DANISH EMISSION INVENTORY FOR INDUSTRIAL PROCESSES AND PRODUCT USE

Results of inventories up to 2021

Scientific Report from DCE – Danish Centre for Environment and Energy No. 567 2023

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Data sheet

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Abstract: This report forms part of the documentation for the emission inventories for industrial processes and product use. The report includes both methodological descriptions for estimating emissions of greenhouse gases and air pollutants and presents the resulting emission data as reported to the United Nations Framework Convention on Climate Change and the United Nations Economic Commission for Europe Convention on Long-Range Transboundary Air Pollution. The results of inventories up to 2021 are included.

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Contents

List of abbreviations

As	Arsenic
BC	Black Carbon
Ca	Calcium
$CaCO_3$	Limestone
CaO	(Burnt) Lime
CAS	Chemical Abstracts Service
Cd	Cadmium
CH_4	Methane
CHP	Combined Heat and Power
CKD	Cement Kiln Dust
CLRTAP	Convention on Long-Range Transboundary Air Pollution
CO	Carbon monoxide
CO_2	Carbon dioxide
CO_2e	CO_2 equivalents, calculated from all GHGs using GWPs
CollectER	Software to support the CORINAIR system
COPERT	Computer Programme to Calculate Emissions from Road Transport
CORINAIR	CORe INventory on AIR emissions
Cr	Chromium
CRF	Common Reporting Format
Cu	Copper
DCE	Danish Centre for Environment and energy
DEA	Danish Energy Agency
DEPA	Danish Environmental Protection Agency
EEA	European Environment Agency
EF	Emission Factor
EMEP	European Monitoring and Evaluation Programme
ENVS	Department of ENVironmental Science, Aarhus University
EPA	Environmental Protection Agency
EU-ETS	European Union Emission Trading Scheme
GHG	Greenhouse gas
GJ	Gigajoul, 10^9 J
GWP	Global Warming Potential
HCB	Hexachlorobenzene
HFCs	Hydrofluorocarbons
Hg	Mercury
IE	Included Elsewhere
IEF	Implied Emission Factor
IIASA	International Institute for Applied Systems Analysis
IPCC	Intergovernmental Panel on Climate Change
kPa	Kilopascal, 1000 Pa
LKD	Lime Kiln Dust
LPG	Liquefied Petroleum Gas
LRTAP	Long-Range Transboundary Air Pollution
LULUCF	Land Use, Land-Use Change and Forestry
µg	Microgram, 10^{-6} g
N_2O	Nitrous oxide
NA	Not Applicable
NACE	Standard nomenclature for economic activities
NE	Not Estimated
NECD	National Emissions Ceiling Directive
NFR	Nomenclature For Reporting
NH_3	Ammonia

Ni	Nickel
NMVOC	Non-Methane Volatile Organic Compounds
NO	Not Occurring
NO_x	Nitrogen Oxides
ODS	Ozone Depleting Substances
Pb	Lead
PCDD/F	PolyChlorinated DibenzoDioxins/Furans
PFCs	Perfluorocarbons
$PM_{2.5}$	Particulate Matter up to 2.5 µm in size
PM_{10}	Particulate Matter up to 10 µm in size
POPs	Persistent Organic Pollutants
PROBAS	Danish Product Register Data Base
QA	Quality Assurance
QC	Quality Control
RAINS	Regional Air Pollution INformation and Simulation
SCR	Selective Catalytic Reduction
Se	Selenium
SF_6	Sulphur hexafluoride
SNAP	Selected Nomenclature for Air Pollution
SO_2	Sulphur dioxide
SPIN	Substances in Preparations In the Nordic countries
TJ	Terajoule, 10^{12} J
TSP	Total Suspended Particles
UCN	Use Categories Nordic
UNECE	United Nations Economic Commission for Europe
UNFCCC	United Nations Framework Convention on Climate Change
VOC	Volatile Organic Compounds
WEA	Danish Working Environment Authority
Zn	Zinc

Preface

DCE - Danish Centre for Environment and Energy, Aarhus University is contracted by the Ministry of Environment and the Ministry of Climate, Energy and Utilities to complete emission inventories for Denmark. Department of Environmental Science, Aarhus University is responsible for the calculation and reporting of the Danish national emission inventory to EU and the UNFCCC (United Nations Framework Convention on Climate Change) and UNECE CLRTAP (Convention on Long-Range Transboundary Air Pollution).

This report forms the documentation of the emission inventories for *Industrial processes and product use*. The report includes both methodological descriptions and emission data. This report contains inventories for the following groups of substances: Greenhouse gases (CO_2, CH_4, N_2O and F-gases (HFCs, PFCs, SF_6 and NF_3)), main pollutants (CO, NH_3, NMVOC, NO_x, SO_2), particulate matter (TSP, PM_{10}, $PM_{2.5}$, BC), heavy metals (As, Cd, Cr, Cu, Hg, Ni, Pb, Se, Zn) and persistent organic pollutants (POPs) (PCDD/F, HCB, PCB and PAHs). The results of inventories up to 2020 are included.

This report is the fifth version of a sectoral report for industrial processes and product use. The fourth version of the report was reviewed by Jytte Boll Illerup from the Danish Environmental Protection Agency and the report has been improved based on the comments received.

The next version of the report is tentatively scheduled for 2026.

Summary

This sector report covers emissions from Industrial Processes and Product Use (IPPU). This sector covers process related emissions mostly related to calcination, evaporation/leaks and fugitive dust. Emissions from combustion are not included in this report, since these emissions are considered under the energy sector. In some cases, it can be difficult to split emissions between combustion and IPPU. In this report, only emissions reported in the IPPU sector are included and described, including plants where fuels and raw materials are in contact during combustion.

Danish emission inventories are prepared on an annual basis and are reported to the United Nations Framework Convention on Climate Change (UNFCCC or simply the Climate Convention) and to the Kyoto Protocol as well as to the United Nations Economic Commission for Europe (UNECE) Convention on Long-Range Transboundary Air Pollution (LRTAP Convention). Furthermore, a greenhouse gas emission inventory is reported to the European Union (EU) due to the EU – as well as the individual member states – being party to the Climate Convention and the Kyoto Protocol. Inventories of air pollutants are estimated for reporting to the European Commission's National Emissions Ceiling Directive (NECD).

The annual Danish emission inventories are prepared by the DCE – Danish Centre for Environment and Energy, Aarhus University. The inventories include the following pollutants relevant to *Industrial processes and product use*: Greenhouse gases: carbon dioxide (CO_2), methane (CH_4), nitrous oxide (N_2O), hydroflourocarbons (HFCs), perflourocarbons (PFCs), sulphur hexafluoride (SF_6). Main air pollutants: sulphur dioxide (SO_2), nitrogen oxides (NO_x), ammonia (NH_3), non-volatile organic compounds (NMVOC). Particulate matter (PM): total suspended particulates (TSP), particles with an aerodynamic diameter less than 10 µm (PM_{10}), particles with an aerodynamic diameter less than 2.5 µm ($PM_{2.5}$), black carbon (BC). Carbon monoxide (CO). Heavy metals (HMs): arsenic (As), cadmium (Cd), chromium (Cr), copper (Cu), mercury (Hg), nickel (Ni), lead (Pb), selenium (Se), zinc (Zn). Polycyclic aromatic hydrocarbons (PAHs): benzo(a)pyrene, benzo(b)fluoranthene, benzo(k)fluoranthene, indeno(1,2,3-cd)pyrene. Polyclorinated dibenzodioxins and –furans (PCDD/F), hexachlorobenzene (HCB) and polychlorinated biphenyls (PCBs).

The pollutants listed above correspond to the requirements of the UNFCCC, UNECE and EU to whom the emission inventories are reported. Other pollutants could be relevant for the source categories included in this report for environmental impact assessments, but these fall outside the scope of the emission inventories and are therefore not included.

The inventories for *Industrial processes and product use* are largely based on official Danish statistics (e.g. from Statistics Denmark) and on a set of emission factors for the various source categories and technologies. For some source categories, the official statistics are supplemented by information from individual plants or from industrial associations. Plant specific emissions for large industrial sources are incorporated into the inventories. This report provides detailed background information on the methodology and references for the input data in the inventory – including activity data and emission factors.

The emission factors are based either on national references (e.g. contact to production plants), on international guidance documents (e.g. EMEP/EEA, 2019 and IPCC, 2006) or from scientific literature. The majority of the country-specific emission factors are determined from data given in Danish research reports or calculated from plant-specific emission data. The plant-specific emission factors are provided by plant operators, e.g. in annual environmental reports or in the reports under the EU Emission Trading Scheme (ETS).

Greenhouse gases

An overview of the relevant sources is presented in Table 0.1 with an indication of the contribution to the overall emission from industrial sources of greenhouse gases in 2021. The emissions are extracted from the Common Reporting Format (CRF) tables, which is the official reporting format for greenhouse gas emissions to the UNFCCC.

Table 0.1 Overview of the greenhouse gas sources in *Industrial processes and product use* (2021).

Process	IPCC Code	Substance(s)	Emission, kt CO_2e	%
Cement production	2A1	CO_2	1,214.6	66
Refrigeration and air conditioning	2F1	HFCs, PFCs	264.4	14
Other uses of carbonates	2A4	CO_2	84.5	4.6
Other non-energy products from fuels and solvent use	2D3	CO_2, CH_4	81.3	4.4
Paraffin wax use	2D2	CO_2, CH_4, N_2O	65.7	3.6
Lime production	2A2	CO_2	48.4	2.6
Lubricant use	2D1	CO_2	31.7	1.7
N_2O from product uses	2G3	N_2O	15.9	0.9
Electrical equipment	2G1	SF_6	13.5	0.7
Glass production	2A3	CO_2	11.2	0.6
Aerosols / Metered dose inhalers	2F4	HFCs	10.1	0.5
Other product use	2G4	CO_2, CH_4, N_2O	5.7	0.3
SF_6 from other product use	2G2	SF_6	1.5	0.1
Catalysts / fertilisers	2B10	CO_2	1.2	0.07
Foam blowing agents	2F2	HFCs	0.6	0.03
Lead production	2C5	CO_2	0.1	0.004
Nitric acid production	2B2	N_2O	NO	NO
Iron and steel production	2C1	CO_2	NO	NO
Other (fibre optics)	2E5	PFCs	NO	NO
Total			1,851	100

NO: Not occurring.

Sources marked as "NO" in Table 0.1 are relevant for the Danish inventories historically, but not for the years 2020s. Greenhouse gas emissions from category 2B2 occur in 1990-2004, from 2C1 in 1990-2001; 2005 and from 2E5 in 2001; 2006-2014; 2017; 2019.

In 2021, the subsector *Mineral industry* (2A) constitutes 73 % and *Product uses as substitutes for ozone depleting substances* (ODS) (2F) constitutes 15 % of the greenhouse gas emission from the *Industrial processes and product use* (IPPU) sector. *Non-energy products from fuels and solvent use* (2D) and *Other product manufacture and use* (2G) constitutes 10 % and 2 %, respectively, while the remaining two subsectors *Chemical industry* (2B) and *Metal industry* (2C) each constitutes below 0.1 % of the total IPPU emission of greenhouse gases in 2021. Greenhouse gas emissions from *Metal industry* (2C) have been low in recent years, since the single Danish steel production facility (2C1) was last in operation in 2005.

The total emission of greenhouse gases in Denmark (incl. emissions/removals from *Land-use, land-use change and forestry* (LULUCF) and incl. indirect CO_2) in 2021 is estimated to 46,026 kt CO_2 equivalents (CO_2e), of which IPPU contributes with 1,851 kt CO_2e (4.0 %). The emission of greenhouse gases from IPPU from 1990-2021 is presented in Figure 0.1.

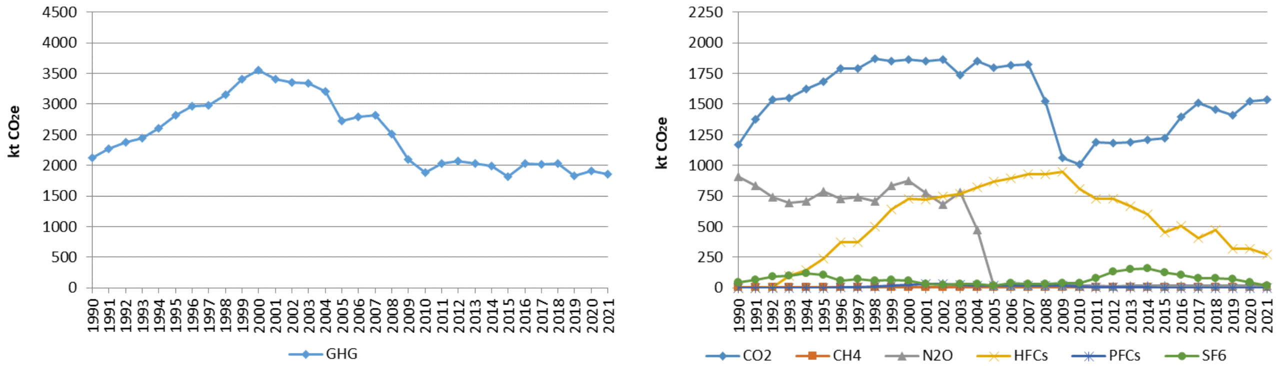


Figure 0.1 Emission of greenhouse gases from *Industrial processes and product use* (CRF Sector 2) from 1990-2021.

The CO_2 emissions from the IPPU sector are dominated by mineral industries and in particular cement production. The emissions increased in the early part of the time series based on increased production of cement. A significant dip in emissions occurred during the global economic recession in 2008-2010. Since then the cement production has increased again leading to increased CO_2 emissions. Emissions of N_2O have decreased significantly since the closure of the only nitric acid plant in Denmark in 2004. HFC emissions are primarily due to the use of commercial refrigeration. The trend of the HFC emission is therefore dominated by the increased use of HFC-125, HFC-134a and HFC-143a in commercial refrigerating appliances up through the 1990s and 2000s until 2009 where the regulations placed on the sector start to show their effect.

The key categories for level of emissions in the IPPU sector in 2021 are *Cement production* and *Refrigeration and air conditioning* - constituting 2.6 % and 0.6 %, respectively, of the total national emission of greenhouse gases (Nielsen et al., 2022a). For 1990, the key categories for level of emissions are *Cement production* and *Nitric acid production* – 1.0 % and 1.2 %, respectively. The key categories according to trend are cement production (CO_2), nitric acid production (N_2O), refrigeration and air conditioning (HFC, PFC) and foam blowing agents (HFC). The trends in greenhouse gases from the IPPU sector/subsectors are presented in Table 0.2 and Annex 0-1 and they will be discussed subsector by subsector below.

Table 0.2 Emission of greenhouse gases from *Industrial processes and product use* from 1990-2020.

Year	1990	1995	2000	2005	2010	2015	2020	2021
CO_2 (kt CO_2)								
A. Mineral industry	973.5	1,459.0	1,632.3	1,566.9	806.9	1,048.6	1,353.0	1,358.7
B. Chemical industry	0.6	0.7	0.9	1.1	1.1	1.5	1.4	1.2
C. Metal industry	30.5	38.7	40.9	16.4	0.2	0.2	0.1	0.1
D. Non-energy products from fuels and solvent use	165.7	186.0	190.2	215.1	199.4	173.0	167.1	178.0
G. Other product manufacture and use	0.1	0.1	0.2	0.2	0.2	0.3	0.2	0.2
Total	1,170.2	1,684.6	1,864.5	1,799.6	1,007.8	1,223.5	1,521.8	1,538.3
CH_4 (kt CO_2e)								
D. Non-energy products from fuels and solvent use	0.3	0.4	0.4	0.6	0.5	0.5	0.5	0.5
G. Other product manufacture and use	2.4	2.4	3.3	3.5	2.3	3.5	1.7	2.7
Total	2.7	2.8	3.8	4.1	2.8	4.0	2.2	3.3
N_2O (kt CO_2e)								
B. Chemical industry	891.5	772.6	857.8	NO	NO	NO	NO	NO
D. Non-energy products from fuels and solvent use	0.0	0.1	0.1	0.2	0.2	0.2	0.1	0.1
G. Other product manufacture and use	15.7	17.7	17.8	16.7	16.4	17.3	17.6	18.7
Total	907.3	790.4	875.8	16.9	16.6	17.4	17.8	18.8
HFCs (kt CO_2e)								
E. Electronics industry	NO	NO	NO	NO	4.5	NO	NO	NO
F. Product uses as substitutes for ozone depleting substances	NO	237.6	728.4	870.4	802.1	450.2	317.3	275.2
Total	NO	237.6	728.4	870.4	806.6	450.2	317.3	275.2
PFCs (kt CO_2e)								
E. Electronics industry	NO	NO	NO	NO	6.7	NO	NO	NO
F. Product uses as substitutes for ozone depleting substances	NO	0.6	22.7	18.9	3.0	0.02	0.01	0.01
Total	NO	0.6	22.7	18.9	9.6	0.02	0.01	0.01
SF_6 (kt CO_2e)								
C. Metal industry	30.6	35.3	20.9	NO	NO	NO	NO	NO
G. Other product manufacture and use	13.2	71.7	37.6	21.3	38.1	125.1	46.9	15.0
Total	43.7	106.9	58.6	21.3	38.1	125.1	46.9	15.0

NO: Not occurring.

The emission of F-gases is documented in the annual report "Danish consumption and emission of F-gases" (Poulsen, 2023) and will only briefly be described in this report.

Other pollutants

Emission of air pollution occurs in many subsectors within the *Industrial processes and product use* sector. An emission overview of the emissions of main pollutants (SO_2, NO_x, NMVOC, CO and NH_3) and particles with an aerodynamic diameter of less than 2.5 µm ($PM_{2.5}$) is shown in Table 0.3 and Annex 0-2. Annex 0-2 also presents data for black carbon (BC).

Production of nitric acid ceased in Denmark in 2005, which caused a significant decrease in the emissions of NO_x and particulate matter from *Industrial processes and product use*. The CO emission has decreased significantly from the source *Other mineral products*, this is due to a decrease in emissions from the Danish producer of mineral wool caused by the establishment of abatement measures in 2009-2010. In the later years emissions of SO_2 have decreased due to lower production of bricks, tiles and expanded clay products (included in *Other mineral products* (NFR Code 2A6)).

Table 0.3 Emission of main pollutants and particulate matter from *Industrial processes and product use*.

