25 660	0	0	0	0	0	0	25 660	0	0	0	0
+ Charcoal production plants	0	0	0	0	0	0	0	0	0	0	0	0
+ Gas-to-liquids plants	5 069	0	0	0	0	5 069	0	0	0	0	0	0
+ Not elsewhere specified	0	0	0	0	0	0	0	0	0	0	0	0

Finland **TJ** **2022**	Total	Solid fossil fuels	Manufac-tured gases	Peat and peat products	Oil shale and oil sands	Oil and petroleum products	Natural gas	Renewables and biofuels	Non-renewable waste	Nuclear heat	Heat	Electricity
Energy sector	**52 486**	**0**	**7 493**	**0**	**0**	**20 869**	**1 632**	**1 883**	**0**	**0**	**4 856**	**15 754**
+ Own use in electricity & heat generation	10 894	0	0	0	0	0	0	0	0	0	0	10 894
+ Coal mines	0	0	0	0	0	0	0	0	0	0	0	0
+ Oil & natural gas extraction plants	0	0	0	0	0	0	0	0	0	0	0	0
+ Patent fuel plants	0	0	0	0	0	0	0	0	0	0	0	0
+ Coke ovens	3 414	0	3 414	0	0	0	0	0	0	0	0	0
+ BKB & PB plants	0	0	0	0	0	0	0	0	0	0	0	0
+ Gas works	0	0	0	0	0	0	0	0	0	0	0	0
+ Blast furnaces	3 580	0	3 580	0	0	0	0	0	0	0	0	0
+ Petroleum refineries (oil refineries)	34 070	0	0	0	0	20 869	1 602	1 883	0	0	4 856	4 860
+ Nuclear industry	0	0	0	0	0	0	0	0	0	0	0	0
+ Coal liquefaction plants	0	0	0	0	0	0	0	0	0	0	0	0
+ Liquefaction & regasification plants (LNG	30	0	0	0	0	0	30	0	0	0	0	0
+ Gasification plants for biogas	0	0	0	0	0	0	0	0	0	0	0	0
+ Gas-to-liquids (GTL) plants	0	0	0	0	0	0	0	0	0	0	0	0
+ Charcoal production plants	0	0	0	0	0	0	0	0	0	0	0	0
+ Not elsewhere specified (energy)	500	0	500	0	0	0	0	0	0	0	0	0
Distribution losses	**25 025**	**0**	**333**	**0**	**0**	**234**	**429**	**0**	**0**	**0**	**13 999**	**10 030**
Available for final consumption	**987 639**	**7 126**	**5 248**	**4 262**	**0**	**265 685**	**27 602**	**237 037**	**2 389**	**0**	**161 561**	**276 728**
Final non-energy consumption	**57 596**	**0**	**0**	**0**	**0**	**55 595**	**2 001**	**0**	**0**	**0**	**0**	**0**
Final energy consumption	**970 194**	**4 552**	**5 255**	**4 262**	**0**	**219 790**	**25 560**	**270 107**	**2 389**	**0**	**161 558**	**276 721**
+ Industry	408 277	4 477	5 255	2 900	0	42 956	23 073	152 631	1 962	0	49 865	125 158
+ Iron & steel	30 911	1 116	4 285	0	0	273	5 957	2	0	0	3 849	15 430
+ Chemical & petrochemical	38 076	0	0	0	0	10 121	2 155	86	492	0	9 113	16 110
+ Non-ferrous metals	10 026	183	0	0	0	1 076	46	36	6	0	1 813	6 865
+ Non-metallic minerals	11 870	1 314	970	10	0	3 429	1 244	999	718	0	575	2 610
+ Transport equipment	2 332	0	0	0	0	165	77	14	0	0	1 132	943
+ Machinery	13 245	0	0	0	0	1 005	226	127	1	0	4 077	7 808
+ Mining & quarrying	7 157	0	0	0	0	928	5	188	0	0	283	5 753
+ Food, beverages & tobacco	17 358	124	0	0	0	1 453	464	470	0	0	7 226	7 621
+ Paper, pulp & printing	223 619	1 739	0	2 353	0	4 908	12 694	140 509	745	0	10 716	49 954
+ Wood & wood products	25 317	0	0	537	0	257	0	9 517	0	0	8 674	6 332
+ Construction	17 473	0	0	0	0	15 011	0	596	0	0	0	1 865
+ Textile & leather	1 044	0	0	0	0	124	65	9	0	0	342	504
+ Not elsewhere specified (industry)	9 849	0	0	0	0	4 203	141	77	0	0	2 065	3 362
+ Transport	161 481	0	0	0	0	133 359	593	23 597	0	0	0	3 931
+ Rail	3 304	0	0	0	0	786	0	31	0	0	0	2 488
+ Road	151 395	0	0	0	0	126 210	427	23 313	0	0	0	1 444
+ Domestic aviation	1 862	0	0	0	0	1 862	0	0	0	0	0	0
+ Domestic navigation	4 754	0	0	0	0	4 501	0	253	0	0	0	0
+ Pipeline transport	32	0	0	0	0	0	32	0	0	0	0	0
+ Not elsewhere specified (transport)	134	0	0	0	0	0	134	0	0	0	0	0
+ Other	400 437	75	0	1 362	0	43 475	1 894	93 879	427	0	111 693	147 632
+ Commercial & public services	124 428	0	0	103	0	10 578	1 010	7 563	427	0	43 382	61 366
+ Households	236 256	0	0	144	0	9 146	799	78 210	0	0	66 190	81 767
+ Agriculture & forestry	29 299	75	0	1 115	0	16 073	80	6 816	0	0	641	4 500
+ Fishing	1 376	0	0	0	0	1 323	0	53	0	0	0	0
+ Not elsewhere specified (other)	9 077	0	0	0	0	6 356	5	1 237	0	0	1 480	0
Statistical differences	**-40 152**	**2 574**	**-7**	**0**	**0**	**-9 699**	**41**	**-33 070**	**0**	**0**	**3**	**6**
Gross electricity production	259 995	12 391	2 131	7 776	0	896	3 445	139 200	1 916	91 210	0	0
Gross heat production	181 802	21 587	1 175	16 249	0	15 066	7 281	96 414	6 345	0	0	491

* note: Data marked with Z (data are not applicable) in Table 1 is presented with zeros (0) in this table.