Pollutant	Unit	Sector	1990	1995	2000	2005	2010	2015	2020	2021
SO_2	kt	2A6 Other mineral products	2.96	3.15	3.07	3.01	1.48	0.73	0.89	0.61
		2B10a Other chemical industry	1.07	1.01	0.62	0.62	0.12	0.16	0.15	0.29
		2C Metal industry (2C1+2C5)	0.04	0.05	0.04	0.02	0.004	0.005	0.001	0.001
		2G4 Other product use	0.03	0.04	0.06	0.06	0.04	0.06	0.03	0.05
		Total	4.10	4.24	3.79	3.71	1.63	0.96	1.07	0.95
NO_x	kt	2B Chemical industry (2B2+2B10a)	0.84	0.65	0.45	0.04	0.02	0.02	0.02	0.02
		2C1 Iron and steel production	0.08	0.09	0.08	0.03	NE	NE	NE	NE
		2G4 Other product use	0.05	0.05	0.06	0.06	0.04	0.06	0.03	0.05
		Total	0.96	0.79	0.59	0.13	0.06	0.09	0.05	0.07
NMVOC	kt	2A Mineral industry (2A3+2A6)	0.08	0.08	0.09	0.08	0.06	0.07	0.08	0.09
		2B10a Other chemical industry	0.47	0.15	0.09	0.04	0.03	0.05	0.02	0.02
		2C1 Iron and steel production	0.03	0.03	0.03	0.01	0.004	0.004	0.004	0.005
		2D3 Solvent use	38.50	46.11	41.64	32.18	26.70	27.77	30.64	30.70
		2G4 Other product use	0.08	0.08	0.09	0.09	0.07	0.08	0.05	0.07
		2H2 Food and beverages industry	3.31	3.36	3.08	3.07	2.78	2.49	2.27	2.22
		Total	42.47	49.81	45.02	35.48	29.65	30.45	33.06	33.09
CO	kt	2A Mineral industry (2A3+2A6)	11.15	8.86	11.45	11.89	0.01	0.02	0.01	0.01
		2C1 Iron and steel production	0.001	0.001	0.001	4E-04	NE	NE	NE	NE
		2D3b,c Use of asphalt products	0.31	0.38	0.35	0.47	0.36	0.41	0.46	0.43
		2G4 Other product use	2.29	2.39	3.59	4.03	2.53	4.05	1.89	3.23
		Total	13.74	11.63	15.40	16.39	2.91	4.48	2.36	3.67
NH_3	kt	2A Mineral industry	0.54	0.49	0.50	0.45	0.31	0.39	0.29	0.34
		2B Chemical industry	0.03	0.08	0.03	0.08	0.12	0.02	0.01	0.01
		2G4 Other product use	0.06	0.05	0.05	0.04	0.04	0.03	0.02	0.02
		2L Other production	0.04	0.05	0.05	0.05	0.04	0.03	0.03	0.03
		Total	0.67	0.67	0.62	0.62	0.51	0.47	0.36	0.41
$PM_{2.5}$	t	2A Mineral industry	0.53	0.51	0.54	0.57	0.45	0.32	0.37	0.34
		2B Chemical industry	0.39	0.34	0.38	0.017	0.020	0.004	0.003	0.004
		2C Metal industry	0.07	0.08	0.04	0.03	0.01	0.01	0.01	0.01
		2D3b,c Use of asphalt products	0.02	0.02	0.02	0.03	0.02	0.02	0.03	0.02
		2G4 Other product use	0.24	0.26	0.32	0.31	0.31	0.30	0.21	0.25
		2H2 Food and beverages industry	0.02	0.02	0.02	0.02	0.01	0.03	0.05	0.04
		2I Wood processing	0.07	0.09	0.10	0.07	0.09	0.09	0.09	0.08
		Total	1.34	1.33	1.42	1.04	0.92	0.78	0.75	0.75

NE: Not estimated.

The emissions of heavy metals (cadmium (Cd), mercury (Hg) and lead (Pb)) and persistent organic pollutants (dioxins/furans (PCDD/F)) are shown in Table 0.4 and Annex 0-3 (also includes As, Cr, Cu, Ni, Se, Zn, PAH, HCB and PCBs).

Table 0.4 Emissions of heavy metals and persistent organic pollutants from industrial processes and product use

Pollutant	Unit	Sector	1990	1995	2000	2005	2010	2015	2020	2021
Cd	t	2A3 Glass production	0.020	0.017	0.022	0.020	0.002	0.002	0.001	0.002
		2C1 Iron and steel production	0.049	0.032	0.027	0.018	0.009	0.010	0.009	0.011
		2C3 Aluminium production	0.001	0.001	0.001	0.001	NO	NO	NO	NO
		2C5 Lead production	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
		2C7c Other metal production	0.00	0.00	0.00	0.01	0.00	0.00	0.00	0.00
		2G4 Other product use	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
		Total	0.08	0.06	0.06	0.05	0.02	0.02	0.02	0.02
Hg	t	2B10a Other chemical industry	0.012	0.016	0.013	0.011	1E-03	1E-03	1E-04	1E-03
		2C1 Iron and steel production	0.250	0.147	0.067	0.017	0.003	0.004	0.003	0.004
		2C5 Lead production	4E-04	5E-04	4E-04	4E-04	4E-04	5E-04	2E-04	2E-04
		2G4 Other product use	6E-04	8E-04	1E-03	1E-03	6E-04	1E-03	5E-04	9E-04
		Total	0.26	0.16	0.08	0.03	0.01	0.01	0.004	0.006
Pb	t	2A3 Glass production	0.48	0.41	0.33	0.15	0.02	0.05	0.04	0.05
		2C1 Iron and steel production	3.28	2.02	0.99	0.59	0.26	0.29	0.25	0.32
		2C3 Aluminium production	0.005	0.005	0.005	0.004	NO	NO	NO	NO
		2C5 Lead production	1.45	1.45	1.45	1.45	1.45	1.45	1.45	1.45
		2C7c Other metal production	0.058	0.067	0.065	0.082	0.069	0.058	0.047	0.046
		2G4 Other product use	2.85	6.64	3.30	2.53	0.04	0.08	0.03	0.06
		Total	8.13	10.59	6.15	4.80	1.85	1.92	1.82	1.93
PCDD/F	g	2A2 Lime production	0.002	0.002	0.002	0.001	0.001	0.001	0.001	0.001
		2A6 Other mineral products	0.078	0.070	0.083	0.079	0.060	0.063	0.073	0.082
		2C1 Iron and steel production	12.00	7.50	0.52	0.75	NE	NE	NE	NE
		2C3 Aluminium production	1.06	1.06	1.15	0.82	NO	NO	NO	NO
		2C5 Lead production	0.003	0.003	0.003	0.003	0.003	0.003	0.002	0.002
		2G4 Other product use	0.077	0.084	0.142	0.159	0.084	0.173	0.070	0.136
		Total	13.22	8.72	1.90	1.81	0.15	0.24	0.15	0.22

NE: Not estimated.

NO: Not occurring.

The closure of the electro steelwork in 2002 with the brief reopening in 2005 as well as the closure of the secondary aluminium plant in 2008 has meant a decrease in emissions of several heavy metals (e.g. Pb, Zn) and POPs (e.g. PCDD/F). Legislation from 2000 and 2007 regulating and eventually forbidding Pb in fireworks has also reduced Pb emissions from *Other product use* substantially.

Sammendrag

Denne sektorrapport omhandler emissioner fra Industrielle Processer og Produktanvendelse (IPPU). Denne sektor dækker procesrelaterede emissioner hovedsageligt relateret til kalcinering, fordampning/lækager og diffust støv. Emissioner fra forbrænding er ikke inkluderet i denne rapport, da disse emissioner rapporteres under energisektoren. I nogle tilfælde kan det være vanskeligt at separere emissioner fra forbrænding og IPPU. I denne rapport er kun beskrevet de emissioner, der rapporteres i IPPU-sektoren, herunder anlæg hvor der er kontakt mellem brændsel og råmateriale under processen.

De danske emissionsopgørelser udarbejdes og afrapporteres årligt til De Forenede Nationers Klimakonvention (UNFCCC) og til Kyotoprotokollen, samt til FN's Økonomiske Kommission for Europas Konvention om Langtransporteret Grænseoverskridende Luftforurening (UNECE LRTAP-konventionen). Ydermere rapporteres de nationale opgørelser af drivhusgasemissioner til EU, da EU, såvel som de enkelte medlemslande, er parter til klimakonventionen samt Kyotoprotokollen. Emissionsopgørelser for luftforurening rapporteres også til Europakommissionens direktiv om nationale emissionslofter (NECD).

De årlige emissionsopgørelser udarbejdes af DCE – Nationalt Center for Miljø og Energi, Aarhus Universitet. Emissionsopgørelserne inkluderer følgende forureningskomponenter af relevans for *Industrielle processer og produkt anvendelse*: Drivhusgasser: Kuldioxid (CO_2), metan (CH_4), lattergas (N_2O), hydroflourkarboner (HFC), perflourkarboner (PFC'er), svovlhexafluorid (SF_6). Hovedgruppe af luftforurenende stoffer: Svovldioxid (SO_2), kvælstofoxider (NO_x), ammoniak (NH_3), andre flygtige organiske forbindelser end metan (NMVOC). Partikler (PM): Samlede suspenderede partikler (TSP), partikler med en aerodynamisk diameter på mindre end 10 µm (PM_{10}), partikler med en aerodynamisk diameter på mindre end 2,5 µm ($PM_{2.5}$), sort karbon (BC). Kulmonooxid (CO). Tungmetaller (HM'er): Arsenik (As), cadmium (Cd), krom (Cr), kopper (Cu), kviksølv (Hg), nikkel (Ni), bly (Pb), selen (Se), zink (Zn). Polycykliske aromatiske kulbrinter (PAH'er): Benzo(a)pyren, benzo(b)fluoranthen, benzo(k)fluoranthen, indeno(1,2,3-cd)pyren. Dioxiner og furaner (PCDD/F), hexachlorbenzen (HCB) og polychlorerede biphenyler (PCB'er).

Den ovenstående liste af stoffer svarer til de forpligtigelser Danmark skal efterleve i henhold til UNFCCC, UNECE og EU til hvilke emissionsopgørelserne rapporteres. Andre stoffer kan være relevante for de kildekategorier, som er inkluderet i denne rapport, men disse ligger uden for opgørelsens formål og er derfor ikke inkluderet.

Emissionsopgørelserne for *Industrielle Processer og Produktanvendelser* er i vid udstrækning baseret på officielle statistiske oplysninger (fra Danmarks Statistik) kombineret med emissionsfaktorer for forskellige sektorer, processer og teknologier. For nogle sektorer er de officielle statistiske oplysninger suppleret med information direkte fra virksomheder eller brancheorganisationer. Anlægsspecifikke emissioner for større industrielle kilder er indarbejdet i emissionsopgørelsen. Denne rapport beskriver detaljeret de metoder samt inputdata og emissionsfaktorer, der er anvendt i beregningen af emissioner fra *Industrielle Processer og Produktanvendelser*.

Emissionsfaktorerne er enten baseret på nationale undersøgelser og målinger (f.eks. kontakt til produktionsanlæggene), på henvisninger til internationale retningslinjer (f.eks. EMEP/EEA, 2019 og IPCC, 2006) eller fra videnskabelig litteratur. Hovedparten af de nationale emissionsfaktorer er baseret på forskningsrapporter eller beregninger baseret på et stort antal målinger på forskellige anlæg. De anlægsspecifikke emissionsfaktorer er tilvejebragt af anlægsejere, f.eks. i forbindelse med udarbejdelsen af grønne regnskaber eller i forbindelse med rapportering under EU's kvotehandelssystem (EU-ETS).

Drivhusgasser

En oversigt over relevante kilder er præsenteret i Tabel 0.1 sammen med en indikation af bidraget til den samlede drivhusgasemission fra *Industrielle processer og produktanvendelse* i 2021. Emissionerne er ekstraheret fra CRF tabellerne (Common Reporting Format).

Tabel 0.1 Oversigt over drivhusgas emissionskilder for *Industrielle processer og produktanvendelse* (2021).

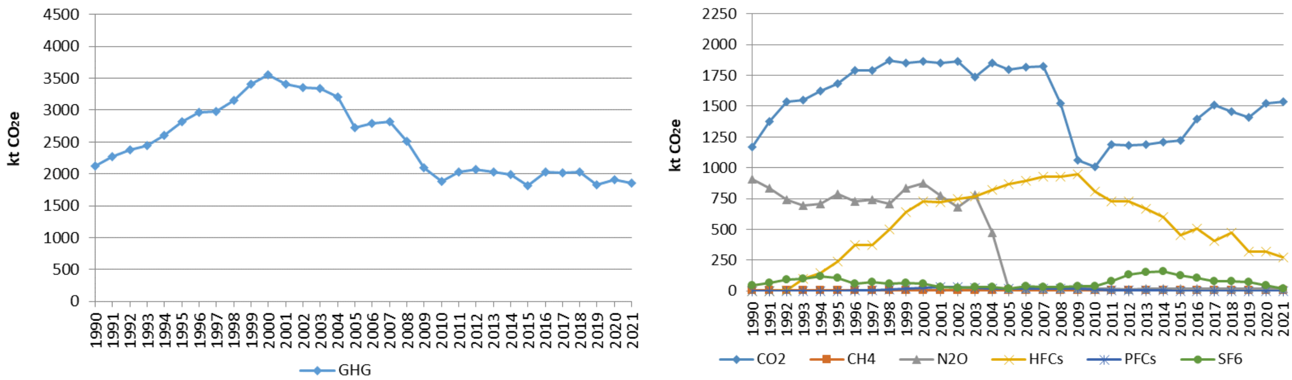
Proces	IPCC Code	Substans	Emission, kt CO_2e	%
Cementproduktion	2A1	CO_2	1,214.6	66
Køling og aircondition	2F1	HFC'er, PFC'er	264.4	14
Andre anvendelser for karbonater	2A4	CO_2	84.5	4.6
Andre ikke-energi produkter fra brændsler og opløsningsmidler	2D3	CO_2, CH_4	81.3	4.4
Paraffinvoks anvendelse	2D2	CO_2, CH_4, N_2O	65.7	3.6
Produktion af brændt kalk	2A2	CO_2	48.4	2.6
Brug af smøreolier	2D1	CO_2	31.7	1.7
N_2O fra andre produktanvendelser	2G3	N_2O	15.9	0.9
Elektrisk udstyr	2G1	SF_6	13.5	0.7
Glasproduktion	2A3	CO_2	11.2	0.6
Aerosoler / Dosisinhalatorer	2F4	HFC'er	10.1	0.5
Øvrige produktanvendelser	2G4	CO_2, CH_4, N_2O	5.7	0.3
SF_6 fra andre produktanvendelser	2G2	SF_6	1.5	0.1
Produktion af katalysatorer / gødning	2B10	CO_2	1.2	0.07
Opskumning	2F2	HFC'er	0.6	0.03
Blyproduktion	2C5	CO_2	0.1	0.004
Salpetersyreproduktion	2B2	N_2O	NO	NO
Jern- og stålproduktion	2C1	CO_2	NO	NO
Øvrige (fiberoptik)	2E5	PFC'er	NO	NO
Total			1,851	100

NO: Forekommer ikke.

Kilder markeret som "NO" i Tabel 0.1 er relevante for de danske emissionsopgørelser for historiske år, men ikke for år 2021. For kategori 2B2, er der drivhusgasemissionerne for årene 1990-2004, fra 2C1 er der emissioner i 1990-2001; 2005 og fra 2E5 i 2001; 2006-2014; 2017; 2019.

Samlet udgør undersektoren *Mineralsk industri* (2A) (cement, tegl, kalk, glas, mv.) 73 % af drivhusgasemissionen i 2021 fra *Industrielle processer og produktanvendelse*. *Produktanvendelser som erstatning for ozonlagsnedbrydende stoffer* (2F) udgør 15 %, *Ikke-energi produkter fra brændsler og opløsningsmidler* (2D) udgør 10 % og *Andre produkters produktion og anvendelse* (2G) udgør 2 %. De resterende to underkategorier (*Kemisk industri* (2B) og *Metal industri* (2C)) udgør hver under 0,1 % af den total drivhusgasemission fra *Industrielle processer og* *produktanvendelse* (IPPU) i 2021. Drivhusgasemission fra *Metal industri* har været lav i de seneste år, siden det eneste stålværk i Danmark ikke har været i drift siden 2005.

Den nationale drivhusgasemission (inkl. emissioner/optag fra arealanvendelse (LULUCF) og inkl. indirekte CO_2) i 2021 er beregnet til 46.026 kt CO_2 ækvivalenter, hvoraf IPPU bidrager med 1.851 kt CO_2e svarende til 4,0 %. Drivhusgasemissionen fra IPPU for 1990-2021 er præsenteret i figur 0.1.



Figur 0.1 Emission af drivhusgasser fra *Industrielle processer og produktanvendelser* (CRF Sektor 2) for 1990-2021.

CO_2-emissionerne fra IPPU-sektoren er domineret af mineralindustrier og især cementproduktion. Emissionerne steg i den tidlige del af tidsserien baseret på øget produktion af cement. Et betydeligt fald i emissionerne skete under den globale økonomiske recession i 2008-2010. Siden da er cementproduktionen igen steget, hvilket har medført øget CO_2-udledning. Udledningen af N_2O er faldet markant siden lukningen af det eneste salpetersyreanlæg i Danmark i 2004. HFC-emissioner skyldes primært brugen af kommerciel køling. Udviklingen i HFC-emissionen er derfor domineret af den øgede brug af HFC-125, HFC-134a og HFC-143a i kommercielle køleapparater op gennem 1990'erne og 2000'erne frem til 2009, hvor de regler, der er pålagt sektoren, begynder at vise deres effekt.

Nøglekategorierne for niveauet af emissioner i IPPU-sektoren i 2021 er Cementproduktion samt F-gasser anvendt til Køle- og klimaanlæg. Disse to kilder udgør henholdsvis 2,6 % og 0,6 % af den samlede nationale udledning af drivhusgasser (Nielsen et al., 2023a). For 1990, er nøglekategorierne for emissionsniveauer Cementproduktion og Salpetersyreproduktion – med henholdsvis 1,0 % og 1,2 % af den nationale GHG-emission. Nøglekategorierne efter trend er Cementproduktion (CO_2), Salpetersyreproduktion (N_2O), Køling og klimaanlæg (HFC, PFC) og Skumblæsemidler (HFC). Udviklingen i drivhusgasemissioner fra IPPU fordelt på hovedkategorier er præsenteret i tabel 0.2 nedenfor og i bilag 0-1. Udviklingen er nærmere beskrevet i de enkelte kapitler i rapporten.

Tabel 0.2 Drivhusgasemission fra *Industrielle processer og produktanvendelse* for 1990-2021.

Year	1990	1995	2000	2005	2010	2015	2020	2021
CO_2 (kt CO_2)								
A. Mineralsk industri	973,5	1459,0	1632,3	1566,9	806,9	1048,6	1353,0	1358,7
B. Kemisk industri	0,6	0,7	0,9	1,1	1,1	1,5	1,4	1,2
C. Metal industri	30,5	38,7	40,9	16,4	0,2	0,2	0,1	0,1
D. Ikke-energi produkter fra brændsler og opløsningsmidler	165,7	186,0	190,2	215,1	199,4	173,0	167,1	178,0
G. Øvrige produkters produktion og anvendelse	0,1	0,1	0,2	0,2	0,2	0,3	0,2	0,2
Total	1170,2	1684,6	1864,5	1799,6	1007,8	1223,5	1521,8	1538,3
CH_4 (kt CO_2e)								
D. Ikke-energi produkter fra brændsler og opløsningsmidler	0,3	0,4	0,4	0,6	0,5	0,5	0,5	0,5
G. Øvrige produkters produktion og anvendelse	2,4	2,4	3,3	3,5	2,3	3,5	1,7	2,7
Total	2,7	2,8	3,8	4,1	2,8	4,0	2,2	3,3
N_2O (kt CO_2e)								
B. Kemisk industri	891,5	772,6	857,8	NO	NO	NO	NO	NO
D. Ikke-energi produkter fra brændsler og opløsningsmidler	0,0	0,1	0,1	0,2	0,2	0,2	0,1	0,1
G. Øvrige produkters produktion og anvendelse	15,7	17,7	17,8	16,7	16,4	17,3	17,6	18,7
Total	907,3	790,4	875,8	16,9	16,6	17,4	17,8	18,8
HFC'er (kt CO_2e)								
E. Elektronik industri	NO	NO	NO	NO	4,5	NO	NO	NO
F. Produktanvendelse som erstatning for ozonnedbrydende stoffer	NO	237,6	728,4	870,4	802,1	450,2	317,3	275,2
Total	NO	237,6	728,4	870,4	806,6	450,2	317,3	275,2
PFC'er (kt CO_2e)								
E. Elektronik industri	NO	NO	NO	NO	6,7	NO	NO	NO
F. Produktanvendelse som erstatning for ozonnedbrydende stoffer	NO	0,6	22,7	18,9	3,0	0,02	0,01	0,01
Total	NO	0,6	22,7	18,9	9,6	0,02	0,01	0,01
SF_6 (kt CO_2e)								
C. Metal industri	30,6	35,3	20,9	NO	NO	NO	NO	NO
G. Øvrige produkters produktion og anvendelse	13,2	71,7	37,6	21,3	38,1	125,1	46,9	15,0
Total	43,7	106,9	58,6	21,3	38,1	125,1	46,9	15,0

NO: Forekommer ikke.

Emissionerne af F-gasser er dokumenteret i den årligt udgivne rapport "Danish consumption and emission of F-gases" (Poulsen, 2023) og vil kun kortfattet blive beskrevet i denne rapport.

Øvrige luftforurenende stoffer

Emissioner af luftforurening finder sted i mange forskellige underkategorier inden for *Industrielle Processer og Produktanvendelse*. Et overblik over emissionerne af hovedforureningskomponenterne (SO_2, NO_x, NMVOC og NH_3), CO og $PM_{2.5}$ (partikler med en diameter under 2.5 µm) er præsenteret i tabel 0.3 og bilag 0-2 (inkluderer også sort karbon (BC) og flere underopdelinger).

Produktionen af salpetersyre ophørte i Danmark i 2005, hvilket medførte et markant fald i udledningen af NO_x og partikler fra IPPU. CO-udledningen er faldet markant fra kategorien *Øvrige mineralske produkter*, dette skyldes et fald i udledningen fra den danske producent, som skyldes installationen af røggasrensningsudstyr 2009-2010. I de senere år er emissionerne af SO_2 faldet på grund af lavere produktion af mursten, fliser og ekspanderede lerprodukter (inkluderet i *Øvrige mineralske produkter* (NFR kode 2A6)).

Tabel 0.3 Emission af hovedforureningskomponenter og partikler fra *Industrielle processer og produktanvendelse*.

Stof	Enhed	Sektor	1990	1995	2000	2005	2010	2015	2020	2021
SO_2	kt	2A6 Øvrige mineralske produkter	2,96	3,15	3,07	3,01	1,48	0,73	0,89	0,61
		2B10a Anden kemisk industri	1,07	1,01	0,62	0,62	0,12	0,16	0,15	0,29
		2C Metal industri (2C1 + 2C5)	0,04	0,05	0,04	0,02	0,004	0,005	0,001	0,001
		2G4 Øvrige produktanvendelser	0,03	0,04	0,06	0,06	0,04	0,06	0,03	0,05
		Total	4,10	4,24	3,79	3,71	1,63	0,96	1,07	0,95
NO_x	kt	2B Kemisk industri (2B2 + 2B10a)	0,84	0,65	0,45	0,04	0,02	0,02	0,02	0,02
		2C1 Jern- og stål produktion	0,08	0,09	0,08	0,03	NE	NE	NE	NE
		2G4 Øvrige produktanvendelser	0,05	0,05	0,06	0,06	0,04	0,06	0,03	0,05
		Total	0,96	0,79	0,59	0,13	0,06	0,09	0,05	0,07
NMVOC	kt	2A Mineralsk industri (2A3 + 2A6)	0,08	0,08	0,09	0,08	0,06	0,07	0,08	0,09
		2B10a Anden kemisk industri	0,47	0,15	0,09	0,04	0,03	0,05	0,02	0,02
		2C1 Jern- og stålproduktion	0,03	0,03	0,03	0,01	0,004	0,004	0,004	0,005
		2D3 Anvendelse af opløsningsmidler	38,50	46,11	41,64	32,18	26,70	27,77	30,64	30,70
		2G4 Øvrige produktanvendelser	0,08	0,08	0,09	0,09	0,07	0,08	0,05	0,07
		2H2 Fødevareproduktion	3,31	3,36	3,08	3,07	2,78	2,49	2,27	2,22
		Total	42,47	49,81	45,02	35,48	29,65	30,45	33,06	33,09
CO	kt	2A Mineralsk industri (2A3 + 2A6)	11,15	8,86	11,45	11,89	0,01	0,02	0,01	0,01
		2C1 Jern- og stålproduktion	0,001	0,001	0,001	4E-04	NE	NE	NE	NE
		2D3b,c Anvendelse af asfaltprodukter	0,31	0,38	0,35	0,47	0,36	0,41	0,46	0,43
		2G4 Øvrige produktanvendelser	2,29	2,39	3,59	4,03	2,53	4,05	1,89	3,23
		Total	13,74	11,63	15,40	16,39	2,91	4,48	2,36	3,67
NH_3	kt	2A Mineralsk industri	0,54	0,49	0,50	0,45	0,31	0,39	0,29	0,34
		2B Kemisk industri	0,03	0,08	0,03	0,08	0,12	0,02	0,01	0,01
		2G4 Øvrige produktanvendelser	0,06	0,05	0,05	0,04	0,04	0,03	0,02	0,02
		2L Øvrig produktion	0,04	0,05	0,05	0,05	0,04	0,03	0,03	0,03
		Total	0,67	0,67	0,62	0,62	0,51	0,47	0,36	0,41
$PM_{2.5}$	t	2A Mineralsk industri (2A3 + 2A6)	0,53	0,51	0,54	0,57	0,45	0,32	0,37	0,34
		2B Kemisk industri (2B2 + 2B10a)	0,39	0,34	0,38	0,017	0,020	0,004	0,003	0,004
		2C Metal industri (2C1 + 2C3 + 2C5)	0,07	0,08	0,04	0,03	0,01	0,01	0,01	0,01
		2D3b,c Anvendelse af asfaltprodukter	0,02	0,02	0,02	0,03	0,02	0,02	0,03	0,02
		2G4 Øvrige produktanvendelser	0,24	0,26	0,32	0,31	0,31	0,30	0,21	0,25
		2H2 Fødevareproduktion	0,02	0,02	0,02	0,02	0,01	0,03	0,05	0,04
		2I Forarbejdning af træ	0,07	0,09	0,10	0,07	0,09	0,09	0,09	0,08
		Total	1,34	1,33	1,42	1,04	0,92	0,78	0,75	0,75

NE: Ikke estimeret.

Emissioner af tungmetaller (kadmium (Cd), kviksølv (Hg) og bly (Pb)) og persistente organiske forbindelsers (dioxiner/furaner (PCDD/F)) er præsenteret i tabel 0.4 og bilag 0-3 (inkluderer også As, Cr, Cu, Ni, Se, Zn, PAH'er, HCB og PCB'er).

Tabel 0.4 Emission af tungmetaller og persistente organiske forbindelser fra *Industrielle processer og produktanvendelse.*

Stof		Sektor	1990	1995	2000	2005	2010	2015	2020	2021
Cd	t	2A3 Glasproduktion	0,020	0,017	0,022	0,020	0,002	0,002	0,001	0,002
		2C1 Jern- og stålproduktion	0,049	0,032	0,027	0,018	0,009	0,010	0,009	0,011
		2C3 Aluminiumproduktion	0,001	0,001	0,001	0,001	NO	NO	NO	NO
		2C5 Blyproduktion	0,004	0,004	0,004	0,004	0,004	0,004	0,004	0,004
		2C7c Anden metalproduktion	0,004	0,004	0,004	0,005	0,005	0,004	0,003	0,003
		2G4 Øvrige produktanvendelser	0,001	0,002	0,004	0,003	0,004	0,005	0,003	0,004
		Total	0,08	0,06	0,06	0,05	0,02	0,02	0,02	0,02
Hg	t	2B10a Anden kemisk industri	0,012	0,016	0,013	0,011	0,001	0,001	0,0001	0,0011
		2C1 Jern- og stålproduktion	0,250	0,147	0,067	0,017	0,003	0,004	0,003	0,004
		2C5 Blyproduktion	4E-04	5E-04	4E-04	4E-04	4E-04	5E-04	2E-04	2E-04
		2G4 Øvrige produktanvendelser	6E-04	8E-04	1E-03	1E-03	6E-04	1E-03	5E-04	9E-04
		Total	0,26	0,16	0,08	0,03	0,01	0,01	0,004	0,006
Pb	t	2A3 Glasproduktion	0,48	0,41	0,33	0,15	0,02	0,05	0,04	0,05
		2C1 Jern- og stålproduktion	3,28	2,02	0,99	0,59	0,26	0,29	0,25	0,32
		2C3 Aluminiumproduktion	0,005	0,005	0,005	0,004	NO	NO	NO	NO
		2C5 Blyproduktion	1,45	1,45	1,45	1,45	1,45	1,45	1,45	1,45
		2C7c Anden metalproduktion	0,06	0,07	0,06	0,08	0,07	0,06	0,05	0,05
		2G4 Øvrige produktanvendelser	2,85	6,64	3,30	2,53	0,04	0,08	0,03	0,06
		Total	8,13	10,59	6,15	4,80	1,85	1,92	1,82	1,93
PCDD/F	g	2A2 Produktion af brændt kalk	0,002	0,002	0,002	0,001	0,001	0,001	0,001	0,001
		2A6 Øvrige mineralske produkter	0,08	0,07	0,08	0,08	0,06	0,06	0,07	0,08
		2C1 Jern- og stålproduktion	12,00	7,50	0,52	0,75	NE	NE	NE	NE
		2C3 Aluminiumproduktion	1,06	1,06	1,15	0,82	NO	NO	NO	NO
		2C5 Blyproduktion	0,003	0,003	0,003	0,003	0,003	0,003	0,002	0,002
		2D3h Paraffinvoksforbrug	0,077	0,084	0,142	0,159	0,084	0,173	0,070	0,136
		2G4 Øvrige produktanvendelser	13,22	8,72	1,90	1,81	0,15	0,24	0,15	0,22
		Total	0,002	0,002	0,002	0,001	0,001	0,001	0,001	0,001

NE: Ikke estimeret.

NO: Forekommer ikke.

Lukningen af Stålvalseværket i 2002 med en kort genåbning i 2005, samt lukningen af sekundær aluminiumsproduktion i 2008, har betydet et fald i emissionerne af flere tungmetaller (f.eks. Pb, Zn) og persistente organiske forbindelser (f.eks. PCDD/F). Lovgivning fra 2000 og 2007 der først begrænsede og sidenhen forbød anvendelsen af bly i fyrværkeri, har ligeledes reduceret bly emissionerne fra *Øvrige produktanvendelser*.

1 Introduction

Industrial processes and product use (IPPU) is one of the five main sectors included in emission inventories based on international agreements. The other four sectors are *Energy*, *Agriculture*, *Land-use, land-use change and forestry* (LULUCF) and *Waste*.

This sector report covers emissions from Industrial Processes and Product Use (IPPU). This sector covers process related emissions mostly related to calcination, evaporation/leaks and fugitive dust. Emissions from combustion are not included in this report, since these emissions are considered under the energy sector in Nielsen (2021). In some cases, it can be difficult to split emissions between combustion and IPPU. In this report, only emissions reported in the IPPU sector are included and described, including emissions from plants where there is contact between fuel and raw material during the process.

Danish emission inventories are prepared on an annual basis and are reported to the United Nations Framework Convention on Climate Change (UNFCCC or Climate Convention) and to the Kyoto Protocol as well as to the United Nations Economic Commission for Europe (UNECE) Convention on Long-Range Transboundary Air Pollution (LRTAP Convention).

The annual Danish emission inventories are prepared by the DCE – Danish Centre for Environment and Energy, Aarhus University. The inventories include the following pollutants relevant to Industrial Processes and Product Use: Greenhouse gases: carbon dioxide (CO_2), methane (CH_4), nitrous oxide (N_2O), hydroflourocarbons (HFCs), perflourocarbons (PFCs), sulphur hexafluoride (SF_6). Main air pollutants: sulphur dioxide (SO_2), nitrogen oxides (NO_x), ammonia (NH_3), non-volatile organic compounds (NMVOC). Particulate matter (PM): Total suspended particulates (TSP), particles with an aerodynamic diameter less than 10 µm (PM_{10}), particles with an aerodynamic diameter less than 2.5 µm ($PM_{2.5}$), black carbon (BC). Carbon monoxide (CO). Heavy metals (HMs): Arsenic (As), cadmium (Cd), chromium (Cr), copper (Cu), mercury (Hg), nickel (Ni), lead (Pb), selenium (Se), zinc (Zn). Polycyclic aromatic hydrocarbons (PAHs): benzo(a)pyrene, benzo(b)fluoranthene, benzo(k)fluoranthene, indeno(1,2,3-cd)pyrene. Polyclorinated dibenzodioxins and –furans (PCDD/F), hexachlorobenzene (HCB) and polychlorinated biphenyls (PCBs).

The pollutants listed above correspond to the requirements of the UNFCCC, UNECE and EU to whom the emission inventories are reported. Other pollutants could be relevant for the source categories included in this report, but these fall outside the scope of the emission inventories and are therefore not included.

The aim of this report is to:

- Document the methodologies used for estimating emissions from Industrial Processes and Product Use
- Identify possible improvements of the current inventory related to completeness, consistency and accuracy including identifying industrial and product use sources not included in the present emission inventory

The present emission inventory includes a number of industrial and product use sources; however, the systematic effort to identify sources of emissions is ongoing. The coverage of sources presented in the EMEP/EEA air pollutant emission inventory guidebook (hereafter the EMEP/EEA guidebook) as well as the IPCC guidelines has been analysed with the purpose of identifying new sources. The industrial and product use sources are included either as area sources or as point sources. Point sources are defined as plants that are treated individually in the inventory, e.g. cement production and iron/steel production. Area sources are for categories where there are too many plants or not enough information for a plant specific approach, e.g. bakeries.

The base year for emission inventories and reduction targets depends on the pollutant and protocol covering the pollutant; see Table 1.0.1. Any incomplete time series have as far as possible been completed through collection of the missing data or by using appropriate techniques for ensuring time series consistency in accordance with the principles included in the 2006 IPCC Guidelines and the 2019 EMEP/EEA Guidebook for the years in question.

Table 1.0.1 Base year for different pollutants.

Pollutant		Base year
Sulphur dioxide	SO_2	1980
Ammonia	NH_3	1985
Nitrogen oxides	NO_x	
Non-Methane Volatile Organic Compounds	NMVOC	
Carbon dioxide	CO_2	1990
Methane	CH_4	
Nitrous oxide	N_2O	
Heavy metals	Arsenic (As)	
	Cadmium (Cd)	
	Chromium (Cr)	
	Copper (Cu)	
	Mercury (Hg)	
	Nickel (Ni)	
	Lead (Pb)	
	Selenium (Se)	
	Zinc (Zn)	
Persistent organic pollutants (POPs)	Polychlorinated dibenzo dioxins and furans (PCDD/F)	
	Hexachlorobenzene (HCB)	
	Polychlorinated biphenyls (PCBs)	
	Benzo(a)pyrene	
	Benzo(b)fluoranthene	
	Benzon(k)fluoranthene	
	Indeno(1,2,3-cd)pyrene	
Particulate matter (PM)	Total suspended particulates (TSP)	
	PM_{10}	
	$PM_{2.5}$	
	Black carbon (BC)	
F-gases	HFCs	1995[1]
	PFCs	
	SF_6	
	NF_3	

[1] Base year under the Kyoto Protocol. For the UNFCCC, the base year is 1990.

The outline of the report follows the subdivision in sectors as applied in the IPPC guidelines for Industrial Processes and Product Use supplemented with industrial sectors of specific relevance for air pollutants in accordance with the EMEP/EEA Guidebook. The main sectors included in this report are:

- Mineral industry
- Chemical industry
- Metal industry
- Non-energy products from fuels and solvent use
- Electronics industry
- Product uses as substitutes for ozone depleting substances (ODS)
- Other product manufacture and use
- Other production
- Wood processing

The consumption of halocarbons and SF_6 (F-gases) is documented in a separate report (Poulsen, 2023) and is therefore only presented and briefly discussed in this report.

Emissions in this report relate to Denmark only and does not include Greenland or the Faroe Islands.

Table 1.0.2 presents an overview of sources and groups of pollutants included in the present reporting. Explanations to the abbreviations are given below the table. In addition to the indicated groups of pollutants some groups do not include all relevant pollutants. For some processes, it is not possible to separate emissions from the fuels and the emissions stemming from the raw materials. This is especially the case for processes with contact, e.g. cement and lime production. Detailed information on this subject can be found in the following table.

Table 1.0.2 Overview of IPPU sector and pollutants included in the Danish inventory.

Industrial sector	CO_2/CH_4 $/N_2O$	F-gas	$SO_2/NO_X/$ NH_3	NMVOC/ CO	PMs	HMs	POPs
Cement production	x	-	IE	IE	IE	IE	IE
Lime production	x	-	IE	IE	x	-	x
Glass production	x	-	x	x	x	x	-
Ceramics	x	-	x	-	-	-	x
Other uses of soda ash	x	-	-	-	-	-	-
Flue gas desulphurisation	x	-	-	-	-	-	-
Stone wool production	x	-	x	x	x	x	x
Quarrying and mining of minerals other than coal	-	-	-	-	x	-	-
Construction and demolition	-	-	-	-	x	-	-
Storage, handling and transport of mineral products	-	-	-	-	x	-	-
Nitric and sulphuric acid production	x	-	x	-	x	-	-
Catalyst production	x	-	x	-	x	-	-
Production of chemical ingredients	-	-	-	x	-	-	-
Pesticide production	-	-	x	x	-	-	-
Production of tar products	-	-	x	x	-	x	x
Iron and steel production	x	-	x	x	x	x	x
Allied metal manufacturing	-	-	IE	IE	-	x	NE
Magnesium production	-	x	-	-	-	-	-
Secondary aluminium production	-	-	IE	IE	x	x	x
Secondary lead production	x	-	x	IE	x	x	x
Lubricant use	x	-	-	-	-	-	-
Paraffin wax use	x	-	-	x	x	-	x
Solvent use	x	-	-	x	-	-	NE
Road paving with asphalt	x	-	-	x	x	-	NE
Asphalt roofing	x	-	-	x	x	-	NE
Urea-based catalysts	x	-	-	-	-	-	-
Other electronics industry	-	x	-	-	-	-	-
Refrigeration and air conditioning	-	x	-	-	-	-	-
Foam blowing agents	-	x	-	-	-	-	-
Aerosols	-	x	-	-	-	-	-
Solvents	-	x	-	-	-	-	-
Electrical equipment	-	x	-	-	-	-	-
SF_6 and PFCs from other product use	-	x	-	-	-	-	-
Medical application	x	-	-	-	-	-	-
Propellant for pressure and aerosol products	x	-	-	-	-	-	-
Other product use	x	-	x	x	x	x	x
Food and beverages industry	-	-	-	x	x	-	-
Wood processing	-	-	-	-	x	-	-
Treatment of slaughterhouse waste	-	-	x	-	-	-	-

X: Included in the present inventory.
-: Not occurring/not applicable.
NE: Not estimated.
IE: Included elsewhere; i.e. in the energy sector.

An overview of the most significant greenhouse gas sources in 2021 is presented in Table 1.0.3; these five source categories comprise more than 90 % of emissions in CO_2 equivalents (CO_2e) from IPPU. The table below also gives an indication of the contribution to the total emission of greenhouse gases in 2021 in the IPPU sector.

Table 1.0.3 Overview of the largest sources to greenhouse gas emissions in the IPPU sector in 2021.