Table 2. Energy Balance Sheet and comparison to inventory 2022, kt CO_2

Finland **CO_2, kt** **2022**	Total	Solid fossil fuels	Manufac-tured gases	Peat and peat products	Oil shale and oil sands	Oil and petroleum products	Natural gas	Non-renewable waste
+ Primary production	2 441	0	0	1 398	0	0	0	1 044
+ Recovered & recycled products	192	0	0	0	0	192	0	0
+ Imports	61 116	10 735	0	39	0	47 716	2 626	0
- Exports	23 596	216	0	0	0	23 379	0	0
+ Change in stock	-496	-2 188	0	2 378	0	-606	-79	0
= Gross available energy	**39 659**	**8 331**	**0**	**3 814**	**0**	**23 923**	**2 547**	**1 044**
- International maritime bunkers	990	0	0	0	0	987	4	0
= Gross inland consumption	**38 668**	**8 331**	**0**	**3 814**	**0**	**22 937**	**2 543**	**1 044**
- International aviation	1 563	0	0	0	0	1 563	0	0
= Total energy supply	**37 105**	**8 331**	**0**	**3 814**	**0**	**21 374**	**2 543**	**1 044**
Transformation input	**61 817**	**9 980**	**891**	**3 371**	**0**	**45 790**	**929**	**856**
+ Electricity & heat generation	10 961	3 883	891	3 371	0	1 258	702	856
+ Coke ovens	3 084	3 084	0	0	0	0	0	0
+ Blast furnaces	2 470	2 470	0	0	0	0	0	0
+ Gas works	0	0	0	0	0	0	0	0
+ Refineries & petrochemical industry	44 532	0	0	0	0	44 532	0	0
+ Patent fuel plants	0	0	0	0	0	0	0	0
+ BKB & PB plants	0	0	0	0	0	0	0	0
+ Coal liquefaction plants	0	0	0	0	0	0	0	0
+ For blended natural gas	0	0	0	0	0	0	0	0
+ Liquid biofuels blended	0	0	0	0	0	0	0	0
+ Charcoal production plants	0	0	0	0	0	0	0	0
+ Gas-to-liquids plants	0	0	0	0	0	0	0	0
+ Not elsewhere specified	769	542	0	0	0	0	227	0
Transformation output	**49 666**	**2 308**	**2 778**	**0**	**0**	**44 552**	**28**	**0**
+ Electricity & heat generation	0	0	0	0	0	0	0	0
+ Coke ovens	3 281	2 308	974	0	0	0	0	0
+ Blast furnaces	1 804	0	1 804	0	0	0	0	0
+ Gas works	0	0	0	0	0	0	0	0
+ Refineries & petrochemical industry	44 196	0	0	0	0	44 196	0	0
+ Patent fuel plants	0	0	0	0	0	0	0	0
+ BKB & PB plants	0	0	0	0	0	0	0	0
+ Coal liquefaction plants	0	0	0	0	0	0	0	0
+ Blended in natural gas	28	0	0	0	0	0	28	0
+ Liquid biofuels blended	0	0	0	0	0	0	0	0
+ Charcoal production plants	0	0	0	0	0	0	0	0
+ Gas-to-liquids plants	356	0	0	0	0	356	0	0
+ Not elsewhere specified	0	0	0	0	0	0	0	0

Finland **CO_2, kt** **2022**	Total	Solid fossil fuels	Manufac-tured gases	Peat and peat products	Oil shale and oil sands	Oil and petroleum products	Natural gas	Non-renewable waste
Energy sector	**2 637**	**0**	**1 081**	**0**	**0**	**1 465**	**90**	**0**
+ Own use in electricity & heat generation	0	0	0	0	0	0	0	0
+ Coal mines	0	0	0	0	0	0	0	0
+ Oil & natural gas extraction plants	0	0	0	0	0	0	0	0
+ Patent fuel plants	0	0	0	0	0	0	0	0
+ Coke ovens	493	0	493	0	0	0	0	0
+ BKB & PB plants	0	0	0	0	0	0	0	0
+ Gas works	0	0	0	0	0	0	0	0
+ Blast furnaces	517	0	517	0	0	0	0	0
+ Petroleum refineries (oil refineries)	1 554	0	0	0	0	1 465	89	0
+ Nuclear industry	0	0	0	0	0	0	0	0
+ Coal liquefaction plants	0	0	0	0	0	0	0	0
+ Liquefaction & regasification plants (LNG)	2	0	0	0	0	0	2	0
+ Gasification plants for biogas	0	0	0	0	0	0	0	0
+ Gas-to-liquids (GTL) plants	0	0	0	0	0	0	0	0
+ Charcoal production plants	0	0	0	0	0	0	0	0
+ Not elsewhere specified (energy)	72	0	72	0	0	0	0	0
Distribution losses	**88**	**0**	**48**	**0**	**0**	**16**	**24**	**0**
Available for final consumption	**22 229**	**659**	**757**	**443**	**0**	**18 655**	**1 528**	**187**
Final non-energy consumption	**4 014**	**0**	**0**	**0**	**0**	**3 903**	**111**	**0**
Final energy consumption	**18 657**	**421**	**758**	**443**	**0**	**15 432**	**1 415**	**187**
+ Industry	5 921	414	758	302	0	3 016	1 277	154
+ Iron & steel	1 070	103	618	0	0	19	330	0
+ Chemical & petrochemical	868	0	0	0	0	711	119	39
+ Non-ferrous metals	96	17	0	0	0	76	3	0
+ Non-metallic minerals	628	121	140	1	0	241	69	56
+ Transport equipment	16	0	0	0	0	12	4	0
+ Machinery	83	0	0	0	0	71	13	0
+ Mining & quarrying	65	0	0	0	0	65	0	0
+ Food, beverages & tobacco	139	11	0	0	0	102	26	0
+ Paper, pulp & printing	1 511	161	0	245	0	345	703	58
+ Wood & wood products	74	0	0	56	0	18	0	0
+ Construction	1 054	0	0	0	0	1 054	0	0
+ Textile & leather	12	0	0	0	0	9	4	0
+ Not elsewhere specified (industry)	303	0	0	0	0	295	8	0
+ Transport	9 396	0	0	0	0	9 364	33	0
+ Rail	55	0	0	0	0	55	0	0
+ Road	8 885	0	0	0	0	8 862	24	0
+ Domestic aviation	131	0	0	0	0	131	0	0
+ Domestic navigation	316	0	0	0	0	316	0	0
+ Pipeline transport	2	0	0	0	0	0	2	0
+ Not elsewhere specified (transport)	7	0	0	0	0	0	7	0
+ Other	3 339	7	0	142	0	3 053	105	33
+ Commercial & public services	843	0	0	11	0	743	56	33
+ Households	701	0	0	15	0	642	44	0
+ Agriculture & forestry	1 256	7	0	116	0	1 129	4	0
+ Fishing	93	0	0	0	0	93	0	0
+ Not elsewhere specified (other)	446	0	0	0	0	446	0	0
Statistical differences	**-442**	**238**	**-1**	**0**	**0**	**-681**	**2**	**0**
Gross electricity production	2 665	1 145	308	809	0	63	191	150
Gross heat production	5 813	1 995	170	1 690	0	1 058	403	497
Total fossil CO_2 emissions (excl. non-energy use), kt CO_2								
Calculated from the energy balance	**32 255**	**4 304**	**2 731**	**3 814**		**18 155**	**2 208**	**1 044**
According to inventory (CRF/CRT Table1.A(a)s1)	**32 026**	**6 430**	**NA (IE)**	**3 852**		**18 562**	**2 085**	**1 097**
Difference between energy balance and inventory	**229**	**605**	**NA (IE)**	**-38**		**-407**	**123**	**-54**

* note: Data marked with Z (data are not applicable) in Table 1 is presented with zeros (0) in this table.

manufactured gases included in solid fossil fuels in comparison

ANNEX 4. Any additional information, as applicable, including detailed methodological descriptions of individual source or sink categories and the national emission balance

The detailed methodological descriptions are given in the sectoral chapters.

ANNEX 5. Assessment of completeness and (potential) sources and sinks of greenhouse gas emissions and removals excluded

The completeness of the Finnish inventory 2022 is evaluated by sectors in the tables below. The completeness is estimated by the gases (CO_2, CH_4, N_2O, F gases) and emission categories according to the detailed CRF classification.

Emission sources, which are judged as insignificant are reported in Table 2.

Abbreviations used in the tables:

X	included in the inventory
C	confidential business information
IE	included elsewhere
NA	not applicable
NE	not estimated
NO	not occurring in Finland

Table 1 Completeness of the Finnish inventory by gases and emission categories

Energy, Fuel combustion (CRF 1.A)

Greenhouse gas source and sink categories	CO_2	CH_4	N_2O	Explanation, -if not estimated -if included elsewhere	Notes
1.A. Fuel combustion activities					
1. Energy industries					
a. Public Electricity and Heat Production	X	X	X		
b. Petroleum Refining	X	X	X		
c. Manufacture of Solid Fuels and Other Energy Industries	X	X	X		
2. Manufacturing Industries and Construction					
a. Iron and Steel	X	X	X		
b. Non-Ferrous Metals	X	X	X		
c. Chemicals	X	X	X		
d. Pulp, Paper and Print	X	X	X		Transferred CO_2 for PCC production is included (subtracted from emissions) in this category.
e. Food Processing, Beverages and Tobacco	X	X	X		
f. Non-metallic minerals	X	X	X		

Greenhouse gas source and sink categories	CO_2	CH_4	N_2O	Explanation, -if not estimated -if included elsewhere	Notes
g. Other:					
Off-road vehicles and other machinery	X	X	X		
Other manufacturing industries	X	X	X		
3. Transport					
a. Domestic Aviation	X	X	X		
b. Road Transportation	X	X	X		
c. Railways	X	X	X		
d. Domestic Navigation	X	X	X		
e. Other Transportation					
Pipeline Transport	X	X	X		
4. Other Sectors					
a. Commercial/Institutional	X	X	X		
b. Residential	X	X	X		
c. Agriculture/Forestry/ Fishing	X	X	X		
5. Other					
a. Stationary					
Other non-specified	X	X	X		
b. Mobile	X	X	X		

Energy, Fugitive emissions from fuels (CRF 1.B)

Greenhouse gas source and sink categories	CO_2	CH_4	N_2O	Explanation, -if not estimated -if included elsewhere	Notes
1.B Fugitive emissions from fuels					
1. Solid Fuels					
a. Coal Mining and Handling	NO	NO	NO		
b. Solid Fuel Transformation	NO	NO	NO		
c. Other	NO	NO	NO		

Greenhouse gas source and sink categories	CO_2	CH_4	N_2O	Explanation, -if not estimated -if included elsewhere	Notes
2. Oil and Natural Gas and Other Emissions from Energy Production					
a. Oil	X	X	NO		
b. Natural Gas	X	X			
c. Venting and Flaring	X	X	X	Only flaring, since there is no venting, all process gases are routed to a fuel gas system, not vented.	
d. Other					
Distribution of town gas	X	X	NO	Only for years 1990-1993.	

Energy, CO_2 transport and storage (CRF 1.C)

Greenhouse gas source and sink categories	CO_2	CH_4	N_2O	Explanation, -if not estimated -if included elsewhere	Notes
Transport of CO_2	IE			CO_2 emissions calculated are from the amount of PCC produced. No losses during the capture, transfer and production are reported separately.	
Injection and storage	NA				

Industrial Processes and Product Use (CRF 2)

Greenhouse gas source and sink categories	CO_2	CH_4	N_2O	Explanation, -if not estimated -if included elsewhere	Notes
2. Industrial Processes and Product Use					
A. Mineral Products					
1. Cement Production	X				
2. Lime Production	X				
3. Glass Production	X				
4. Other Process Uses of Carbonates					
a. Ceramics	X				
b. Other Uses of Soda Ash	X				
c. Non-metallurgical Magnesium Production	NO				
d. Other	X				

Greenhouse gas source and sink categories	CO_2	CH_4	N_2O	Explanation, -if not estimated -if included elsewhere	Notes
B. Chemical Industry					
1. Ammonia Production	X	NO	NO		No ammonia production in Finland after 1992.
2. Nitric Acid Production			X		Includes also N_2O emissions from fertiliser production.
3. Adipic Acid Production	NO		NO		
4. Caprolactam, Glyoxal and Glyoxylic Acid Production	NO		NO		
5. Carbide Production	NO	NO			
6. Titanium Dioxide Production	NO				
7. Soda Ash Production	NO				
8. Petrochemical and Carbon Black Production					
a. Methanol	NO	NO			
b. Ethylene	IE	X			Ethylene is produced in Finland, but emitted CH_4 is used as fuel in the ovens of petrochemical plants and CO_2 emissions are included in the Energy Sector, only fugitive CH_4 emissions are included 2.B.8. See Section 4.3.5
c. Ethylene Dichloride and Vinyl Chloride Monomer	NO	NO			
d. Ethylene Oxide	NO	NO			
e. Acrylonitrile	NO	NO			
f. Carbon Black	NO	NO			
g. Other	NO	NO			
9. Fluorochemical production				No production in Finland (no F gases emissions)	
a. By-Product Emissions					
b. Fugitive Emissions					
10. Other					
Phosphoric Acid Production	X	NO	NO		
Hydrogen Production	X	NO	NO		
Limestone and Dolomite Use	X	NO	NO		
Formalin production	X	NO	NO		New emission source
Chemicals Production	NO	NO	NO		Only NMVOC emissions.
C. Metal Production					
1. Iron and Steel Production	X	X			Includes CO_2 emissions from integrated ferrochromium and stainless steel plant. Also CO_2 emissions from limestone use in steel plants and CH_4 emissions from coke production are included in this category
2. Ferroalloys Production	IE	NO		Emissions from integrated ferrochromium and stainless steel plant have been allocated to 2.C.1 Iron and steel production.	
3. Aluminium Production	NO	NO			

Greenhouse gas source and sink categories	**CO_2**	**CH_4**	**N_2O**	**Explanation, -if not estimated -if included elsewhere**	**Notes**
4. Magnesium Production	NO				SF_6 emissions are included in 2.H.3
5. Lead Production	NO				
6. Zinc Production	C			Emissions are included in 2.C.7 Other due to confidentiality reasons.	
7. Other	X				Includes CO_2 emissions from zinc, copper and nickel production and NMVOC emissions from metal production.
D. Non-energy Products from Fuels and Solvent Use					
1. Lubricant Use	X	X	X		
2. Paraffin Wax Use	X				Also includes use of paraffin candles.
3. Other					
Solvent Use	NO				Includes NMVOC emissions.
Road paving with asphalt	NO				Includes NMVOC emissions from all asphalt uses.
Asphalt roofing	NO			NMVOC emissions are included in Road paving with asphalt.	
Use of urea-based catalysts	X				
Use of urea in NOx control	X				
G. Other Product Manufacture and Use					
3. N_2O from Products Uses			X		
H. Other					
1. Pulp and paper					NMVOC emissions only.
2. Food and beverages industry					NMVOC emissions only.