Process	IPCC Code	Substance	Emission kt CO_2e	%*
Cement production	2A1	CO_2	1215	65.6
Refrigeration and air conditioning	2F1	HFCs, PFCs	264	14.3
Other process uses of carbonates[2]	2A4	CO_2	85	4.6
Other[1]	2D3	CO_2, CH_4	81	4.4
Paraffin wax use	2D2	CO_2, CH_4, N_2O	66	3.6
Total of five largest sources			1711	92.4

*of total CO_2 equivalent emissions from the IPPU sector.
[1] 2D3 consists of solvent use, road paving with asphalt, asphalt roofing and urea use in vehicle catalysts. [2] 2A4 consists of ceramics production, other uses of soda ash, flue gas desulphurisation and stone wool production.

For 2021, the subsector Mineral Industry (2A) constitutes 73 % of the GHG emissions from the IPPU sector and Product Uses as Substitutes for ODS (2F) constitutes 15 %. Non-Energy Products from Fuels and Solvent Use (2D) and Other Product Manufacture and Use (2G) constitutes 10 and 2 %, respectively, while Chemical Industry (2B) and Metal production (2C) together constitutes below 0.1 %. The total emission of greenhouse gases (incl. LULUCF and incl. indirect CO_2) in Denmark in 2021 is estimated to 46.0 Mt CO_2 equivalents of which IPPU contribute with 1.9 Mt CO_2 equivalents (4.0 %). The emissions of greenhouse gases from IPPU from 1990-2021 are presented in Figure 1.0.1.

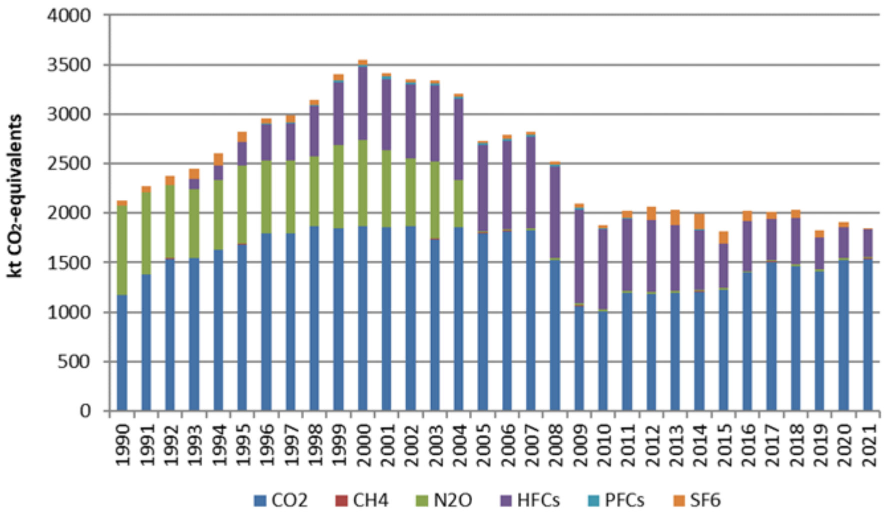


Figure 1.0.1 Emission of individual- and total greenhouse gases from IPPU (CRF Sector 2) from 1990-2021.

The majority of CO_2 emissions in the IPPU sector are emitted from the cement production, the small drop in CO_2 emissions in 2003 and the larger decrease in 2008-2010 are caused by a lower production of cement for these years caused by the global financial crisis that resulted in significant less construction activity. The production of nitric acid closed down during 2004 causing the N_2O emission to drop drastically from 680-907 kt CO_2 equivalents in 1990-2003 to 14-20 kt CO_2 equivalents in 2005-2021. The use of HFCs in mainly refrigeration and air conditioning has increased significantly during the time series but is decreasing in recent years. The decreasing trend is the result of political focus and means of action like taxes and bans on high GWP F-gasses. HFC emissions peaked in 2009 with 951 kt CO_2 equivalents, but has decreased to 275 kt CO_2 equivalents in 2021. The SF_6 emission in the 1990s is mainly caused by magnesium production (ceased in 2000) and manufacturing of soundproof windows (ceased in 2001). Because these two major contributions end around 2000, the SF_6 emission in the 2000s is low. The stock of soundproof windows are modelled to be disposed of in the years 2011-2021, and the SF_6 emission is therefore higher in these years also.

Table 1.0.4 presents an overview of the most significant source categories for air pollutants in 1990 and 2021. Many changes have occurred over the time series; some plants have closed and others have opened, Table 1.0.4 is therefore only representable for the years 1990 and 2021.

Table 1.0.4 Overview of 1990 and 2021 emissions from Industrial processes and product use (IPPU).

	Total emission from IPPU		Fraction of national total, %	Largest contributor in IPPU	Emission from largest contributor		Fraction of IPPU, %
1990							
SO_2	4.10	kt	2.3	2A6 Other mineral products	2.96	kt	72.1
NO_x	0.96	kt	0.3	2B2 Nitric acid production	0.81	kt	84.0
NMVOC	42.47	kt	20.0	2D3i Other solvent use	21.08	kt	49.6
CO	13.74	kt	1.9	2A6 Other mineral products	11.15	kt	81.1
NH_3	0.67	kt	0.5	2A6 Other mineral products	0.27	kt	41.1
TSP	10.73	kt	9.8	2A5b Construction and demolition	7.92	kt	73.8
HMs	23.73	t	8.1	Zn from 2C1 Iron and steel production	12.02	t	50.6
POPs	0.35	t	2.8	PAHs from 2C1 Iron and steel production	0.29	t	83.6
2021							
SO_2	0.95	kt	11.1	2A6 Other mineral products	0.61	kt	63.9
NO_x	0.07	kt	0.1	2G Other product use	0.05	kt	70.0
NMVOC	33.09	kt	31.0	2D3i Other solvent use	17.76	kt	53.7
CO	3.67	kt	1.9	2G Other product use	3.23	kt	87.8
NH_3	0.41	kt	0.6	2A6 Other mineral products	0.27	kt	66.2
TSP	7.11	kt	8.4	2A5b Construction and demolition	4.43	kt	62.3
HMs	7.14	t	4.8	Cu from 2G Other product use	2.22	t	31.1
POPs	0.09	t	2.1	PAHs from 2G Other product use	0.09	t	99.7

All annexes referenced in this report are available only online, please see https://envs.au.dk/en/research-areas/air-pollution-emissions-and-effects/air-emissions/reporting-sectors/industrial-processes (Bottom).

2 Methodology and data sources

The methodologies applied for the inventory of process and product use related emissions are those contained in the technical guidance documents mandated for use for air pollutants and greenhouse gases, i.e.:

- EMEP/EEA Guidebook (EMEP/EEA, 2019)
- IPCC guidelines (IPCC, 2006 and 2014)

The main data sources applied in the inventory are:

- National statistics
- Company environmental reports/Reports to Electronic Pollutant Release and Transfer Registry (E-PRTR)
- Company reports to the European Union Emission Trading Scheme (EU-ETS)
- EMEP/EEA guidebook
- IPCC guidelines
- The Coordinated European Programme on Particulate Matter Emission Inventories, Projections and Guidance (CEPMEIP)

When considered relevant, emission factors based on information on industrial sector level will be developed. The different data sources are presented below.

2.1 Company environmental reports

By law, some companies are obligated to report environmental information to the Danish Environmental Protection Agency (DEPA) (DEPA, 2021). The Statutory order specifies the branches of industries that are obligated to report environmental information as well as the contents of the reporting. The reports are made public annually at a website hosted by the DEPA[1].

When plants measure and report emissions of pollutants this information is generally used in the inventory after an assessment of the quality by comparing the emission level to that of previous years as well as comparing an implied emission factor with that of similar plants. Any value that is outside an acceptable range is investigated further and if needed the plant is contacted to get the value verified. If such verification cannot be provided, then the value is not used in the emission inventory.

In general, most information is available regarding emissions of NO_x, SO_2 and TSP. For other pollutants, the information is scarcer.

2.2 EMEP/EEA guidebook

The EMEP/EEA guidebook (EEA, 2019) provides methodologies for estimation of emissions of the following groups of substances:

- Main pollutants: NH_3, NMVOC, NO_x, SO_2 and additionally CO
- Particulate matter: TSP, PM_{10}, $PM_{2.5}$, BC

[1] https://miljoeoplysninger.dk/ (PRTR).

- Heavy metals: As, Cd, Cr, Cu, Hg, Ni, Pb, Se, Zn
- Persistent organic pollutants: PCDD/F, HCB, PCBs, benzo(a)pyrene, benzo(b)fluoranthene, benzo(k)fluoranthene, indeno(1,2,3-cd)pyrene

The following editions of the guidebook have been used for the present inventory:

- EMEP/EEA air pollutant emission inventory guidebook 2019 (EMEP/EEA, 2019)

2.3 IPCC guidelines

The IPCC guidelines provide methodologies for estimating emissions of greenhouse gases, i.e.:

- CO_2
- CH_4
- N_2O
- F-gases (HFCs, PFCs, SF_6 and NF_3)

The following editions of the IPCC guidelines have been used for the present inventory:

- 2006 IPCC guidelines for national greenhouse gas inventories (IPCC, 2006), hereafter the 2006 IPCC guidelines
- Revised Supplementary Methods and Good Practice Guidance Arising from the Kyoto Protocol (IPCC, 2014)

2.4 EU-ETS (European Union - Emission Trading Scheme)

A number of Danish companies are covered by the EU-ETS and are as a consequence hereof obligated to report their emission of CO_2 annually. The emissions of CO_2 reported to EU-ETS are a subset of the national emission of CO_2 and therefore this reporting can be used to improve the national inventory and to ensure consistency between EU-ETS and the national inventory.

Guidelines for calculating company specific CO_2 emissions are developed by the EU (EU Commission, 2022). The guidelines present standard methods for plants with small emissions and requirements for developing individual plans for plants with large emissions. The standard methods include default emission factors similar to the default emission factors presented by the IPCC (e.g. for limestone), whereas the major emitters have to use individual methods to determine the actual composition of raw materials (e.g. purity of limestone or Ca content in dolomite) or the actual CO_2 emission from the specific process.

2.4.1 Description of EU-ETS in the Danish context

About 360 Danish stationary plants are included in the EU-ETS. These plants are within the transformation sector, offshore installations or manufacturing industries. Few of the processes that are included under the EU-ETS are occurring in Denmark and only CO_2 is reported from Danish plants since the potential sources of PFCs (primary aluminium production) and N_2O (production of nitric acid, adipic acid, glyoxal and glyoxylic acid) are not occurring in

Denmark. A list of the processes covered by the EU-ETS with an indication of the processes that occur in Denmark is included in Chapter 2.4.2.

2.4.2 Processes covered

The EU-ETS covers a wide range of processes. The full list of activities that could be relevant in terms of industrial processes (IP) is included in Table 2.4.1 below. Indicated in the table are the activities that are relevant in Denmark.

Table 2.4.1 List of activities included in the European Union Emission Trading Scheme (Directive, 2009a).

Activities	Greenhouse gases	Relevant in Denmark
Combustion of fuels in installations with a total rated thermal input exceeding 20 MW (except in installations for the incineration of hazardous or municipal waste)	CO_2	X
Refining of mineral oil	CO_2	X
Production of coke	CO_2	
Metal ore (including sulphide ore) roasting or sintering, including pelletisation	CO_2	
Production of pig iron or steel (primary or secondary fusion) including continuous casting, with a capacity exceeding 2.5 tonnes per hour	CO_2	
Production or processing of ferrous metals (including ferro-alloys) where combustion units with a total rated thermal input exceeding 20 MW are operated. Processing includes, inter alia, rolling mills, re-heaters, annealing furnaces, smitheries, foundries, coating and pickling	CO_2	
Production of primary aluminium	CO_2, PFCs	
Production of secondary aluminium where combustion units with a total rated thermal input exceeding 20 MW are operated	CO_2	
Production or processing of non-ferrous metals, including production of alloys, refining, foundry casting, etc., where combustion units with a total rated thermal input (including fuels used as reducing agents) exceeding 20 MW are operated	CO_2	
Production of cement clinker in rotary kilns with a production capacity exceeding 500 tonnes per day or in other furnaces with a production capacity exceeding 50 tonnes per day	CO_2	X
Production of lime or calcination of dolomite or magnesite in rotary kilns or in other furnaces with a production capacity exceeding 50 tonnes per day	CO_2	X
Manufacture of glass including glass fibre with a melting capacity exceeding 20 tonnes per day	CO_2	X
Manufacture of ceramic products by firing, in particular roofing tiles, bricks, refractory bricks, tiles, stoneware or porcelain, with a production capacity exceeding 75 tonnes per day	CO_2	X
Manufacture of mineral wool insulation material using glass, rock or slag with a melting capacity exceeding 20 tonnes per day	CO_2	X
Drying or calcination of gypsum or production of plaster boards and other gypsum products, where combustion units with a total rated thermal input exceeding 20 MW are operated	CO_2	
Production of pulp from timber or other fibrous materials	CO_2	
Production of paper or cardboard with a production capacity exceeding 20 tonnes per day	CO_2	X
Production of carbon black involving the carbonisation of organic substances such as oils, tars, cracker and distillation residues, where combustion units with a total rated thermal input exceeding 20 MW are operated	CO_2	
Production of nitric acid	CO_2, N_2O	
Production of adipic acid	CO_2, N_2O	
Production of glyoxal and glyoxylic acid	CO_2, N_2O	
Production of ammonia	CO_2	
Production of bulk organic chemicals by cracking, reforming, partial or full oxidation or by similar processes, with a production capacity exceeding 100 tonnes per day	CO_2	
Production of hydrogen (H_2) and synthesis gas by reforming or partial oxidation with a production capacity exceeding 25 tonnes per day	CO_2	
Production of soda ash (Na_2CO_3) and sodium bicarbonate ($NaHCO_3$)	CO_2	
Capture of greenhouse gases from installations covered by this Directive for the purpose of transport and geological storage in a storage site permitted under Directive (2009b)	CO_2	
Transport of greenhouse gases by pipelines for geological storage in a storage site permitted under Directive (2009b)	CO_2	
Geological storage of greenhouse gases in a storage site permitted under Directive (2009b)	CO_2	

2.4.3 Survey of companies included

The number of plants included in the EU-ETS in Denmark varies across the years as some new plants have been founded, while others have been closed and/or reopened. The largest structural change is the inclusion of waste incineration in the EU-ETS from 2013. This caused an increase in the number of plants covered by the EU-ETS. The reports for the waste incineration plants have been surveyed and the CO_2 emissions from the use of limestone for flue gas desulphurisation in waste incineration plants are now calculated based on EU-ETS data. All other emissions related to waste incineration are included as combustion emissions and are not addressed in this report.

The plants included in Table 2.4.2 have reported process emissions under the EU-ETS and have been included in the inventory. In the column "plant type" the activity relevant for process emissions has been listed. Some plants are included due to exceeding the threshold for combustion installations, but nevertheless they have process emissions related to e.g. *Mineral wool production* or *Flue gas cleaning*. For combustion installations, the process emission refers to the CO_2 emission associated with limestone used for flue gas desulphurisation/purification of sugar.

Table 2.4.2 List of plants included in the European Union Emission Trading Scheme with process emissions in 2021.

Plant	Plant type
Aalborg Portland A/S	Production of cement clinker
Sønderborg Kraftvarme I/S	Combustion installation
Nordjyllandsværket	Combustion installation
Nordic Sugar, Nakskov Sukkerfabrik	Combustion installation
I/S Reno Syd	Combustion installation
Esbjergværket	Combustion installation
Carl Matzens Teglværk A/S	Manufacture of ceramic products
Imerys Fur A/S	Manufacture of ceramic products
Imerys Mors A/S	Manufacture of ceramic products
LECA Danmark	Manufacture of ceramic products
Faxe Kalk, Ovnanlægget Stubberup	Production of lime
Gråsten Teglværk	Manufacture of ceramic products
Helligsø Teglværk A/S	Manufacture of ceramic products
Højslev Tegl A/S	Manufacture of ceramic products
Monier A/S	Manufacture of ceramic products
Pedershvile Teglværk	Manufacture of ceramic products
Petersen Tegl A/S	Manufacture of ceramic products
Wienerberger A/S - Petersminde Teglværk	Manufacture of ceramic products
Gandrup Teglværk	Manufacture of ceramic products
Hammershøj Teglværk	Manufacture of ceramic products
Ardagh Glass Holmegaard A/S	Manufacture of glass including glass fibre
Rockwool A/S, Doense	Manufacture of stone wool
Rockwool A/S, Vamdrup	Manufacture of stone wool
Saint Gobain Isover A/S	Manufacture of glass including glass fibre
Strøjer Tegl A/S	Manufacture of ceramic products
Vesterled Teglværk A/S	Manufacture of ceramic products
Vindø Teglværk	Manufacture of ceramic products

2.4.4 Procedure for inclusion of data

The EU-ETS started in 2005 and have had three phases: 2005-2007, 2008-2012 and 2013-2022. The quality of the reported data increased significantly during the first few years and now the data quality in general is excellent.

The information included in the plant reports under the EU-ETS have been used in the inventory for all years, where the data are available.

In preparation for the EU-ETS, there was a data collection to assess the allocation of emission allowances to the different plants. Therefore, there are data available for some earlier years. These data have also been used in the inventory.

However, since the base year for CO_2 is 1990 there is a challenge in ensuring time series consistency. For some sectors, the time series are very consistent as it has been possible to match the different methodologies. For some sectors, e.g. *Flue gas desulphurisation*, the time series consistency is more uncertain and emission data have been estimated and validated as best possible, for more information please refer to the individual source category chapters.

2.5 CEPMEIP database

The Co-ordinated European Programme on Particulate Matter Emission Inventories, Projections and Guidance (CEPMEIP) was part of the activities aimed at supporting national experts in reporting particulate matter emission inventories. Within this work programme, Netherlands Organisation for Applied Scientific Research (TNO) has compiled an overview of particulate emission estimation methods and applied these in a European emission inventory for particulates for the base year 1995.

TNO compiled information on emission of particulate matter expressed as TSP, PM_{10} and $PM_{2.5}$ from different industrial sectors. The result is organised in a database available online[2]. Emission factors are developed for four pollution levels:

- Low - good/well maintained abatement/BAT
- Medium
- Medium high
- High - low/poor maintained equipment/abatement and old plants

It is not always obvious, where Danish companies should be placed on the scale. In the cases, where TSP is known for the Danish companies, they are placed on the scale, and the distribution between TSP, PM_{10} and $PM_{2.5}$ can be found.

It should be noted that "best available technique" in practise is a fluent term as new and improved techniques are constantly being developed. What is considered BAT according to CEPMEIP may therefore not be considered so today.

[2] http://www.air.sk/tno/cepmeip/

2.6 Methodological tiers

In the international agreed guidelines for compiling emission inventories (IPCC, 2006 & EEA, 2019), the methodological guidance is provided for different methodological tiers. Tier 1 is the most basic methodology and will typically consist of a default emission factor multiplied by appropriate activity data. The higher the tier, the higher accuracy of the emission estimate, but the higher methodological tiers also require more detailed data. Under the EU ETS, the methodological requirements are also divided into tiers based on the plant's annual emissions. The general principle is the same, i.e. the higher the tier, the higher the accuracy, but the tiers under the EU ETS are not directly comparable to the tier levels in the IPCC Guidelines.

An overview of the applied tiers are presented in Table 2.6.1 and Table 2.6.2.

Table 2.6.1 Overview of methodologies used for the 2021 data (or the latest active year for activities that have ceased) (PS: plant specific, CS: country specific, D: default, OTH: other).