F gases (CRF 2.E, CRF 2.F, CRF 2.G and CRF 2.H)

Greenhouse gas source and sink categories	**HFC_s**	**PFC_s**	**SF_6**	**NF_3**	**Explanation, -if not estimated -if included elsewhere**	**Notes**
2. Industrial Processes and Product Use						
E. Electronics Industry						
1. Integrated Circuit of Semiconductor	C	C	C	NO	C included in 2.H.3.	
2. TFT Flat Panel Display	NO	NO	NO	NO		

Greenhouse gas source and sink categories	HFC_s	PFC_s	SF_6	NF_3	Explanation, -if not estimated -if included elsewhere	Notes
3. Photovoltaics	NO	NO	NO	NO		
4. Heat Transfer Fluid	NO	NO	NO	NO		
5. Other	NO	NO	NO	NO		
F. Consumption of Halocarbons and SF_6						
1. Refrigeration and Air Conditioning Equipment	X	X	NO	NO		
2. Foam Blowing Agents	X	NO	NO	NO		Excl. one component foam.
3. Fire Protection	C	NO	NO	NO	C included in 2.H.3.	
4. Aerosols	X	NO	NO	NO		Incl. one component foam.
5. Solvents	NO	NO	NO	NO		
6. Other applications	NO	NO	NO	NO		
G. Other Product Manufacture and Use						
1. Electrical Equipment	NO	C	X	NO	C included in 2.H.3.	
2. SF_6 and PFCs from Other Product Use		NO	C	NO	C included in 2.H.3.	
4. Other	NO	NO	NO	NO		
H. Other						
3. Grouped confidential data of halocarbons and SF_6	X	X	X	NO		

Agriculture (CRF 3)

Greenhouse gas source and sink categories	CO_2	CH_4	N_2O	Explanation, -if not estimated -if included elsewhere	Notes
3. Agriculture					
3.1 Livestock					
A. Enteric fermentation					
1. Cattle					
Dairy Cattle		X			
Non-Dairy Cattle		X			

Greenhouse gas source and sink categories	CO_2	CH_4	N_2O	Explanation, -if not estimated -if included elsewhere	Notes
2. Sheep		X			
3. Swine		X			
4. Other Livestock					
Poultry		NE		No methodology in the 2006 IPCC Guidelines	
Horses		X			
Goats		X			
Reindeer		X			
Fur-bearing Animals		X			
B. Manure Management					
1. Cattle		X	X	Emissions from composting and anaerobic digestion of manure regarded as insignificant; see Section 5.3.2.2, Manure management systems for details. Thus, NE is used for composting and anaerobic digestion of manure for all other animals except for reindeer which is solely in pasture.	
Dairy Cattle		X	X		
Non-Dairy Cattle		X	X		
2.Sheep		X	X		
3.Swine		X	X		
4. Other Livestock					
Poultry		X	X		
Horses		X	X		
Goats		X	X		
Reindeer		X	NO		
Fur-bearing Animals		X	X		
5. Indirect N_2O Emissions			X		
C. Rice Cultivation					
1. Irrigated		NO			
2. Rainfed		NO			
3. Deep Water		NO			
4. Other		NO			

Greenhouse gas source and sink categories	CO_2	CH_4	N_2O	Explanation, -if not estimated -if included elsewhere	Notes
D. Agricultural Soils					
1. Direct N_2O Emissions From Managed Soils					
1.Inorganic N Fertilisers			X		
2. Organic N Fertilisers			X		
3. Urine and Dung Deposited by Grazing Animals			X		
4. Crop Residues			X		
5. Mineralisation/Immobilisation Associated with Loss/Gain of Soil Organic Matter			X		
6. Cultivation of Organic Soils			X		
7. Other			NO		
2. Indirect N_2O Emissions From Managed Soils					
1. Atmospheric Deposition			X		
2. Nitrogen Leaching and Run-off			X		
E. Prescribed Burning of Savannas					
Forest land		NO	NO		
Grassland		NO	NO		
F. Field Burning of Agricultural Residues					
1.Cereals		NO	NO		
2.Pulses		NO	NO		
3.Tubers and Roots		NO	NO		
4.Sugar Cane		NO	NO		
5.Other		NO	NO		
G. Liming					
1. Limestone $CaCO_3$	X				
2. Dolomite $CaMg(CO_3)_2$	X				
H. Urea Application					
1. Urea application	X				
I. Other Carbon-containing Fertilisers (no emissions)					
J. Other (no emissions)					

Land Use Land-use change and Forestry (CRF 4)

Greenhouse gas source and sink categories	CO_2	CH_4	N_2O	Explanation, -if not estimated -if included elsewhere	Notes
4. Land use, Land-use change and Forestry					
A. Forest land					
1. Forest land remaining forest land					
Carbon stock change	X, IE			IE: Litter and dead wood are reported under soil organic matter	See NID 6.4.2
2. Land converted to forest land					
Carbon stock change					
- Cropland converted	X, IE, NA			IE: Litter and dead wood are reported under soil organic matter, Losses in living biomass are included in gains, the method gives an estimate for a net change	See NID 6.4.2, Appendix_6c
- Grassland converted	X, IE, NA				
- Wetlands converted	X, IE, NA				
- Settlements converted	X, IE, NA				
- Other land converted	X, IE, NA				
B. Cropland					
1. Cropland remaining cropland					
Carbon stock change	X, IE			IE: CSCs in DOM are taken into account in biomass losses	See NID 6.5.2
2. Land converted to cropland					
Carbon stock change				NE: The CSC in DOM is considered insignificant.	
- Forest land converted	X				
- Grassland converted	X, NE				
- Wetlands converted	X, NE, NA				
- Settlements converted	X, NE				
- Other land converted	NA				
C. Grassland					
1. Grassland remaining grassland					
Carbon stock change	X, NE			NE: Emissions from DOM are considered minor.	See NID 6.6.2
2. Land converted to grassland					
Carbon stock change				NE: The CSC in DOM is considered insignificant.	
- Forest land converted	X				
- Cropland converted	X, NA				
- Wetlands converted	X, NA, NE				
- Settlements converted	NA, NE				
- Other land converted	NA				
D. Wetlands					
1. Wetlands remaining wetlands					

Greenhouse gas source and sink categories	**CO_2**	**CH_4**	**N_2O**	**Explanation, -if not estimated -if included elsewhere**	**Notes**
Carbon stock change					
1. Peat Extraction remaining peat extraction	X, NA, NO				
2. Flooded Land remaining flooded land	X, NA, NO				
3. Other Wetlands remaining other wetlands	X, NA, NO				
2. Land converted to wetlands					
Carbon stock change					
1. Land converted for peat extraction					
Forest land	X, NA, NO				
Cropland	X, NA, NO				
Grassland	X, NA, NO				
2. Land converted to Flooded land					
Forest land converted	X, NA, NO				
Cropland converted	X, NA, NO				
Grassland converted	X, NA, NO				
Settlements converted	X, NA, NO				
Other land converted	X, NA, NO				
3. Land converted to Other Wetlands					
Forest land converted	X, NA, NO				
Grassland converted	NA, NO				
Settlements converted	NA, NO				
E. Settlements					
1. Settlements remaining settlements					
Carbon stock change	NA				
2. Land converted to settlements					
Carbon stock change					
Forest land converted	X, NA				
Cropland converted	X, NA				
Grassland converted	X, NA				
Wetlands converted	X, NA				
Other land converted	NA				
F. Other land					
1. Other land remaining other land					
Carbon stock change	NA				

Greenhouse gas source and sink categories	CO_2	CH_4	N_2O	Explanation, -if not estimated -if included elsewhere	Notes
2. Land converted to other land					
Carbon stock change					
Forest land converted	NA, NO				
Cropland converted	NA, NO				
Grassland converted	NA, NO				
Wetlands converted	NA, NO				
Settlements converted	NA, NO				
G. Harvested wood products	X				
H. Other					
4 (I) Direct N_2O emissions from N Inputs to Managed Soils			X, NA, NO, IE	IE: emissions from S are reported under Agriculture sector	See NID 6.10.1
4(II) Emissions and removals from drainage and rewetting and other management of organic and mineral soils	IE, NA, NO	X, NA, NO	X, NA, NO	IE: CO_2 emissions are reported under Tables 4.A to 4.D.	See NID 6.10.2
4(III) Direct N_2O emissions from N Mineralisation/Immobilisation			X, NA		
4(IV) Indirect N_2O emissions from managed soils			X		
4(V) Biomass Burning					
Controlled Burning	IE, NA, NO, NA	X, IE, NO, NA	X, IE, NO, NA	IE: Forest land: CO_2 emissions are included in carbon stock change in dead organic matter as cutting waste (category 4.A.1). IE: Cropland: included in Agriculture sector Table 3.F.	See NID 6.10.5
Wildfires	NA, IE, NE	X, NA, IE, NE	X, NA, IE, NE	NE: wildfires on Settlements and Wetlands are not estimated because there is no method to estimate these emissions. IE: Forest land: CO_2 emissions are included in carbon stock change (category 4.A.1). IE: Cropland: Wildfires on cropland are included in grassland because there is no method to separate these fires from each other.	

Waste (CRF 5)

Greenhouse gas source and sink categories	**CO_2**	**CH_4**	**N_2O**	**Explanation, -if not estimated -if included elsewhere**	**Notes**
5. Waste					
A. Solid Waste Disposal					
1. Managed Waste Disposal Sites					
Anaerobic	NO	X			
Semi-aerobic	NO	NO			
2. Unmanaged Waste Disposal Sites	NO	IE		Unmanaged waste disposal, which occurred in early 1990s, is included under managed waste disposal.	
3. Uncategorized Waste Disposal Sites	NO	NO			
B. Biological Treatment of Solid Waste					
1. Composting					
Municipal Solid Waste		X	X		
Other					
Municipal Sludge		X	X		
Industrial Sludge		X	X		
Industrial solid waste and construction waste		X	X		
2. Anaerobic Digestion at Biogas Facilities					
Municipal Solid Waste		X, NO	NA		
Other					
Municipal Sludge		X	NA		
Industrial Sludge		X, NO	NA		
Industrial solid waste and construction waste		X, NO	NA		
C. Incineration and Open Burning of Waste					
1. Waste incineration				Waste incineration without energy recovery is nearly zero. Waste incineration with and without energy recovery are included in the calculations of the energy sector (CRF 1.A.).	
Biogenic	IE	IE	IE		
Non-biogenic	IE	IE	IE		
2. Open Burning of Waste					
Biogenic	NE	NE		Insignificant category	
Non-biogenic	NE	NE			
D. Wastewater treatment					
1. Domestic Wastewater		X	X, NE	Insignificant category (actively nitrogen removing plants)	
2. Industrial Wastewater		X	X		
3. Other					
Fish farming		NO	X		
E. Other	NO	NO	NO		

ANNEX 6. Description of the Compliance Monitoring Data system YLVA

The YLVA compliance data system functions as a tool for the 13 Centres for Economic Development, Traffic and the Environment (ELY-centre) in their work on processing and checking compliance of environmental permits. The data system contains information on the environmental permits of clients and on their generated wastes, discharges into water and emissions to air. This baseline data are used by the ELY Centres and by other interested parties. Additionally, case management has been incorporated into the system.

YLVA contains information on how installations comply with environmental regulations.

Currently, there are over 600 active users of the system in the environmental administration. Moreover, the data system provides substantial reports for the diverse needs of the administration and for other interested parties needing information.

The user interface makes it possible to add new customers, change or add customer data, retrieve reports from the database and write inspection reports. Additionally, the system has other helpful functions, such as mapping functions and a calendar to remind an inspector of time limits.

YLVA is a customer information system (operators must have an environmental permit from the authorities or they have registered their activities) containing, for example, the following information (Figure 1):

- Identification details
- Contact persons
- Respective authorities
- Licence conditions
- Environment insurance
- Loading points (stacks and sewers)
- Emissions control equipment
- Treatment plans
- Boilers and fuels used
- Landfills
- Emissions to air, discharges to water and wastes
- Energy and other production
- Raw materials and water consumption
- Production
- Water consumption
- Fish farming
- Peat production area
- Animal shelters
- Analyses

Figure 1. Structure of the YLVA Data System

Emission data reported by the facilities

The permit or the plant-specific emission monitoring and reporting programme annexed to the permit includes requirements on what the operator (i.e. the person or legal person in charge of a facility) must report to the authorities. The annual reporting obligation of an installation concerns emissions for which the installation has an emission limit value (ELV) in the environmental permit. The monitoring system for these substances is stipulated together with the ELV for these compounds. Of emissions reported to the UNFCCC, ELVs are usually given for emissions of sulphur (as SO_2) and nitrogen oxides (as NO_2), but not for carbon dioxide, methane or nitrous oxide. However, the operators may also report these compounds based on the reporting obligations to the integrated emission registers such as the European Pollutant Release and Transfer Register (E-PRTR). The PRTR reporting substance lists also include carbon dioxide, nitrous oxide and F gases. However, the data to the integrated emission registers are reported as total emissions for the industrial site and cannot be split between the CRF reporting categories.

In addition to emission data, the operators also report on the types, characteristics and consumption of fuels, though these data may not be as complete as emission data. In addition, waste amounts (with classification data) to solid waste disposal sites and wastewater handling data are reported to the YLVA Data System.

Quality checking carried out by the supervising authority

When receiving the emission report from the operator, the supervising authority checks whether the data are produced according to the methods agreed in the permit or in a separate monitoring programme for the plant. The methods usually include use of international standards or approved in-house methods. The principles of the EU IED Reference Document on Monitoring of Emissions (Monitoring REF) are also followed.

Reporting options for the operators

The operators may submit the emission reports to the supervising authorities either as hard copies or electronically by email or through the Internet (Figure 2). Larger industrial installations have developed reporting systems which are based on direct information flow from the plant information systems to the supervising authority. The emission data are always checked by the supervising authority before recording into the YLVA data system as described in Section 1.3. When the operator chooses to send the data over the Internet using a centralised data collection system the data will be automatically checked for completeness and only the completed data will be sent to the authorities for checking of the substance.