IPCC code	Process	Substance	Tier	EF	Key category 1990/2021/ trend
2A1	Cement production*	CO_2	T3	PS	Yes/Yes/Yes
2A2	Lime production	CO_2	T2	PS/CS	No/No/No
2A3	Glass production	CO_2	T3	PS	No/No/No
2A4a	Ceramics	CO_2	T3	CS	No/No/No
2A4b	Other uses of soda ash	CO_2	T3	D	No/No/No
2A4d	Other process uses of carbonates	CO_2	CS/T3	D	No/No/No
2B2	Nitric acid production	N_2O	T2	PS	Yes/No/Yes
2B10	Catalyst production	CO_2	CS	PS	No/No/No
2C1	Iron and steel production*	CO_2	T1	CS, D	No/No/No
2C4	Magnesium production	SF_6	T2	D	No/No/No
2C5	Secondary lead production	CO_2	T1	D	No/No/No
2D1	Lubricant use	CO_2	T1	D	No/No/No
2D2	Paraffin wax use	CO_2, N_2O, CH_4	T2	OTH/D	No/No/No
2D3	Paint application	CO_2	CS/T2	CS	No/No/No
2D3	Degreasing, dry cleaning and electronics	CO_2	CS/T2	CS	No/No/No
2D3	Chemical products manufacturing or processing	CO_2	CS/T2	CS	No/No/No
2D3	Other use of solvents and related activities	CO_2	CS/T2	CS	No/No/No
2D3	Road paving with asphalt	CO_2, CH_4	T2	OTH	No/No/No
2D3	Asphalt roofing	CO_2	T2	OTH	No/No/No
2D3	Urea-based catalysts	CO_2	T3	D	No/No/No
2E5	Other electronics industry	HFCs, PCFs	T2	D	No/No/No
2F1	Refrigeration and air conditioning	HFCs, PFCs	T2	D/CS	No/Yes/Yes
2F2	Foam blowing agents	HFCs	T2	D	No/No/Yes
2F4	Aerosols	HFCs	T2	D	No/No/No
2F5	Solvents	PFCs	T2	D	No/No/No
2G1	Electrical equipment	SF_6	T3	D	No/No/No
2G2	SF_6 and PFCs from other product use	SF_6	T2	D	No/No/No
2G3a	Medical application	N_2O	T1	D	No/No/No
2G3b	Propellant for pressure and aerosol products	N_2O	T1	D	No/No/No
2G4	Other product uses	CO_2, CH_4, N_2O	T2	D/CS/OTH	No/No/No

* The methodology used for this category varies over the time series, see Table 2.6.2.

Table 2.6.2 Overview of implemented methodologies for categories where the methodology varies over the time series.

Process	Years	Available activity data	Available emission factors	Resulting methodology
2A1 Cement production	1990-1997	Production of white cement and production of three types of grey clinker.	Plant specific factors for the three individual grey clinker types and for white cement.	Tier 1/PS
	1998-2021	Consumption of raw materials.	Plant specific measured carbonate content of raw materials.	Tier 3/PS
2A4a Ceramics	1990-2005	Estimated $CaCO_3$ eq. data based on national statistics	Country specific	Tier 2/CS
	2006-2021	Plant specific data on carbonate consumption	Country specific	Tier 3/CS
2A4d Other process uses of carbonates	1990-2005	Estimated $CaCO_3$ data based on total produced flue gas cleaning residue	Default	Tier 2/D
	2006-2021	Plant specific data on carbonate consumption	Default	Tier 3/D
2C1 Iron and steel production	1990-1992, 2005	Extrapolation, interpolation, expert judgement	Expert judgement	Tier 1/CS,D
	1993-2001	Environmental reports	Environmental reports	Tier 2/CS,D

3 Mineral industry

The sector *Mineral industry* (CRF/NRF 2A) covers the following industries relevant for the Danish air emission inventory:

- Cement production (SNAP 030311, 040612); see section 3.2
- Lime production (SNAP 030312, 040613, 040614); see section 3.3
- Glass production (SNAP 030315, 030316); see section 3.4
- Ceramics (SNAP 040691, 040692); see section 3.5
- Other uses of soda ash (SNAP 040619); see section 3.6
- Flue gas desulphurisation (SNAP 040618); see section 3.7
- Stone wool production (SNAP 030318, 040618); see section 3.8
- Quarrying and mining of minerals other than coal (SNAP 040616); see section 3.9
- Construction and demolition (SNAP 040624); see section 3.10
- Storage, handling and transport of mineral products (SNAP 040690); see section 3.11

3.1 Emissions

3.1.1 Greenhouse gas emissions

Total greenhouse gas emissions from the Mineral industry sector are available in Annex A0-1. The emission time series for the source categories within *Mineral industry* (2A) are presented in Figure 3.1.1 and individually in the subsections below (Sections 3.2 – 3.8). The following figure gives an overview of how much the individual source categories contribute throughout the time series. CO_2 is the only greenhouse gas emitted from mineral industries.

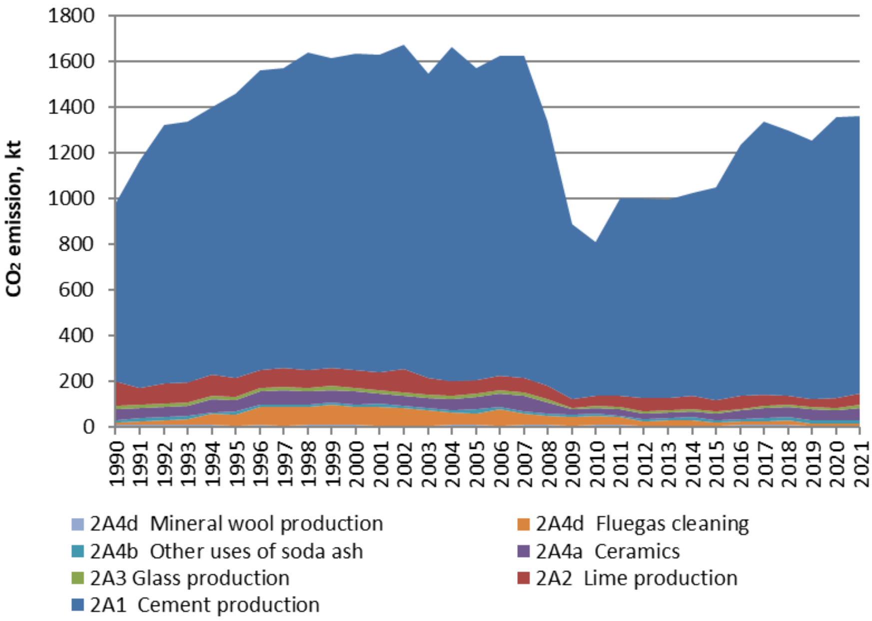


Figure 3.1.1 Emission of CO_2 from the individual source categories compiling *2A Mineral industry*, kt.

Greenhouse gas emissions from *Mineral industry* are made up mostly by CO_2 emissions from the production of cement; min. 80 % (1990) to max. 91 % (2020).

Emissions from *Mineral industry* increased with 72 % from 1990 to the time series peak in 2002 (2002 emission: 1670 kt CO_2). The overall development in the CO_2 emission for 1990 to 2021 shows an increase from 973 kt CO_2 to 1359 kt CO_2, i.e. 40 %.

The increase from 1990 to 1997 is explained by the increase in cement production. The emission factor has only changed slightly (0.51-0.57 t CO_2 per t clinker) as the distribution between types of cement especially grey/white cement has been almost constant from 1990-1997. The increase in emissions from 2010-2017 is a result of increased production which may be explained by an increase in the construction activity after the financial crisis in 2008-2010 and hence an increase in cement demand.

3.1.2 Air pollution emissions

The time series for emissions of acidifying substances, NMVOC, particulate matter, heavy metals, and POPs from *Mineral products* (NFR 2A) is available in Annex A0-2. Table 3.1.1 presents an overview of emissions from 2021.

Table 3.1.1 Overview of 2021 emissions from *Mineral products*.

	Total emission from Mineral industries		Fraction of IPPU, %	Largest contributor in Mineral industries	Emission from largest contributor		Fraction of Mineral industries, %
SO_2	0.61	kt	63.9	2A6 Other mineral products	0.61	kt	100.0
NMVOC	0.09	kt	0.3	2A3 Glass production	0.06	kt	62.6
CO	0.01	kt	0.3	2A6 Other mineral products	0.01	kt	76.6
NH_3	0.34	kt	83.5	2A6 Other mineral products	0.27	kt	79.3
TSP	5.89	kt	82.9	2A5b Construction and demolition	4.43	kt	75.1
HMs	0.14	t	1.9	Pb from 2A3 Glass production	0.05	t	32.8
POPs	0.01	kg	0.01	PCBs from 2A2 Lime production	0.01	kg	94.2

3.2 Cement production

The production of cement in Denmark is concentrated at one company: Aalborg Portland A/S situated in Aalborg. The following SNAP categories are covered:

- 04 06 12 Cement (decarbonising)

Emissions associated with the fuel combustion in cement kilns are estimated and reported in the energy sector; and are therefore not included in this sector report. Only emissions related to the calcination of raw materials fed to cement kilns are reported under the IPPU sector. Some pollutants originate from both the fuel and the raw material, e.g. SO_2 and heavy metals. These emissions are reported under the energy sector, but some of the methodological details are included in this chapter, where the emission factors are based on the amount of cement produced rather than based solely on fuel consumption (SNAP 03 03 11).

3.2.1 Process description

The primary raw materials (i.e. virgin raw materials) are chalk, sand and water. A number of other raw materials are also used in minor amounts. The main products are grey cement (Rapid® cement, Basis® cement and Low Alkali Sulphate Resistant cement) and white cement (Aalborg White®) as well as cement clinker for sale.

The emissions to air from cement production can be explained by the use of different fuels (combustion process), release of CO_2 from calcination, and release of pollutants from raw materials.

Chalk is extracted from a chalk pit located at the factory ground. The chalk is transported by conveyor belts to a wash mill, where impurities are removed. The chalk is then mixed with water to form chalk slurry. Sand is extracted from the seabed at different locations by dredgers. The sand is transported to the factory and is ground in a sand mill. The main secondary raw materials (i.e. recycled materials) are fly ash, paper pulp, ferro oxide and gypsum from flue gas cleaning. A number of other secondary raw materials are used in minor amounts. The main processes at Aalborg Portland are raw meal production, clinker production, grinding of clinker and storage of cement.

Aalborg Portland uses a semi-dry process. The first step is production of raw meal. The chalk slurry and the grounded sand are mixed as slurry that is injected into a drier crusher. The raw materials are converted into raw meal that releases CO_2 in the calciner.

In a rotary kiln the material is burned to clinker that afterwards is ground to cement in the cement mill. During the process, cement kiln dust is recirculated.

Production of cement is a very high energy consuming process and a number of different fuels are used e.g. coal, petroleum coke, fuel oil and alternative fuels (meat and bone meal, regenerated oil with low sulphur content, ash residue, residue from production of wood concrete slabs (Troldtekt), dried sewage sludge, and "CemMiljø fuel"[3]). The company focuses on alternative fuels in order to reduce cost as well as environmental effects. The emissions that are related to combustion are not included in this report (Nielsen, 2021).

The fuels are injected in the bottom of the rotary kiln whereas the raw materials are injected in the top of the kiln. The product (i.e. cement clinker) is in contact with the fuel and potential pollutants in the fuels may be incorporated in the clinker meaning that the alkaline environment in the rotary kiln acts as a flue gas cleaning system (especially for acid gases and certain heavy metals).

3.2.2 Methodology

Process emissions are released from the calcination of raw materials (primarily chalk and sand). The overall process for calcination is:

$CaCO_3 \rightarrow CaO + CO_2$

1990-1997

The emission of CO_2 depends on the ratio: white/grey cement and the ratio between the three types of clinker used for grey cement: GKL-clinker (rapid cement)/FKH-clinker (basis cement)/SKL-RKL-clinker (low alkali cement).

The emission factor (EF) has been estimated from the loss on ignition determined for the different kinds of clinkers produced, combined with the volumes of grey and white cements produced.

[3] Produced from non-specified combustible waste (CemMiljø, 2003).

The ratio white/grey cement and the ratio GKL-clinker/FKH-clinker/SKL-RKL-clinker is known for 1990-1997. White cement peaked in 1990 and decreased thereafter. The production of SKL/RKL-clinker peaks in 1991 and decreases thereafter. FKH-clinker is introduced in 1992 and increases to a share of 35 % in 1997. The CO_2 emission is calculated according to the following equation:

$$M_{CO_2} = M_{grey} * \frac{M_{GLK} * EF_{GLK} + M_{FKH} * EF_{FKH} + M_{SKL/RKL} * EF_{SKL/RKL}}{M_{GLK} + M_{FKH} + M_{SKL/RKL}} + M_{white} * EF_{white}$$

M_{grey}	Grey cement	t
M_{white}	White cement	t
M_{GLK}	GKL clinker (rapid cement)	t
M_{FKH}	FKH clinker (basis cement)	t
$M_{SKL/RKL}$	SKL/RKL clinker (low alkali cement)	t
EF_{white}	CO_2 emission factor	t/t white cement
EF_{GLK}	CO_2 emission factor	t/t GLK clinker
EF_{FKH}	CO_2 emission factor	t/t FKH clinker
$EF_{SKL/RKL}$	CO_2 emission factor	t/t SKL/RKL clinker

The company has stated that data until 1997 cannot be improved as there is no further information available (Aalborg Portland, 2005). Data for white cement is therefore used as an estimate for white clinker making the methodology used for the years 1990-1997 a Tier 1.

1998-2005

From 1998-2005, the carbonate content of the raw materials has been determined by loss on ignition methodology. Determination of loss on ignition takes into account all the potential raw materials leading to release of CO_2 based on full oxidation and omits the Ca-sources leading to generation of CaO in cement clinker without CO_2 release. The applied methodology is in accordance with EU guidelines on calculation of CO_2 emissions (Aalborg Portland, 2008). Clinker data are available.

2006-2021

From the year 2006, the CO_2 emission determined by Aalborg Portland independently verified and reported under the EU-ETS (EU Emission Trading Scheme) is used in the inventory (Aalborg Portland, 2022a). The reporting to EU-ETS also provides detailed information of alternative fuels used in the production of clinker and the amount of clinker produced; see Table 3.2.1.

Table 3.2.1 Alternative fuels used in production of cement clinker (Aalborg Portland 2022a).

Fuel type	Biomass fraction, %
Cemmiljø fuel (CMB/CMBH/CMBL)	30-54
Dry wastewater sludge	100
Meat and bone meal	100
Wood waste (sawn wood/woodchips)	100

The information on fuels is used in the compilation of the emission inventory for the fuel combustion part (Nielsen, 2021).

Activity data

Activity data for cement (measured in total cement equivalents (TCE)) and clinker production are presented in Table 3.2.2 and Annex A1-1. TCE is the standard unit for the production obtained by calculation of the equivalent cement tonnage if sales and changes in clinker stocks had been processed into cement. Each type of clinker is therefore multiplied by a factor that expresses addition of other materials for production of cement. Process emissions of CO_2 are based on clinker production alone, cement production data are used for verification.

Table 3.2.2 Production statistics for cement and clinker, kt (Aalborg Portland, 2008, 2013, 2020, 2022a, b).

	1990	1995	2000	2005	2010	2015	2018	2019	2020	2021
kt TCE	1620	2274	2613	2706	1454	1902	2360	2342	2444	2568
kt clinker[1]	1406	2353	2452	2521	1314	1715	2141	2146	2240	2202

[1] 1990-1997: Clinker production is estimated as grey clinker plus white cement (Aalborg Portland, 2008).

Emission factors

The calculated implied emission factors (IEF) for cement and clinker production are presented in Table 3.2.3 and Annex A1-2.

Table 3.2.3 Implied emission factors for CO_2 for cement production[1,2,3,4].

	1990	1995	2000	2005	2010	2015	2020	2021
IEF t CO_2 per t TCE	0.478	0.546	0.530	0.504	0.462	0.490	0.502	0.471
IEF t CO_2 per t clinker	0.551	0.528	0.565	0.541	0.512	0.543	0.548	0.549

[1] 1990-1997: IEF based on information provided by Aalborg Portland (2005).

[2] 1998-2005: IEF based on emissions provided by Aalborg Portland (2008).

[3] 2006-2021: IEF based on emissions reported to EU-ETS (Aalborg Portland, 2022a).

[4] 1998-2021: IEF based on production statistics provided by Aalborg Portland (2013, 2020, 2022a, b).

The IEF for CO_2 from the calcination process is expressed per tonne of cement or clinker and depends on the actual input of chalk/limestone in the process. The IEF will therefore vary as the allocation of different cement/clinker types produced varies. A higher share of white cement will lead to a higher implied emission factor, as white cement production has the highest emission factor; see Table 3.2.4. The share of white cement decreases through the early part of the 1990s causing the emission per clinker to decrease as well. In 1990, 25 % of all cement produced was white cement; in 1991-1997 that same share fluctuates around 22 % (20.1-24.8 %).

Table 3.2.4 Emission factors used for 1990-1997 (Aalborg Portland, 2008).

Product	Value	Unit
White cement	0.669	t CO_2/t white cement
GLK clinker	0.477	t CO_2/t GLK grey clinker
FKH clinker	0.459	t CO_2/t FKH grey clinker
SKL/RKL clinker	0.610	t CO_2/t SKL/RKL grey clinker

For the entire time series, the emission factor (carbon content) has been estimated from the loss on ignition determined for the different kinds of clinkers produced (1990-1997) or different raw materials used (since 1998). Determination of loss on ignition estimates the CO_2 emissions based on full oxidation of all carbonate materials and omits the Ca sources leading to generation of CaO in cement clinker without CO_2 release. As a result, there is no need to consider uncalcined cement kiln dust (CKD) not recycled to the kiln.

The company reporting to the EU-ETS applies the following emission factors for the most important raw materials used in 2021, similar data are available back to 2006 (Aalborg Portland, 2022a) and to a less detailed degree back to 1998 (Aalborg Portland, 2020).

Table 3.2.5 Emission factors for some of the raw materials used in 2021 (Aalborg Portland, 2022a).

Raw material	t CO_2 per t raw material
Limestone	0.44
Magnesium carbonate	0.52
Ferrous carbonate	0.38
Sand	0.01-0.03
Fly ash	0.08
Bottom ash from biomass	0.47
Oxiton	0.03

The emission factors for limestone and carbonates are in accordance with the stoichiometric factors, sources marked as "negligible CO_2 source" apply fixed representative standard value for emission factor and the emission factors for the remaining raw materials (i.e. fly ash and Hals Barre sand) are determined by individual daily or weekly Tier 3 analysis.

The emissions of heavy metals were measured in 1997 (Illerup et al., 1999) – see Table 3.2.6. The emission of heavy metals originates from the fuels and the raw materials. In the Danish inventory, these emissions together with emissions of CO, NO_x, SO_2, and POPs have been allocated to the combustion part of cement production and are reported in the energy sector. These emissions are therefore not included in this report. However, as the emission factors refer to cement production rather than fuel consumption, they are briefly presented below.

Table 3.2.6 Emission factors for heavy metals (Illerup et al., 1999).

Pollutant	Unit	Emission factor
As	mg/t	20
Cd	mg/t	7
Cr	mg/t	10
Cu	mg/t	10
Hg	mg/t	0.06
Ni	mg/t	20
Pb	mg/t	10
Se	mg/t	7
Zn	mg/t	50

Emissions of NO_x, SO_2, and CO are continuously measured and reported annually in the environmental report of Aalborg Portland since 2006. Prior to this, emissions are calculated using emission factors derived from information in the environmental reports by Aalborg Portland. For 1990-1995, the same emission factors have been assumed as in1996.