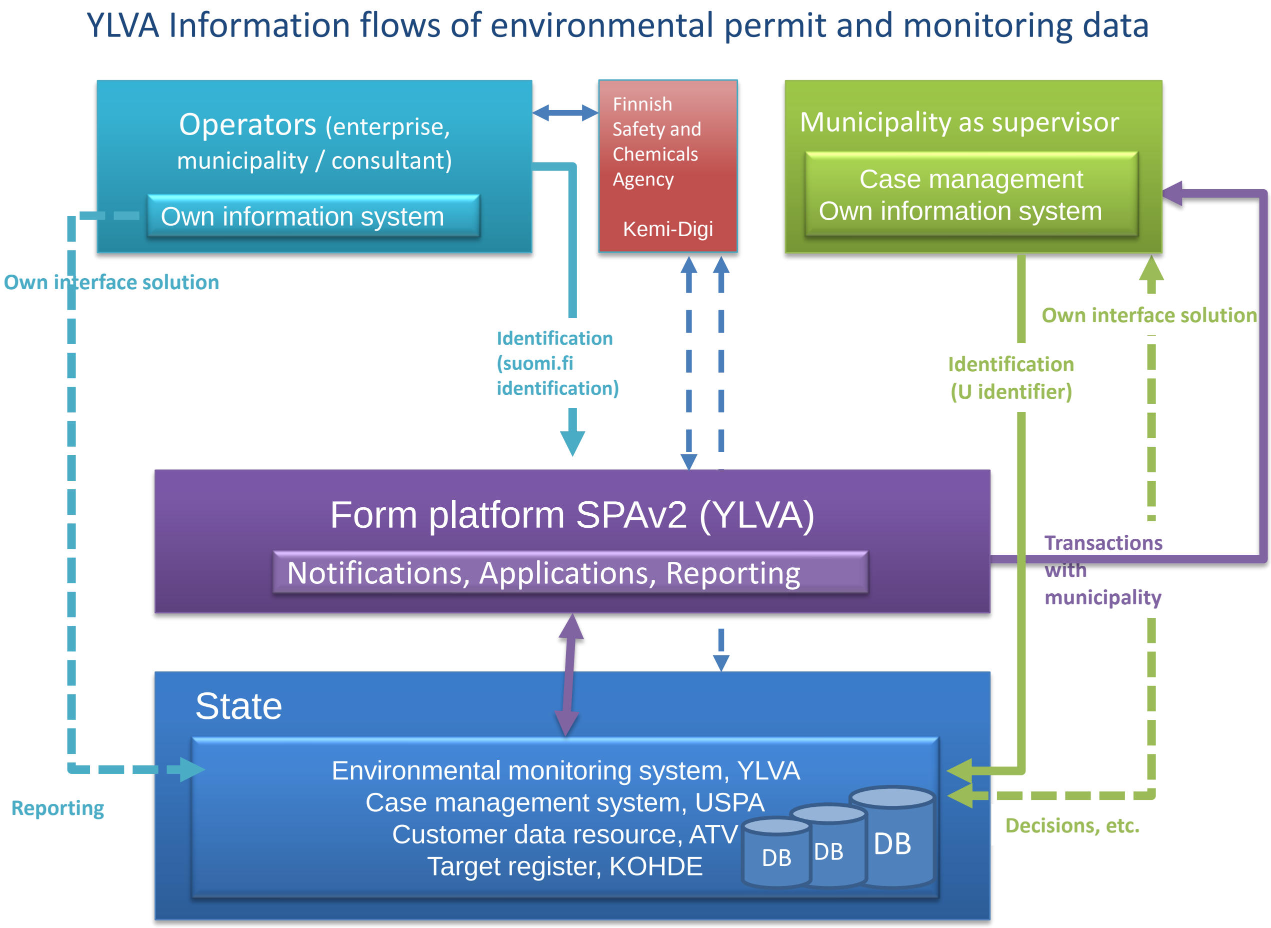

Figure 2. Data flows of environmental permits and compliance assurance in YLVA data system

Further information on the YLVA Data System is available from Mr. Juha Lahtela, the Ministry of the Environment (email: firstname.surname@ym.fi)

ANNEX 7. Information related to additional reporting requirements under the EU Governance Regulation (2018/1999)

Additional information on the national system

Reporting information referred to in Article 37, paragraph 2 of the EU Governance Regulation

According to Article 37 of the EU Governance Regulation, Member States shall ensure that their competent inventory authorities have access to data reported under the Union's Emissions Trading System (EU ETS), data collected on fluorinated gases under regulation (EU) 517/2014 and regulation (EC) 166/2006 on data and methodologies reported by facilities, data reported under the energy statistics regulation (1099/2008) and data collected via geographical tracking of land areas in the context of existing Union and Member State programmes and surveys, including the LUCAS (Land Use Cover Area frame Survey) and Copernicus Programme. Member Stats shall make use of reporting systems established for regulation (517/2014) to improve the estimate of fluorinated gases and are able to undertake the annual consistency checks for year x-2 with EU ETS emissions, air pollutants (EU 2016/2284), fluorinated gases reported pursuant to Article 19 (1) of Regulation EU 517/2014 and energy data reported under Regulation EC 1099/2008).

The Finnish national system has continuous access to all these data. The access is ensured by law, administrative arrangements (the Finnish Environment Institute, which performs the F gas calculations for the inventory is the competent authority for the F gas regulation and Statistics Finland is responsible for both the GHG inventory and the energy statistics) and/or agreements under the national system.

Overview of reporting the additional information

Overview of reporting on greenhouse gas inventory data pursuant to Article 8(2) and Annex VII in Regulation (EU) 2020/1208 is provided in the table below. In addition the table includes overview of data reported pursuant to Articles 11, 13, 19 to 24 in Regulation (EU) 2020/1208 and pursuant to point (m) of Part 1 of Annex V in Regulation 2018/1999 to ensure transparent reporting.

[Article of] Regulation	Information provided in the NID	Information provided in a separate annex	Reference to chapter in the NID or in separate annex	Comment
Article 9 Reporting on recalculations	x		NID Section ES.6, 10.1 and Table 10.1-1.	
Article 10 Reporting on implementation of recommendations in Table 1 of Annex VIII	x	x	NID Section 10.4, Table 10.4-2. Art10_AnnexVIII_Recommendations_FI_2024-03-15.xlsx	Table in the NID is based on review report of the UNFCCC 2022 review, since there were no UNFCCC review in 2023. Recommendations from previous reviews which were not been resolved for the 2023 submission are included in the table.
Article 10 Reporting on implementation of recommendations in Table 2 of Annex VIII		x	Art10_AnnexVIII_Recommendations_FI_2024-03-15.xlsx	Table is reported empty as Finland received no recommendations in the 2023 ESD review (the review as no a comprehensive review).
Article 11 Reporting on inventory methods, emission factors and on related methodological descriptions for Union key categories		x	Art11_AnnexIX_Methods, Emissions Factors and Methodological Description.xlsx / Sheet FIN	Information saved in the excel file in the SharePoint
Article 12(1) Reporting on uncertainty	x	x	Art12_AnnexX_Uncertainty and completeness_FI_2024-03-15.xlsx Section 1.6 and Annex 2 (Assessment of uncertainty)	
Article 12(2) Reporting on completeness	x		Section 1.7 and Annex 5 (Completeness), also all sector-specific chapters and CRF Tables	
Article 13 Reporting on indicators		x	Art13_AnnexXI_Indicators_FI_2024-03-15.xlsx	
Article 14(1) Reporting on consistency of reported emissions with data from the emissions trading scheme (Annex XII data)		x	Art14_AnnexXII_Consistency with ETS_FI_2024-03-15.xlsx	
Article 14(2) Reporting on consistency of reported emissions with data from the emissions trading scheme (textual information)	x	x	Section 3.2.4.4/Verification and also QA Sections of the IPPU sector Art14_AnnexXII_Consistency with ETS_FI_2024-03-15.xlsx	

[Article of] Regulation	Information provided in the NID	Information provided in a separate annex	Reference to chapter in the NID or in separate annex	Comment
Article 15 Reporting on consistency of the reported data on air pollutants	x	x	Art15_AnnexXIII_Consistency with air pollution data_FI_2024-03-15.xlsx and NID, Annex 7	
Article 16 Reporting on consistency of the data reported on fluorinated greenhouse gases	x		NID, Annex 7	
Article 17 Reporting on consistency with energy statistics	x	x	NID, Annex 7 and Art17_AnnexXIV_Consistency with energy statistics_FI_2024-03-15.xlsx	
Article 18 Reporting on changes in descriptions of national inventory systems or registries	x		Chapter 11 (national inventory system) and Chapter 12 (registries)	
Article 19 Reporting on greenhouse gas emissions covered by Regulation (EU) 2018/842		x	Art19_AnnexXV_Emissions covered by the ESR_FI_2024-03-15.xlsx	
Article 20 Reporting on summary information on concluded transfers in accordance with Regulation 2018/841		x	Art20_AnnexXVI_Concluded transfers for LULUCF_FI_2024-03-15.xlsx	
Article 21 Reporting on summary information on concluded transfers in accordance with Regulation (EU) 2018/842		x	Art21_AnnexXVII_Concluded transfers for ESR_FI_2024-03-15.xlsx	
Article 22 Reporting information on intended use of flexibilities in accordance with Regulation (EU) 2018/842		x	Art22_AnnexXVIII_Intended use of flexibilities_FI_2024-03-15.xlsx	
Article 23 Reporting on the use of revenues from transfers in accordance with Regulation (EU) 2018/842		x	Art23_AnnexXIX_Use of revenues_FI_2024-03-15.xlsx	
Article 24 Reporting on accounted greenhouse gas emissions and removals				Reporting in 2027 and 2032
point (m) of Part 1 of Annex V in Regulation 2018/1999 information on quality assurance and quality control plan	x		Section 1.5	

Comparisons with other international reportings

Reporting information referred to in Annex V, Part I, (j) (iii) of the EU Governance Regulation (2018/1999)

Quantitative information and explanations for differences of more than +/- 2% in apparent consumption at aggregate level for the reference approach.

In Finland, the difference at aggregate level was 5.0% in 2022. The reasons for differences in the greenhouse gas inventory data compared to the energy statistics data are explained below. Table includes data and explanations for differences for 2022 but also explanations concerning differences in previous years.

FUEL TYPES			Apparent consumption reported in GHG inventory	Apparent consumption using data reported pursuant to Regulation (EC) No 1099/2008	Absolute difference (1)	Relative difference (2)	Explanations for differences (2022)	Explanations for differences (Historical)
			(TJ) (3)	(TJ) (3)	(TJ) (3)			
Liquid fossil	Primary fuels	Crude oil	392 899	392 899	0.0	0.0 %		*Stock changes:* Alternative, more reliable, approach to estimate stock changes is used in RA instead of using IEA data. Annual stock changes of crude oil are calculated by subtracting observed consumption in refineries from the imports data in 1990-1997. In the IEA data set there is an old NCV prior to 2000.
		Orimulsion		0				
		Natural gas liquids	31 372	31 372	0.0	0.0 %		*Imports:* No NGL imports have been reported to the IEA from 1990 to 1994 since no revisions are made to IEA data prior to 2000.
	Secondary fuels	Gasoline	-110 670	-110 670	0.0	0.0 %		
		Jet kerosene	-19 750	-19 745	-5.2	0.0 %		
		Other kerosene	9 482	9 486	-4.4	0.0 %		
		Shale oil		0				
		Gas/diesel oil	-28 859	-28 848	-11.0	0.0 %		*Stock changes:* customers' stock changes are not included in IEA data
		Residual fuel oil	-24 608	-24 844	236.7	-1.0 %	IEA data should/will be updated	*Stock changes:* customers' stock changes are not included in IEA data
		Liquefied petroleum gases (LPG)	46 115	46 115	0.0	0.0 %		
		Ethane		0				
		Naptha	15 638	15 638	0.0	0.0 %		*Imports:* Imports of naphtha are reported in the IEA data from 1992-1994 and IEA figures for naphtha imports for 1991 are higher than in the CRFs since no revisions are made to IEA data prior to 2000.
		Bitumen	8 804	8 804	0.0	0.0 %		
		Lubricants	-7 839	-7 839	0.0	0.0 %		*Imports:* IEA data has not been revised. CRF imports of lubricants are lower than those reported to the IEA in 1991.
		Petroleum coke	1 742	1 742	0.0	0.0 %		

FUEL TYPES			**Apparent consumption reported in GHG inventory**	**Apparent consumption using data reported pursuant to Regulation (EC) No 1099/2008**	**Absolute difference (1)**	**Relative difference (2)**	**Explanations for differences (2022)**	**Explanations for differences (Historical)**
			(TJ) (3)	**(TJ) (3)**	**(TJ) (3)**			
		Refinery feedstocks	358	-553	910.2	254.4 %	Different mapping of product imports	methanol used in refineries is included in Refinery feedstocks in RA, but Additives /oxygenates in IEA data
		Other oil	-12 436	-11 877	-559.3	4.5 %	Different set of products, different allocation, different NCV, corrections in product allocations in IEA data (products transferred, interproduct transfer)	different set of products, different allocation, different NCV, corrections in product allocations in IEA data (products transferred, interproduct transfer) (Other oil, Naphtha, Gasoline)
Other liquid fossil				0				
Liquid fossil totals			302 247	301 680	567.0	0.2 %		
Solid fossil	Primary fuels	Anthracite(3)		0				
		Coking coal	32 469	34 047	-1 577.7	-4.9 %	Different NCV, different mapping (coal tar and benzene)	slightly different allocation (coal tar and benzene) and import data used in RA and IEA data.
		Other bituminous coal	51 435	51 537	-101.7	-0.2 %		*Stock changes:* Some plant level balance data may have been updated when coal piles are exhausted (2007). The amount of coal in the piles has always some uncertainty. *Imports:* There is an erroneous figure in 1996 IEA data which has not been revised. *Imports:* In the latest years, the NCV of imported hard coal differs from hard coal used in energy production, because there is some pulverized coal injection (PCI) to blast furnaces. PCI-coal differs from normal steam coal, and that affects the average NCV of imported coal. In GHG inventory data PCI has been treated as process use, and therefore not taken into account when calculating total energy use and average NCV. This average NCV calculated from the inventory data has been used in RA calculations. (PCI coal, as well as other blast furnace inputs are split to industrial process emissions and energy based emissions as BFG use).
		Sub-bituminous coal		0				
		Lignite		0				

FUEL TYPES			**Apparent consumption reported in GHG inventory**	**Apparent consumption using data reported pursuant to Regulation (EC) No 1099/2008**	**Absolute difference (1)**	**Relative difference (2)**	**Explanations for differences (2022)**	**Explanations for differences (Historical)**
			(TJ) (3)	**(TJ) (3)**	**(TJ) (3)**			
		Oil shale and tar sand		0				
	Secondary fuels	BKB$^{(4)}$ and patent fuel		0				
		Coke oven/gas coke	3 653	3 809	-156.0	-4.3 %	Different NCV	
		Coal tar		-1 295	1 295.0		Different mapping (included in coking coal in RA data; is benzene from coke production included here or not?)	
Other solid fossil				0				
Solid fossil totals			87 557	88 097	-540.3	-0.6 %		
Gaseous fossil		Natural gas (dry)	46 288	47 273	-984.9	-2.1 %	-	incl. LNG
Other gaseous fossil				0				
Gaseous fossil totals			46 288	47 273	-984.9	-2.1 %		
Waste (non-biomass fraction)			13 994	13 311	682.9	4.9 %	Slightly different split to biomass/non-biomass fractions in RA and IEA data (partially plant-specific in RA, default average in IEA)	*Production:* There have been some changes in what has been included in industrial wastes in the IEA data before 1996 and after 1999
Other fossil fuels				0				
Peat			36 667	36 667	0.0	0.0 %		*Production:* the IEA dataset has not been revised for years prior to 2000
Total			486 753	487 028	-275.3	-0.1 %		No revisions are made to IEA data prior to 2000 since every correction should be taken into account in every part of the energy balance. The inventory data are better updated than the IEA dataset for the period (1990-1999). CRF time series are consistent.