Emissions of HCB, PCBs, benzo(a)pyrene, benzo(b)flouranthene, benzo(k)fluoranthene and indeno(1,2,3-cd)pyrene are estimated based on the fuel consumption and not the production of cement.

Emissions of particulate matter and PCDD/F are estimated using emission factors expressed per produced amount of clinker.

3.2.3 Emission trend

The emission trend for the CO_2 emission from cement production is presented in Table 3.2.7, Figure 3.2.1 and Annex A0-1.

Table 3.2.7 CO_2 emission for cement production, kt.

	1990	1995	2000	2005	2010	2015	2018	2019	2020	2021
CO_2	774.7	1242.6	1385.3	1363.4	672.2	931.5	1159.7	1129.2	1227.0	1214.6

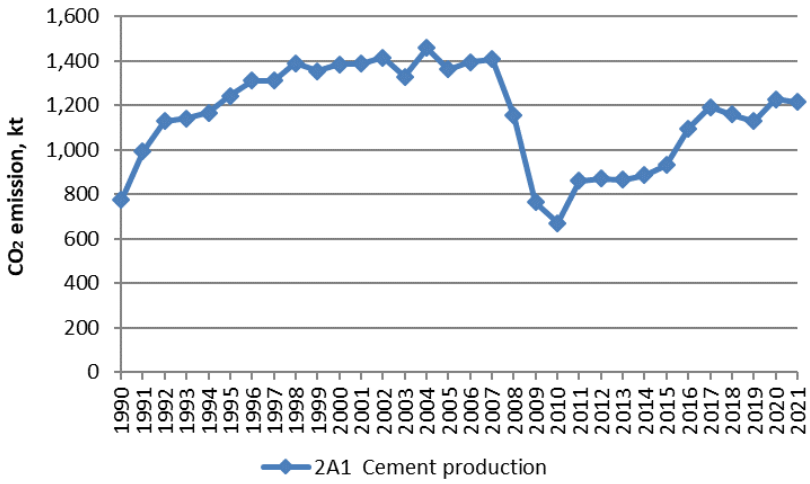


Figure 3.2.1 Emission of CO_2 from cement production.

The increase in CO_2 emission from the production of cement from 1990 to 1997 is explained by the increase in annual cement production. The most significant change to occur in the time series is the significant decline in emission from 2007-2010, the decrease is due to reduced production resulting from the economic recession caused by the global financial crisis. The emissions increased by 81 % from 2010 to 2021, but the emissions are still below the pre-recession levels. However, the overall development in the CO_2 emission from 1990 to 2021 is an increase from 775 to 1215 kt CO_2, i.e. 57 %. The maximum emission occurred in 2004 and constituted 1 459 kt CO_2.

3.2.4 EU-ETS data for cement production

The applied methodology for Aalborg Portland is specified in the individual monitoring plan that is approved by the Danish competent authority, which is the Danish Energy Agency (DEA) prior to the reporting of the emissions. Cement production applies the Tier 3 methodology for calculating the CO_2 emission for 1998-2021. See EU Commission (2022) for a description of the methodological tiers for cement production.

The implied CO_2 emission factor for Aalborg Portland is plant specific and based on the reporting to the EU Emission Trading Scheme (EU-ETS). The EU-ETS data have been applied for the years 2006 – 2021.

The CO_2 process emissions for cement production are based on measurements of the consumption of calcium carbonate to the calcination process – kiln input based approach. These measurements fulfil a Tier 3 methodology (± 0.8 %, Aalborg Portland, 2022c) as defined in the EU decision (EU Commission, 2022). The quantity of $CaCO_3$, $MgCO_3$ and $FeCO_3$ in produced chalk sludge is continuously calculated based on constant measurement of chalk sludge flow and measuring the corresponding liter weight with a density meter as well as analysis of the $CaO/MgO/Fe_2O_3$ percentage, as determined several times a day by Aalborg Portland's Production Laboratory via X-ray fluorescence. A subset of the production-registered chalk sludge ($CaCO_3$) is used for flue gas scrubbing for SO_2 content in the furnace desulphurisation system. The emission factor is based on continuous measurements with flow meters, density meters, X-ray and CaO analysis. (Aalborg Portland, 2022c).

3.2.5 Verification

The ratios in cement production and clinker production data from Aalborg Portland (presented in Table 3.2.2) shows that for most years the cement is 102-117 % (109 % in average) higher than the clinker data. This is as expected since Aalborg Portland only uses their own produced clinker, but for 1995 and 1996, the ratios are 97 %. In the comparison against the cement data from Statistics Denmark (VARER1 21/02-2022) (presented in Annex A1-3) these two years are where the data from Statistics Denmark are notably higher than those from Aalborg Portland (310 and 210 kt higher, respectively). If a corresponding ratio is calculated for 1995-1996 with clinker data from Aalborg Portland (Table 3.2.2) and cement data from Statistics Denmark (Annex A1-3) the resulting ratios are 106-110 %, as with the rest of the time series. This indicates that the used activity data for cement given by Aalborg Portland might be a little low for these years. It does however not affect the emission estimates as these are based on clinker production data.

Information on production, import and export of cement and clinker were investigated in order to ensure that the Tier 1 method (year 1990-1997) is being implemented in accordance with the IPCC Guidelines (IPCC, 2006). The supply of cement clinker, grey cement and white cement in Denmark is shown in Table 3.2.8 and Annex A1-4; however, the mass balance is incomplete due to missing information. The missing information may be explained by confidentiality, as the statistics can be kept confidential, if there are fewer than three producers.

Table 3.2.8 Production, import, export and supply of cement, kt (Statistics Denmark, KN8Y 21/02-2022).

	1990	1995	2000	2005	2010	2015	2020	2021
Cement clinker								
Produced	NAV	NAV	103	43	4	NO	NO	NO
Import	0.4	0.01	0.002	31	22	90	0.5	241.9
Export	17	281	90	56	12	0.1	0.1	0.0
Supply	-	-	12	18	14	90	0.4	241.8
Portland cement, white								
Produced	412	531	551	715	482	614	779	802
Import	NO	0.02	11	15	23	8	119	82
Export	367	473	546	508	501	551	400	412
Supply	44	58	17	222	3	71	498	472
Portland cement, grey								
Produced	1244	2053	1985	2166	1085	1414	1719	1707
Import	190	272	238	215	160	198	305	324
Export	19	790	634	732	201	264	279	274
Supply	1414	1535	1589	1650	1044	1348	1745	1757

NAV: Personal communication with the single Danish producer of cement makes it clear what it unfortunately is not - and never will be, possible to acquire these data for 1990-1997 (Aalborg Portland, 2013).
NO: Not occurring.

The data presented in Table 3.2.8 and Annex A1-4 have verification purposes only and are not used in the emission calculations.

Table 3.2.8 and Table 3.2.2 show the produced amount of cement (grey and white) according to Statistics Denmark and the amount of cement produced according to Aalborg Portland, respectively. The two datasets show good agreement in spite of different methodologies. The fluctuations are believed mainly to be caused by changes in stocks, and the overall sum of produced cement only differs on average -1.0 % (-21.9 kt) through the time series (1990-2021). The most comprehensive activity data are believed to be the information on yearly produced amount of cement obtained from the Danish producer. A comparison between the two datasets are presented in Table 3.2.9 and Annex A1-3.

Table 3.2.9 Production data for Portland cement as given by Aalborg Portland and Statistics Denmark (VARER1 17/05-2023) respectively.

	Unit	1990	1995	2000	2005	2010	2015	2020	2021
Aalborg Portland	kt	1620	2274	2613	2706	1454	1902	2444	2568
Statistics Denmark	kt	1656	2584	2536	2881	1567	2028	2498	2509
Difference	kt	-36	-310	77	-174	-113	-126	-54	59

The activity data for clinker production provided by the company includes clinker used in cement production, while clinker data from Statistics Denmark only includes the amount of clinker sold. The production data for clinker can therefore not be compared (Table 3.2.8 and Table 3.2.2).

Table 3.2.10 compares the default emission factor from the IPCC (2006) with the measured/calculated implied emission factor for 1990-2021. The average IEF for these years is 0.54 tonnes per tonne clinker. The comparison shows good agreement between the two methods.

Table 3.2.10 Comparison of default (Tier 1) and calculated implied (Tier 3) CO_2 emission factors for cement production.

Methodology	Value	Unit	Source
Tier 1	0.52	t/t clinker	IPCC (2006)[4]
Tier 3	0.51-0.57	t/t clinker	Aalborg Portland (2008, 2020, 2022a, b)

Figure 3.2.2 below presents CO_2 emissions calculated with a Tier 1 method and the applied Tier 1/2 combination (emissions from grey cement are calculated using Tier 2 and white cement with Tier 1) (IPCC, 2006). The comparison shows that emissions are higher when using the Tier 2 methodology for grey cement, except for the year 1990. In 1990, white cement amounts to 25 % of the total cement production of 1656 kt. For 1991-1997, this number is only 20-22 % of 2019-2629 kt.

[4] Volume 3: Industrial Processes and Product Use, Chapter 2.2: Cement production, Equation 2.4, page 2.12.

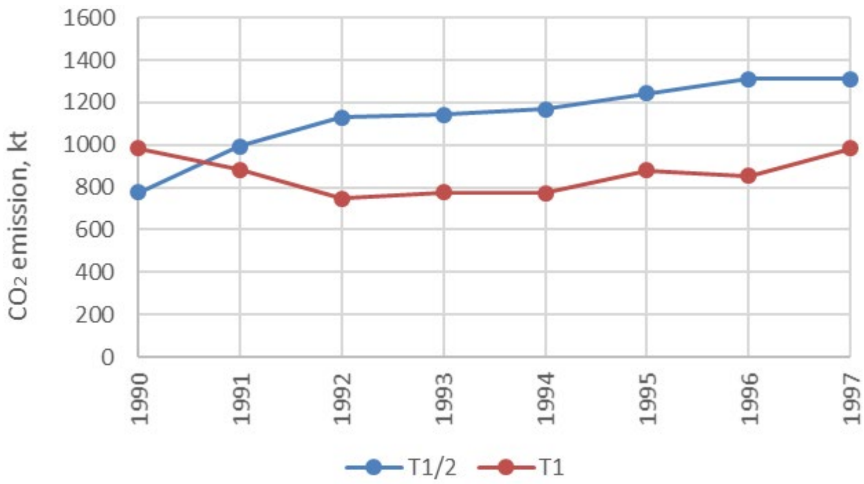


Figure 3.2.2 Comparison of calculation methods for CO_2 emissions from cement production in 1990-1997.

3.2.6 Time series consistency and completeness

Since Denmark only has one cement factory, all data collected from the production are in fact plant specific data. The inventory on cement production is complete in accordance with the IPCC (2006).

For 1990-1997, activity data for grey cement production fulfil the Tier 2 methodology while activity data for white cement (20-25 % of mass produced) fulfil the Tier 1 methodology (IPCC, 2006). The company has informed that data until 1997 cannot be improved as there is no further information available.

Since 1998, the determination of activity data for cement production has met the requirements of the Tier 3 methodology.

Emission factors have been determined by analyses using loss on ignition for the entire time series, which fulfil the requirements of the Tier 3 methodology. The loss on ignition method consists of strongly heating a sample of the material to a specified temperature, allowing volatile substances to escape, until its mass ceases to change. In this case, until all carbon in the raw material has been oxidised to CO_2.

Due to extensive verification, the methodology is believed to be consistent.

3.2.7 Input to emission database (CollectER)

The input data/data sources are presented in Table 3.2.11.

Table 3.2.11 Input data for calculating emissions from cement production.

	Year	Parameter	Comment/Source
Activity data	1985-1997	Grey/white cement	Aalborg Portland (1999)/ Illerup et al. (1999)
	1997	Cement equivalents	Aalborg Portland (2008)
	1998-2021	Cement equivalents	Aalborg Portland (2020, 2022b)
	1998-2021	Clinker produced	Aalborg Portland (2008; 2013)
Emissions	1985-1997	CO_2	Aalborg Portland (2005)
	1998-2005	CO_2	Aalborg Portland (2008)
	2006-2021	CO_2	Aalborg Portland (2022a)

3.3 Lime production

The production of limestone ($CaCO_3$) and lime (also called burned lime or quicklime) (CaO) is located at a few localities: Faxe Kalk (Lhoist group) situated in Faxe, Scandinavian Calcium Oxide ApS situated in Støvring, Dankalk A/S situated in Løgstør with limestone quarries/limeworks in Aggersund, Mjels, Poulstrup and Batum.

In addition to the marketed lime production, there is lime production related to production of sugar. Sugar production is concentrated at one company: Nordic Sugar (previously Danisco Sugar A/S) located in Assens (closed since 2007), Nakskov and Nykøbing Falster. This lime is produced and consumed by the sugar industry and is therefore called un-marketed lime.

The following SNAP-codes are covered:

- 03 03 12 Lime (incl. iron and steel and paper pulp industry)
- 04 06 14 Lime (decarbonising)

The following pollutants are included for the lime production process:

- CO_2
- Particulate matter: TSP, PM_{10}, $PM_{2.5}$, BC
- Persistent organic pollutants: HCB, PCDD/F, PCBs

In addition to emissions from marketed lime, CO_2 from the decarbonising of un-marketed lime is included in this section. Emissions of NMVOC from sugar refining are presented in Chapter 10.2 Food and beverages industry and emissions associated with the fuel use are estimated and reported in the energy sector and therefore not included in this report.

3.3.1 Process description

Calculation of CO_2 emissions from oxidation of carbonates follows the general process:

$$M_x(CO_3) + \text{heat} \rightarrow M_xO + CO_2$$

and for limestone:

$$CaCO_3 + \text{heat} \rightarrow CaO + CO_2$$

Addition of water results in the following reaction:

$$CaO + H_2O \rightarrow Ca(OH)_2$$

The emission of CO_2 results from heating of the carbonates in the lime-kiln. The lime-kilns can be located either at the location for limestone extraction or at the location for use of burned lime.

3.3.2 Methodology

The CO_2 emission from the production of marketed burnt lime has been estimated from the annual production figures registered by Statistics Denmark (VARER1 17/04-2023) (see Table 3.3.1) and emission factors from 1990 until 2005.

Since 2006, point source data for Faxe Kalk (i.e. the largest Danish producer) have been applied, but the total national production always sums up to the national statistics. Plant specific activity data for marketed lime from Faxe Kalk are available from EU-ETS since 2006 (Faxe Kalk 2022). Faxe Kalk constitutes 22-83 % (55 % in average) of the Danish activity in 2006-2021, see Table 3.3.1. The plant specific activity data are available back to 1995 from the environmental reports but these are not applied as a point source. Different smaller productions account for the remaining production of marketed lime in Denmark.

Since 2006, process CO_2 emissions from Faxe Kalk have been calculated by the company and reported to EU-ETS and since 2008, Faxe Kalk have measured and included the content of CO_3 in the process emissions. For the sake of consistency, the same method has been applied for the entire time series and for all producers, i.e. correcting for impurities by assuming the same $CaCO_3/MgCO_3$ ratio as the measured average from Faxe Kalk in 2008-2012. (Faxe Kalk, 2020). By this, Denmark applies a country specific emission factor and Tier 2 methodology according to IPCC (2006).

Limestone consumption data for production of sugar are available from the company's environmental reports (Nordic Sugar, 2022; Nordic Sugar Nykøbing, 2010; Nordic Sugar Nakskov, 2012; Danisco Sugar Assens, 2007) back to 1996 and sugar commodity statistics ("sale of own goods") are available from Statistics Denmark (VARER1, 08/08-2022) for the entire time series. The commodity statistics is assumed to be equivalent with the production activity. Limestone consumption data are used when available and national statistics on sugar production are used as surrogate data for the remaining years (1990-1995). Raw material consumption data are for 1996-2006 only given in amount of limestone, these data are calculated into amount of burnt lime (CaO) equivalents using the stoichiometric relation between $CaCO_3/CaO$ and the 2007-2013 average measured $CaCO_3$ content in limestone of 11.62 % (Nordic Sugar Nakskov, 2012 and Nordic Sugar, 2022).

Emissions of air pollutants from lime production are calculated based on activity data on the amount of lime produced on a national level from Statistics Denmark (2022) (total lime production from Table 3.3.1) and emission factors from the EMEP/EEA Guidebook (EEA, 2019) and national literature.

Activity data

National statistics from Statistics Denmark (VARER1 of 8/8-2022) have been chosen as data source for marketed lime production to ensure consistent data throughout the time series. However, after EU- ETS data have become available for Faxe Kalk from 2006, the company specific production data have been included and the data from Statistics Denmark adjusted to cover only producers not covered by EU-ETS. The production data for burnt lime are presented in Table 3.3.1 and Annex A2-1.

Table 3.3.1 Production of burnt lime, kt.

	1990	1995	2000	2005	2010	2015	2018	2019	2020	2021
From Faxe Kalk[1]	-	-	-	-	25.6	30.1	29.3	15.9	11.7	32.0
From other producers[2]	-	-	-	-	24.8	33.4	15.8	25.5	42.3	29.6
From sugar production	5.8	5.1	5.8	4.7	2.0	0.7	1.3	1.3	1.4	1.3
Total lime production	133.8	105.9	97.8	75.9	52.4	64.2	46.4	42.8	55.4	62.9

[1] Faxe Kalk (2013 and 2022).

[2] Non-ETS producers of marketed lime, calculated as national statistics data minus Faxe Kalk.

Emission factors

The country specific CO_2 emission factor that is applied for calcination of both marketed and non-marketed calcium carbonate is based on measurements from Faxe Kalk in 2008-2012. The emission factor applied is 0.788 kg CO_2 per kg CaO (Faxe Kalk 2022) and includes a small impurity of MgO. It is assumed that the degree of calcination is 100 % and that no lime kiln dust (LKD) emits from the process.

The actual reported emissions are used for Faxe Kalk in 2008-2021. This means that the implied emission factor for marketed lime production will vary as the measured emission factor for Faxe Kalk fluctuates, the implied emission factor is between 0.769 kg CO_2 per kg CaO (2021) and 0.793 kg CO_2 per kg CaO (2018). For all other producers and for Faxe Kalk 1990-2007, the country specific implied emission factor of 0.788 kg CO_2 per kg CaO is applied.

This method causes fluctuations in the implied emission factor for the years since 2008, but not for 1990-2007.

Table 3.3.2 Implied emission factors for Danish lime production.

	1990-2007	2008-2021
Faxe Kalk	0.788	0.752-0.796
Other marketed lime	0.788	0.788
Un-marketed lime	0.788	0.788

In comparison, the IPCC (2006) default Tier 1 emission factor is 0.75 tonnes CO_2 per tonne lime produced. The Tier 1 methodology includes the assumption that the lime production consists of 85 % high calcium lime and 15 % dolomitic lime. For more information, please refer to section 3.3.5 Verification below.

The applied air pollution emission factors are shown in Table 3.3.3 and Table 3.3.4 along with their respective sources. Emission factors from EMEP/EEA (2019) are valid for a controlled process (Tier 2[5]). The emission factors for TSP, PM_{10}, and $PM_{2.5}$ are dependent on process conditions including pollution abatement equipment.

Table 3.3.3 Emission factors for marketed lime production, g per tonne.

Level	TSP	PM_{10}	$PM_{2.5}$	BC	Reference	Comment
Low	300	150	30		CEPMEIP	
Medium	500	200	40		CEPMEIP	
High	1000	300	60		CEPMEIP	
Tier 1	9000	3500	700	3.2	EMEP/EEA, 2019	
Tier 2, uncontrolled	9000	3500	700	3.2	EMEP/EEA, 2019	
Tier 2, controlled	400	200	30	0.1	EMEP/EEA, 2019	Applied in Danish inventory

For the Danish inventory the Tier 2, controlled emission factors published by EMEP/EEA (2019) have been chosen as default as they are assumed to cover an average of small and large plants operating with Danish standards.