(1) Apparent consumption reported in GHG inventory minus apparent consumption using data reported pursuant to Regulation (EC) No 1099/2008
(2) Absolute difference divided by apparent consumption reported in GHG inventory
(3) Data with one decimal point for kt and one decimal point for % values

Reporting information referred to in Annex V, Part I, (j) (i) of the Governance Regulation (2018/1999)

Quantitative information and explanations for differences of more than +/- 5% in total emissions excluding LULUCF of any of the air pollutants CO, SO_2, NOx and NMVOC reported in the national greenhouse gas inventory and under the **NEC Directive.**

EMISSION CATEGORIES	Emissions for pollutants reported in GHG inventory (in kt)	Emissions for pollutants reported in NEC, submission 15 February 2024 (in kt)	Absolute difference in kt (1)	Relative difference in % (2)	Explanations for differences
Total (Net Emissions) (NOx)	91.0	89.5	1.4	1.6	Different guidelines in use in the NEC and GHG inventories of Agriculture (Section 3.B and 3.D).
Total (Net Emissions) (NMVOC)	75.4	60.6	14.8	19.6	Different guidelines in use in the NEC and GHG inventories of Agriculture (Section 3.B and 3.D).
Total (Net Emissions) (SOx as SO_2)	23.4	22.7	0.7	2.9	
Total (Net Emissions) (NH_3)	NA	31.6			
Total (Net Emissions) (CO)	305.1	310.2	-5.1	-1.7	

(1) Emissions reported in GHG inventory minus emissions reported in NEC inventory
(2) Difference in kt divided by emissions reported in GHG inventory
NA = not applicable

Reporting information referred to in Annex V, (j)(ii) of the EU Governance Regulation (2018/1999)

The use and handling of F gases is controlled by the EU Regulation on certain fluorinated greenhouse gases (517/2014/EU) and the Directive relating to emissions from air conditioning systems in motor vehicles (40/2006/EC). The F gas Regulation (517/2014/EU) which applies from 1 January 2015 replaced the original F gas Regulation (842/2006/EC). The original Regulation placed requirements on the proper recovery of equipment, containment, labelling and reporting of F gases as well as the training and certification of personnel handling the gases. The Regulation also included specific bans for certain F gases containing applications. The current F gas Regulation strengthened the existing measures and also introduced a number of new bans on the use of F gases. The main driver of the move towards more climate-friendly technologies is the phase down of the quantities of HFCs that can be placed on the EU market. The phase down is applied to the aggregate amount of HFCs (measured in equivalent tonnes of CO_2) and takes place in a series of steps, starting with a cap in 2015 and reaching a 79% cut in 2030. The phase down is accompanied by a quota system that will specify the amounts of HFCs that individual companies can place on the market, based on sales reported under the existing F gas Regulation plus an allowance for new entrants. Production or import of HFCs into the EU requires a quota.

Each producer, importer and exporter of fluorinated greenhouse gases report their activity for the previous calendar year annually before 31 March to the European Environment Agency (EEA) if the amount exceed one metric tonne or 100 tonnes of CO_2 equivalent fluorinated greenhouse gases. In addition the reporting obligation applies to undertakings that destroyed one metric tonne or 1000 tonnes of CO_2 equivalent or more of F gases, undertakings that used 1000 tonnes of CO_2 equivalent of F gases as feedstock, undertakings that placed 500 tonnes of CO_2 equivalent of F gases or gases contained in products or equipment on the market (no obligation to report if these gases were bought on the EU market or imported as bulk before being put in the equipment), undertakings that placed on the market pre-charged refrigeration, air conditioning and heat pump equipment where HFCs contained in this equipment have not previously been placed on the EU market. Reported imports and exports of F gases include only quantities imported from, or exported to, countries outside the European Union. Reporting is performed via the Business Data Repository (BDR) in the EEA's Eionet web service. It is not necessary to send the report additionally to the Commission and to the Competent Authority in the Member State. They have access to the relevant reports in BDR. Finnish Environment Institute (Syke) acts as the competent authority of the F gas Regulation in Finland. Data collected through this reporting system is available when preparing Finnish national greenhouse gas inventory.

25 companies from Finland reported data under the F gas regulation for 2022. F gases are not produced in Finland and therefore no production of F gases was reported. All the data reported under the F gas regulation were compared to the data collected in the F gas greenhouse gas inventory surveys.

One company reported import of HFC-134a in medical aerosol products. The same company reported import of HFC-134a in medical aerosol products also in the aerosol greenhouse gas inventory survey. The imported amount reported in the inventory survey was the same as the amount reported under the F gas regulation. The company imported metered dose inhalers (MDIs) to Finland from outside of the EU.

Altogether 23 companies in the refrigeration and air conditioning sector reported data under the F gas regulation. Five companies reported bulk import of F gases and 15 companies reported import of F gases in equipment. Two companies reported bulk export of F gases. In addition, one company reported both bulk import of F gases and import of F gases in equipment.

Three companies had reported exactly the same amount of bulk import under the F gas regulation and in the inventory survey. They had imported refrigerants to Finland from outside the EU. Two companies that had reported bulk import under the F gas regulation were missing from the inventory survey. The reported amounts were not significant. However, the companies will be contacted during the preparation on 2024 inventory survey to see if they import refrigerants into Finland. One of the companies that had reported bulk export under the F gas regulation reported exactly the same amount of bulk export under the F gas regulation and in the inventory survey. The other company that had reported bulk export under the F gas regulation had not reported the bulk export in the inventory survey since the refrigerant had only been circulated through Finland (imported from outside of EU via Finland to the outside of EU).

In the case of 10 companies importing of F gases in equipment, the reported amounts under the F gas regulation were the same compared to the amounts reported in the inventory survey as import to Finland from outside the EU. The data of four companies, that had reported import of F gases in equipment under the F gas regulation, were missing from the inventory. In addition, data of one company, that had reported import of F gases in bulk, was missing from the inventory. Their data will be further investigated and, if appropriate, the data will be included in the 2025 submission. The amounts reported under the F gas regulation were not significant.

Two companies reported import of F gases in mobile air conditioning equipment for passenger cars or vans. In the greenhouse gas inventory, the import data of vehicles is taken from statistics of Finnish Transport and Communications Agency (Traficom). The share of imported vehicles equipped with MACs and the used refrigerants come from the MAC inventory survey (passenger cars and vans).

The only F gas destruction facility in Finland reports the amount of destructed F gases under the F gas regulation. This data was previously used in the mass balance approach used for emission estimation in the category 2.F.1. However, the data is not used in the emission factor approach introduced in the 2018 submission for category 2.F.1.