[5] EMEP/EEA (2019) Guidebook, chapter 2.A.2 Lime production, page 11, Table 3.3.

The emission factors used to calculate the HCB, PCDD/F and PCBs emissions from lime production are shown in Table 3.3.4 along with their respective sources.

Table 3.3.4 Emission factors for other pollutants for production of marketed lime.

Pollutant	Unit	Value	Source
HCB	mg/t	0.01	Bipro (2006)
PCDD/F	µg/t	0.02	Hansen og Hansen (2003)
PCBs	mg/t	0.15	Bipro (2006)

3.3.3 Emission trend

The trends for the emissions from lime production, including that in sugar production are presented in Table 3.3.5, Figure 3.3.1 and Annex A2-2.

Table 3.3.5 Emissions from lime production, kt.

						200	201	201	202	202
			1990	1995	2000	5	0	5	0	1
	Total	kt	105.4	83.4	77.1	59.8	41.3	50.6	43.2	48.4
CO_2	Lime production	kt	100.8	79.4	72.5	56.1	39.8	50.0	42.1	47.4
	Sugar production	kt	4.6	4.0	4.6	3.7	1.6	0.6	1.1	1.0
TSP	Total	t	53.5	42.4	39.1	30.4	21.0	25.7	22.1	25.2
PM_{10}	Total	t	26.8	21.2	19.6	15.2	10.5	12.8	11.1	12.6
$PM_{2.5}$	Total	t	4.0	3.2	2.9	2.3	1.6	1.9	1.7	1.9
BC	Total	kg	18.5	14.6	13.5	10.5	7.2	8.9	7.6	8.7
HCB	Total	g	1.1	0.8	0.8	0.6	0.4	0.5	0.4	0.5
PCDD/F	Total	mg	2.4	1.9	1.8	1.4	0.9	1.2	1.0	1.1
PCB	Total	g	20.1	15.9	14.7	11.4	7.9	9.6	8.3	9.4

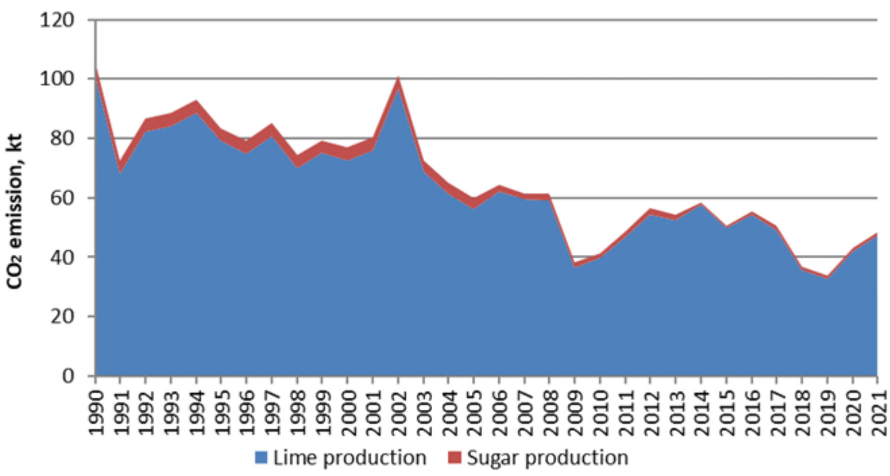


Figure 3.3.1 CO_2 emission trends for lime production.

The emission from sugar production only comprises 1 % (2015) to 6 % (1991) of the total CO_2 emission from lime production; 4 % in average over the time series.

There is a peak in the activity data in 2002 causing peaks in the emissions for this year. The activity data are based on the official statistics from Statistics Denmark and there is no immediate explanation for the peak. There are very few producers in Denmark and therefore it will not be possible to obtain more detailed data from Statistics Denmark.

3.3.4 EU-ETS data for lime production

The applied methodology for Faxe Kalk is specified in the individual monitoring plan that is approved by the Danish competent authority, which is the Danish Energy Agency (DEA) prior to the reporting of the emissions. Lime production at Faxe Kalk applies the Tier 2 methodology for the activity data (uncertainty ± 1.0 %) and Tier 3 for the emission factor.

The implied CO_2 emission factor for Faxe Kalk is plant specific and based on the reporting to the EU Emission Trading Scheme (EU-ETS). The EU-ETS data have been applied for the years 2006-2021.

The CO_2 emission for lime production is based on sales (± 1.0 %) and measurements of the CaO and MgO contents in the product (annual averages of weekly measurements) (Faxe Kalk, 2020).

3.3.5 Verification

For verification, the implied emission factors are calculated; these are constant at 0.788 tonnes CO_2 per tonne lime for all years and for both marketed lime production (excl. Faxe Kalk) and production of lime in the sugar industry. For Faxe Kalk, the IEF is 0.788 tonnes CO_2 per tonne lime for the years until 2016. For 2017-2021, the IEF for Faxe Kalk varies between 0.752 and 0.796 tonnes CO_2 per tonne lime.

If the stoichiometric emission factor of 0.7848 tonnes CO_2 per tonne lime produced[6] had been used instead of using plant specific emission factors from EU-ETS data, i.e. if the MgO impurity is ignored, then the CO_2 emission from the marketed lime production would have been 0.4 % lower (0.1-0.4 kt CO_2), proving that the impurity is in fact insignificant.

The 2006 IPCC guidelines provide basic parameters for lime; see Table 3.3.6. According to the values provided by the IPCC, Danish measured MgO impurities of 0.4 % are in the lower end of the expected range.

Table 3.3.6 Basic parameters for calculation of emission factors for lime products (2006 IPCC guidelines).

Lime type	Stoichiometric ratio t CO_2/t CaO or CaO-MgO	Range of CaO content %	Range of MgO content %	Default value for CaO or CaO-MgO content	Default emission factor t CO_2/t
High-calcium lime	0.785	93-98	0.3-2.5	0.95	0.75

As presented in Table 3.3.6, IPCC (2006) default Tier 1 calculations assume an impurity of 5 % in high-calcium lime. In addition, the Tier 1 methodology includes the assumptions that 85 % of total lime production is high calcium lime, that the remaining 15 % is dolomitic lime and that dolomitic lime has an impurity of 5 % (for developed countries); resulting in a default Tier 1 emission factor for developed countries of 0.77 tonnes CO_2 per tonne lime produced. The default impurities are too high for Danish standards.

TSP emissions from the largest lime producer (Faxe Kalk) are available for 2001-2008. Emissions and the calculated IEFs are presented in Table 3.3.7.

[6] Default emission factor calculated as the stoichiometric relation between CO_2 and CaO, IPCC (2006, V3, Ch2, Table 2.4)

Table 3.3.7 TSP emission factor at Faxe Kalk A/S (Faxe Kalk, 2013).

	Unit	2001	2002	2003	2004	2005	2006	2007	2008
Flue gas	10^6 m^3	158	225	269	271	219	233	211	285
TSP concentration	mg TSP/m^3	42	40	31	26	23	24	7	20
TSP emission	t	6.6	9.0	8.5	7.1	5.0	5.5	1.5	5.7
Lime production	kt	70.5	69.8	63.3	64.1	57.3	62.8	57.0	57.8
IEF TSP	g/t	94	129	134	110	88	88	26	99

The average emission factor for the years 2001-2008 is 96 g TSP per tonne lime. This figure is very low compared to the chosen emission factor of 400 g TSP per tonne lime from EMEP/EEA (2019). The production at Faxe Kalk represents 57-82 % of the total produced amount of marketed lime in 2001-2008. An overestimation of particle emissions from this source category is therefore likely. The inclusion of the measured TSP values from Faxe Kalk are part of the planned improvements, see Chapter 16.

3.3.6 Time series consistency and completeness

The chosen methodology, activity data and emission factor for calculation of CO_2 emissions from marketed lime are consistent throughout the time series.

Although the activity data for non-marketed lime production at the sugar factories are based on actual carbonate consumption from 1996 onward and on estimated consumptions for 1990-1995, the methodology and applied emission factor are both considered consistent.

With regards to completeness concerning production of other lime products than burnt lime, dolomitic lime/dolomite ($CaMg(CO_3)_2$) is not produced in Denmark and the production of hydrated lime (slaked lime) from burnt lime does not lead to any emissions. All burnt lime that is later slaked is included in the statistical data on which the calculations are based, and adding the production of slaked lime to the activity data would therefore result in double counting.

Other industries that typically use lime as an intermediate product are e.g. chemical industries, metal industries and productions where lime consumption for emissions abatement is large enough to make internal lime production profitable. These have been investigated with respect to completing this source but nothing was found. Regarding industries producing lime as intermediate products only one was identified (i.e. Nordic Sugar). Denmark has virtually no chemical or metal industry, so the need for lime in the Danish industry is non-existing with the exception of the sources listed, and the sector must therefore be complete.

3.3.7 Input to CollectER

The input data/data sources for calculating emissions are presented in Table 3.3.8.

Table 3.3.8 Input data for calculating emissions from production of lime incl. slaked lime.

	Year	Parameter	Comment/Source
Activity	All	Production	Danisco Sugar, Nordic Sugar, Statistics Denmark
Emissions	All	CO_2	Stoichiometric relations combined with product information from one company
	2006-2021	CO_2	Faxe Kalk (2022), Nordic Sugar (2022)
	2006-2021	TSP, PM_{10}, $PM_{2.5}$, BC	EMEP/EEA (2019)
	All	HCB, PCB	Bipro (2006)
	All	PCDD/F	Hansen og Hansen (2003)

3.4 Glass production

Glass production covers production of:

- Container glass
- Industrial art glass
- Glass wool

The production of flat glass (SNAP 03 03 14 Flat glass) is concentrated at few European producers and none of these have plants in Denmark. The processes in Denmark are limited to mounting of sealed glazing units. The mounting process is not considered to contribute to emission of pollutants to air in Denmark.

The production of container glass for packaging is concentrated at one company: Ardagh Glass Holmegaard A/S (previously Rexam Glass Holmegaard A/S) and the production of industrial art glass products is concentrated at Holmegaard A/S both situated in Fensmark, Næstved. Saint-Gobain Isover situated in Vamdrup is the only Danish producer of glass wool. The following SNAP-codes are covered:

- 03 03 15 Container glass
- 03 03 16 Glass wool (except binding)
- 04 06 13 Glass (decarbonising)

Emissions of the following pollutants are included from the glass production processes:

- CO_2
- NMVOC
- CO
- NH_3
- Particulate matter: TSP, PM_{10}, $PM_{2.5}$, BC
- Heavy metals: As, Cd, Cr, Ni, Pb, Se, Zn

Emissions associated with the fuel use are generally estimated and reported in the energy sector. In some cases however, emissions are measured for processes with contact between product and fuel, and emissions cannot be separated between the two. This is the case with some air pollutants from glass wool production. Here the total emissions are therefore attributed to the sector where the majority of the emission belongs, i.e. IPPU. See section 3.4.2 emission factors below.

3.4.1 Process description

The following descriptions as well as data are based on Holmegaard (2003), Rexam (2002) and Saint-Gobain Isover (2003).

The primary raw materials in glass production are dolomite ($CaMg(CO_3)_2$), feldspar ($(Ca,K,Na)AlSi_2O_8$), limestone ($CaCO_3$), sodium sulphate (Na_2SO_4), pluriol, sand (SiO), recycled glass (cullets), soda ash (Na_2CO_3), and colourants. Cullets constitute 40-50 % of the raw materials. For the art industrial glass products a number of additional raw materials are used: aluminium hydrate, barium carbonate, borax, potash (carbonised), kaolin, lithium carbonate, titanium dioxide, and zinc oxide.

The primary constituents of glass are e.g. SiO_2, Al_2O_3, CaO, MgO, Fe_2O_3, Na_2O, K_2O, BaO, PbO, B_2O_3 etc. where the actual composition depends on the final use of the product. The most common composition of glass for packaging is 60-75 % SiO_2, 5-12 % CaO, and 12-18 % Na_2O (Lenntech).

The products are bottles and glass jars (Rexam Glass Holmegaard) as well as drinking glasses and glass art products; e.g. vases (Holmegaard).

Emissions from glass production can be related to use of fuels, release of pollutants from raw materials and recycled glass, and release of CO_2 from use of soda ash.

Glass wool is produced from glass fibres and a binder (that is hardened to bakelite). The glass fibres are produced from sand, soda, limestone, dolomite, and auxiliaries (nephelin, dolomite, rasorite, palfoss, sodium nitrate and manganese dioxide) and glass waste. The raw materials are mixed with crushed glass. The mixture is melted in an electric furnace. The melted glass is drawn into fibres by a natural gas flame.

The fibres are mixed with binder and formed into wool. The glass wool is hardened in a furnace fired with natural gas. The emission originates from energy consumption and decarbonising of carbonate based raw materials.

3.4.2 Methodology

For the production of both container glass, art glass and glass wool, the main raw materials are soda ash (Na_2CO_3), dolomite ($CaMg(CO_3)_2$), limestone ($CaCO_3$) and recycled glass (cullets).

CO_2 emissions are calculated for each carbonate raw material individually. The remaining pollutants are calculated using total production data and emission factors.

Activity data

The activity data for container- and art glass production are presented in Table 3.4.1 and Annex A3-1. Information on consumption of carbon containing raw materials in container- and art glass production is available from the environmental reports for 1997-2013 (Ardagh, 2014) and from EU-ETS since 2006 (Ardagh, 2022) (confidential). For the years prior to 1997, the production data for glass are based on information contained in Illerup et al. (1999).

The annual produced amount of container glass is estimated based on the consumption of raw materials.

Table 3.4.1 Production of container/art glass, activity data, kt.

	1990	1995	2000	2005	2010	2015	2018	2019	2020	2021
Production of glass[1, 2]	164.0	140.0	183.3	168.2	172.9	155.7	156.2	158.1	140.4	157.2
Consumption of soda ash[3, 4]	17.8	15.2	16.4	13.0	c	c	c	c	c	c
Consumption of limestone[3,4]	14.4	12.3	7.7	5.7	c	c	c	c	c	c
Consumption of dolomite[3,4]	1.0	0.8	9.1	6.1	c	c	c	c	c	c

[1] 1990-1997: Illerup et al. (1999).
[2] 1998-2016: Estimated based on Illerup et al. (1999) and consumption of raw materials.
[3] 1990-1996: Estimated based on Illerup et al. (1999) and the consumption of raw materials in 1997.
[4] 1997 onward: Environmental reports and EU-ETS data; Ardagh (2014, 2022).
c Confidential: Data from EU-ETS (Ardagh, 2022).

Only one industrial art glass producer with virgin glass production exists in Denmark; Holmegaard A/S. Emissions from this production are included in the data on container glass above.

The activity data for glass wool production are presented in Table 3.4.2 and Annex A3-2. Information on produced amount of glass wool and consumption of carbon containing raw materials in glass wool production is available from the environmental reports for 1996-2014 (Saint-Gobain Isover, 2015), EU-ETS since 2006 (Saint-Gobain Isover, 2022a) (confidential) and PRTR (Saint-Gobain Isover, 2022b).

For the years prior to 1996 the production of glass wool and consumption of carbonates are assumed constant as the average production from 1997-1999.

Table 3.4.2 Production of glass wool, activity data, kt.

	1985	1990	1995	2000	2005	2010	2015	2019	2020	2021
Production of glass wool[1]	35.6	35.6	35.6	39.7	37.3	24.9	33.0	44.6	42.1	49.4
Consumption of soda ash[2, 4]	-	3.6	3.6	3.0	3.6	c	c	c	c	c
Consumption of limestone[2, 4]	-	0.8	0.8	0.2	0.6	c	c	c	c	c
Consumption of dolomite[3]	-	1.0	1.0	1.0	1.0	c	c	c	c	c

[1] 1990-1996: Estimated: Assumed constant on the average production from 1997-1999.
[2] 1990-1995: Estimated: Assumed constant on the average consumption from 1996-1998.
[3] 1990-2005: Estimated: Assumed constant on the average consumption from 2006-2008.
[4] 1996-2005: Environmental reports (Saint-Gobain Isover, 2015).
c Confidential: Data from EU-ETS (Saint-Gobain Isover, 2022a).

The time series for activity data for the glass sector are presented in Figure 3.4.1.

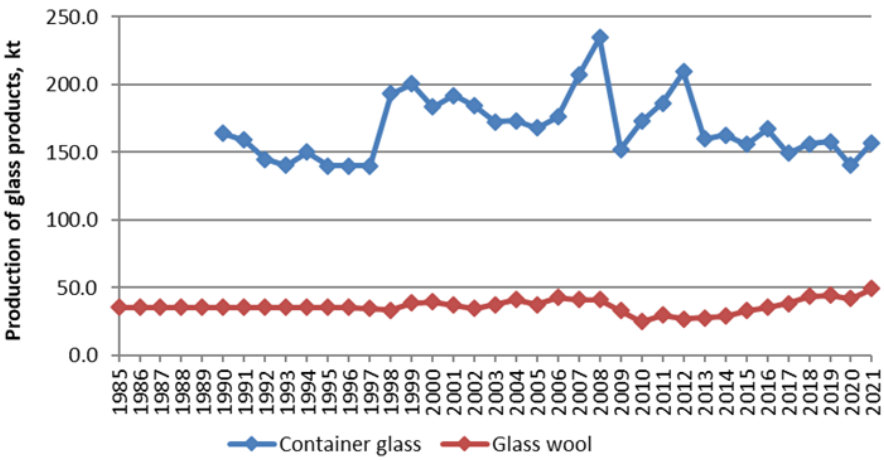


Figure 3.4.1 Activity data for container glass and glass wool production.

Both the container glass and glass wool production display a significant decrease from 2008 to 2010 that can be explained by the global financial crisis.

Emission factors

The applied emission factors for the glass industry are a combination of default Tier 2 emission factors from the EMEP/EEA guidebook (2019) and calculated implied emission factors based on measurements by the specific producers (environmental reports/PRTR). CO_2 emissions are estimated from the calcination of carbonate compounds and are based on stoichiometry or measurements.

Soda ash is either extracted from natural carbonate bearing deposits (I) or produced from calcium carbonate and sodium chloride (II).

(I) $2\ Na_2CO_3,NaHCO_3,2H_2O \rightarrow 3Na_2CO_3 + 5H_2O + CO_2$

(II) $CaCO_3 + 2NaCl \rightarrow Na_2CO_3 + CaCl_2$

The CO_2 emission factors from using soda ash and other carbonate containing raw materials in production of virgin glass and glass wool, based on stoichiometric relationships, are:

- 0.4149 t CO_2/t Na_2CO_3
- 0.4397 t CO_2/t $CaCO_3$
- 0.464-0.477 t CO_2/t $CaMg(CO_3)_2$
- 0.522 t CO_2/t $MgCO_3$

The emission factor for dolomite is 0.48 tonnes CO_2 per tonne for glass wool production and 0.46 tonnes CO_2 per tonne for container/art glass production in 2021. The average emission factor for dolomite in container glass production is 0.491 tonnes CO_2 per tonne dolomite for 2008-2021. The calcination of all carbonates in all years is assumed to be complete, i.e. a calcination fraction equal to 1, in line with the 2006 IPCC guidelines.

From 2006 onwards, the CO_2 emissions are calculated by the companies and reported under EU-ETS (Ardagh, 2022; Saint-Gobain Isover, 2022a), but the applied emission factors remain the same for the entire time series.

The emission of CO_2 is estimated from the following equation:

$E_{CO2} = \sum EF_s \times Act_s$ where:

E_{CO2} is emission of CO_2
EF_s is emission factor for substance *s*
Acts is consumption of substance *s*

Yearly emissions for selected pollutants from production of container glass are available in the environmental reports/PRTR based on measurements; these provide emissions of TSP (1997-2014), Pb (1997-2014), Se (1997-2009; 2012-2013) and Zn (1997-2001) (Ardagh, 2014 and 2015). Emissions of As, Cd, Cr and Ni are estimated from standard emission factors, the same is the case where direct emissions are not available for TSP, Pb, Se and Zn.

PM_{10} and $PM_{2.5}$ emissions are estimated from the distribution between TSP, PM_{10} and $PM_{2.5}$ (1/0.9/0.8) and BC is estimated as 0.062 % of $PM_{2.5}$, all available from EMEP/EEA (2019), Tier 2 container glass. All used emission factors are shown in Table 3.4.3. From 2006, measured particle emissions from the singular Danish container glass producer decrease 90 % due to installation of abatement equipment; all calculated particle and heavy metal emissions are therefore also lowered with 90 % from 2006. Emission factors applied for container glass production are presented in Table 3.4.3.

Table 3.4.3 Emission factors for production of container glass.

Pollutant	Applied for the years	Unit	Value	Source
TSP	1990-1996	g/t	280	EMEP/EEA (2019)
	2015-2021	g/t	13.7	EMEP/EEA (2019) with CS abatement[1]
PM_{10}	All	% of TSP	90	EMEP/EEA (2019)
$PM_{2.5}$	All	% of TSP	80	EMEP/EEA (2019)
BC	All	% of $PM_{2.5}$	0.062	EMEP/EEA (2019)
As	1990-2005	g/t	0.29	EMEP/EEA (2019)
	2006-2021	g/t	0.03	EMEP/EEA (2019) with CS abatement[1]
Cd	1990-2005	g/t	0.12	EMEP/EEA (2019)
	2006-2021	g/t	0.01	EMEP/EEA (2019) with CS abatement[1]
Cr	1990-2005	g/t	0.37	EMEP/EEA (2019)
	2006-2021	g/t	0.04	EMEP/EEA (2019) with CS abatement[1]
Ni	1990-2005	g/t	0.24	EMEP/EEA (2019)
	2006-2021	g/t	0.02	EMEP/EEA (2019) with CS abatement[1]
Pb	1990-1996	g/t	2.9	EMEP/EEA (2019)
	2015-2021	g/t	0.29	EMEP/EEA (2019) with CS abatement[1]
Se	1990-1996	g/t	1.5	EMEP/EEA (2019)
	2010-2011; 2014-2021	g/t	0.19	Average IEF (2008-09;2012-13)
Zn	1990-1996; 2002-2005	g/t	0.23	Average IEF (2007-2001)
	2006-2021	g/t	0.02	Average IEF (2007-2001) with CS abatement[1]

[1]Country specific abatement is measured by the producer to 90 %.

The emission of NH_3 and TSP from the production of glass wool has been measured yearly for 1996-2021 and are available in the company's environmental reports (Saint-Gobain Isover, 2015 and 2022b) supplemented with personal contact to the company (Saint-Gobain Isover 2022c). NMVOC and CO have also been measured for 2007-2014 and 1996-1997, respectively. For the years where no measured emission data are available, emissions are calculated using implied emission factors (IEFs) based on the available measurements. PM_{10} and $PM_{2.5}$ are estimated from the distribution between TSP, PM_{10} and $PM_{2.5}$ (1/0.9/0.8) from EMEP/EEA (2019). All applied emission factors are shown in Table 3.4.4. As the process includes contact between fuel and raw material, it has not been possible to separate process emissions from the emissions from fuel combustion, the measured/calculated emissions from glass wool production presented here account for the entire production.

Table 3.4.4 Emission factors for production of glass wool.

Pollutant	Applied for the years	Unit	Value	Source
NMVOC	1985-2006	kg/t	1.35	Average IEF (2007-2009)
	2015-2021	kg/t	1.17	Average IEF (2012-2014)
CO	1985-1995; 1998-2021	kg/t	0.06	IEF (1997)
NH_3	1985-1995	kg/t	7.6	Average IEF (1996-1998)
	2015	kg/t	4.4	Average IEF (2012-2014)
TSP	1990-1995	kg/t	2.9	Average IEF (1996-2000)
PM_{10}	All	% of TSP	90	EMEP/EEA (2019)
$PM_{2.5}$	All	% of TSP	80	EMEP/EEA (2019)
BC	All	% of $PM_{2.5}$	2.0	EMEP/EEA (2019)

3.4.3 Emission trend

For the years from 2006 onwards, information on the CO_2 emission is available in the company's reports under the EU-ETS (Ardagh, 2022; Saint-Gobain Isover, 2022a). However, this information is confidential and data since 2006 can therefore only be presented as total emitted CO_2.

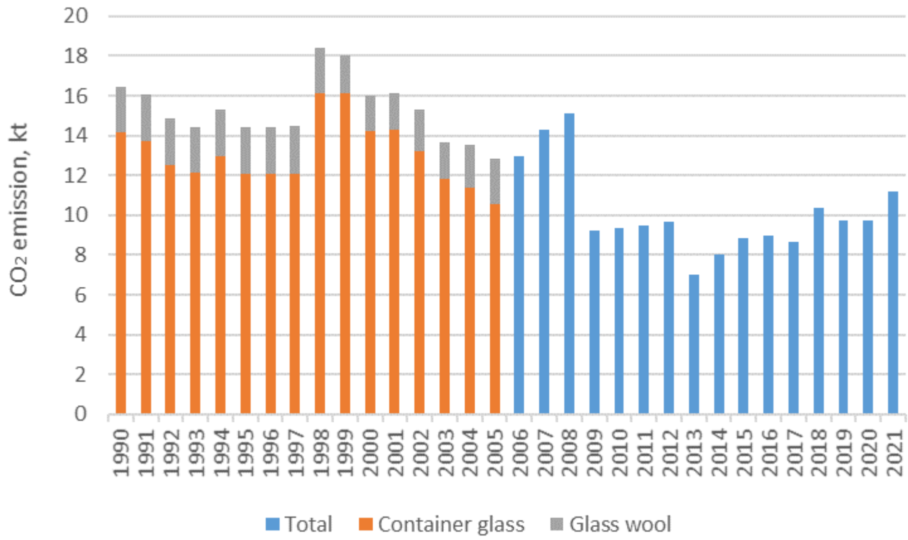


Figure 3.4.2 CO_2 emissions from glass production.

The only pollutants to which both container glass and glass wool production contribute are particles. Table 3.4.5 and Annex A3-3 show the individual emissions from the two sources.

Table 3.4.5 Emission from glass production.

	Pollutant	Unit	1985	1990	1995	2000	2005	2010	2015	2018	2019	2020	2021
Container glass	TSP	t	-	46	39	26	7.0	1.7	2.1	2.1	2.2	1.9	2.2
	PM_{10}	t	-	41	35	23	6.3	1.5	1.9	1.9	1.9	1.7	1.9
	$PM_{2.5}$	t	-	36	31	20	5.5	1.3	1.7	1.7	1.7	1.5	1.7
	BC	kg	-	22	19	13	3.4	0.8	1.0	1.0	1.1	0.9	1.0
	As	kg	-	48	41	53	49	5.0	4.5	4.5	4.6	4.1	4.6
	Cd	kg	-	20	17	22	20	1.7	1.6	1.6	1.6	1.4	1.6
	Cr	kg	-	61	52	68	62	6.4	5.8	5.8	5.8	5.2	5.8
	Ni	kg	-	39	34	44	40	4.2	3.7	3.7	3.8	3.4	3.8
	Pb	kg	-	476	406	330	148	24	45	45	46	41	46
	Se	kg	-	246	210	340	107	33	30	30	30	27	30
	Zn	kg	-	38	32	57	39	4.0	3.6	3.6	3.6	3.2	3.6
Glass wool	NMVOC	t	48	48	48	54	50	32	39	51	52	49	58
	CO	t	2.0	2.0	2.0	2.3	2.1	1.4	1.9	2.5	2.5	2.4	2.8
	NH3	t	271	271	271	225	116	108	145	76	99	65	71
	TSP	t	-	102	102	111	85	26	38	40	38	34	19
	PM_{10}	t	-	92	92	100	77	23	34	36	34	30	17
	$PM_{2.5}$	t	-	82	82	89	68	21	30	32	30	27	15
	BC	t	-	1.6	1.6	1.8	1.4	0.4	0.6	0.6	0.6	0.5	0.3

3.4.4 EU-ETS data for glass production

The applied methodologies for Ardagh Glass Holmegaard and Saint-Gobain Isover are specified in the individual monitoring plan that is approved by the Danish competent authority, which is the Danish Energy Agency (DEA) prior to the reporting of the emissions.

Glass production applies the Tier 3 for both methodology and emission factors as the calculations are based on individual carbonates used as raw materials.

The CO_2 emission from container glass production is based on consumption of carbonate raw materials (based on invoices and corrected for changes in inventory by measures on the storage silos; Tier 2: 0.45-0.66 % depending on the silo) and standard emission factors except for dolomite where Ca/Mg analysis are performed for each new batch (Ardagh, 2020).

The CO_2 emission from glass wool production is based on weight measures of carbonate raw materials (Tier 1: ±2.5%) and standard emission factors (Saint-Gobain Isover, 2020).

3.4.5 Verification

For verification purposes, the implied CO_2 emission factors for glass production are presented in Figure 3.4.3.

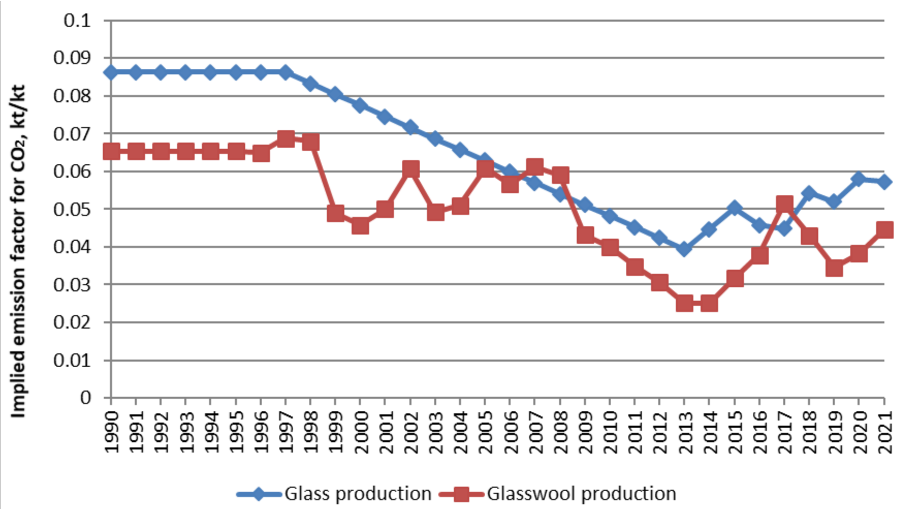


Figure 3.4.3 Implied emission factors for glass production.

Figure 3.4.3 shows that improvements in both glass production processes have lowered the IEFs significantly during the time series, but that there have also been an increase in IEF in the later years for both glass productions.

CO_2 emissions from glass production is based on raw material consumption for 1997-2021. Production data is known for 1997 and 2013-2021. For 1998-2012, production data are interpolated resulting in a straight line for IEF for glass production for 1997-2013.

CO_2 emissions from container glass production are calculated using both a Tier 1 method and a Tier 2 method and the results are then compared with the applied Tier 3 method, see Figure 3.4.4. The following assumptions are used for the two lower Tiers:

- Tier 1: 0.2 tonnes CO_2 per tonne product and 0.5 cullet ratio (IPCC, 2006[7])
- Tier 2: 0.21 kg CO_2 per kg container glass (IPCC, 2006[8]) and the actual annual cullet ratios (0.34-0.76)

[7] Volume 3 Industrial Processes and Product Use, Chapter 2.4.1.2 page 2.29 and chapter 2.4.1.3, page 2.30.
[8] Volume 3 Industrial Processes and Product Use, Chapter 2.4.1.2 page 2.30 (Table 2.6).

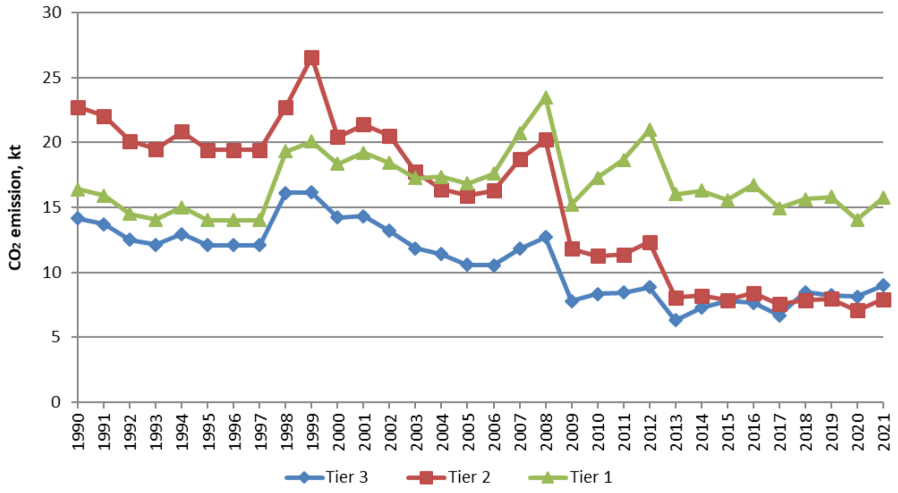


Figure 3.4.4 Comparison of CO_2 emission from container glass production calculated using different methods.

The Tier 1 method is a decent match in the beginning of the 1990s, but as the Danish production improves over the years, the basis of the Tier 1 estimate is constant. The Tier 2 calculations (including the actual cullet ratios known for 1997-2002 and 2004-2013) are in good agreement with the Tier 3 calculations with a decrease in emissions over the time series. However, Tier 2 generally results in an overestimation of emissions up until 2015.

A similar verification using different method Tiers is not possible for glass wool since there are no default methods available in the 2006 IPCC guidelines.

3.4.6 Time series consistency and completeness

CO_2 emissions from container/art glass and glass wool production are calculated based on consumption of carbonates and stoichiometric emission factors for the entire time series, the time series is therefore consistent.

In relation to completeness, the production of flat glass (SNAP 03 03 14) does not occur in Denmark. The processes in Denmark are limited to mounting of sealed glazing units. The mounting process does not contribute to greenhouse gas emissions in Denmark.

Efforts have been made to ensure that all glass producers are included in the inventory. Smaller facilities producing art glass do exist in Denmark, but none of these was found to produce their own virgin glass. The source category of glass production is therefore considered to be complete.

3.4.7 Input to CollectER

The environmental reports/PRTR present energy as well as process related emissions. The process related air emissions are used as input for the emission calculations along with the CO_2 emissions from calcination of the raw materials. The TSP emission from both container glass and glass wool production is based on the environmental reports with a distribution between PM_{10} and $PM_{2.5}$ as reported in EMEP/EEA (2019) i.e. 90 % and 80 % of TSP, respectively. The input data/data sources are presented in Table 3.4.6.

Table 3.4.6 Input data for calculating emissions from glass production.

	Year	Parameter	Comment/Source
Activity data	1990-1997	Container glass production	Illerup et al. (1999)
	1998-2012	Container glass production	Estimated from consumption of carbonate raw materials
	1990-1996	Consumption of raw materi-als for container glass	Estimated from production
	1997-2021	Consumption of raw mate-ri-als for container glass	Ardagh (2014 and 2022)
	1985-1996	Glass wool production	Assumed to be average 1997-1999
	1997-2021	Glass wool production	Saint-Gobain Isover (2015 and 2022a)
	1990-1995 (1990-2005)	Carbonate consumption for glass wool production	Assumed to be average 1996-1998 (2006-2008 for dolomite)
	1996-2021	Carbonate consumption for glass wool production	Saint-Gobain Isover (2015 and 2022a)
Emissions	1990-1996, 2015-2021	Pb	Illerup et al. (1999), EMEP/EEA (2019)
	1997-2014	Pb	Ardagh (2014 and 2015)
	1990-1996, 2010-2011, 2014-2021	Se	Illerup et al. (1999), EMEP/EEA (2019)
	1997-2009, 2012-2013	Se	Ardagh (2014 and 2015)
	1990-1996, 2015-2021	TSP	Illerup et al. (1999), EMEP/EEA (2019)
	1997-2014	TSP	Ardagh (2014, 2015), Saint-Go-bain Isover (2015, 2022b)
	All	PM_{10}, $PM_{2.5}$, BC	Distribution between TSP, PM_{10}, $PM_{2.5}$ and BC from EMEP/EEA (2019)
	All	As, Cd, Cr, Ni	EMEP/EEA (2019)
	1997-2001	Zn	Ardagh (2014)
	1990-1996; 2002-2021	Zn	Calculated from activity data and implied emission factors (IEF) (1997-2001)
	1985-2006	NMVOC	Calculated from activity data and IEF (2007-2009)
	2015-2021	NMVOC	Calculated from activity data and IEF (2012-2014)
	2007-2014	NMVOC	Saint-Gobain Isover (2015 and 2022b)
	1985-1995	NH_3	Average IEF for 1996-1998
	1996-2014, 2016-2021	NH_3	Saint-Gobain Isover (2015 and 2022b)
	2015	NH_3	Average IEF for 2012-2014
	1985-1996, 1998-2021	CO	Calculated from activity data and IEF (1997)
	1996-1997	CO	Saint-Gobain Isover (2015)
	1990-2005	CO_2	Estimated from consumption of carbonates raw materials
	2006-2021	CO_2	EU-ETS (Ardagh, 2022; Saint-Gobain Isover, 2022a)

3.5 Ceramics

This section covers production of bricks/tiles (aggregates or bricks/blocks for construction) and expanded clay products for different purposes (aggregates as absorbent for chemicals, cat litter, and for other miscellaneous purposes). The following SNAP categories are covered:

- 04 06 91 Production of bricks
- 04 06 92 Production of expanded clay products

The production of bricks (including tiles) is found all over the country, where clay is available. Producers of expanded clay products are located in the northern part of Jutland.

Emissions associated with the fuel use are estimated and reported in the energy sector and therefore not included in this report.

Emissions of the following pollutants are included:

- CO_2
- SO_2
- PCDD/F

3.5.1 Process description

During the production of ceramics, the raw materials are collected and finely crushed in successive grinding operations. The ground particles are then fired in a kiln to produce a powder (which may be liquefied). Additives are subsequently added and the ceramic is formed.

The clays used in the production process include small amounts of carbonates, which is oxidised during the process thereby generating CO_2. In addition, some of the clays contain significant amounts of sulphur, which is oxidised and released as SO_2 during the process.

The production sites of bricks, tiles and expanded clay products are found all over the country; see Table 3.5.1 and Figure 3.5.1. Many of the facilities have shot down operations over the later years.

Table 3.5.1 Producers of bricks, tiles and expanded clay products.

Product	Company	Location
Bricks and tiles	Strøjer Teglværk	5610 Assens
	Vesterled Teglværk	6400 Sønderborg
	Vindø Teglværk	9500 Hobro
	Pedershvile Teglværk	3200 Helsinge
	Prøvelyst Teglværk[1]	2980 Kokkedal
	Lundgård Teglværk[1]	7850 Stoholm, Jylland
	Bachmanns Teglværk[1]	6400 Sønderborg
	Petersen Tegl	6310 Broager
	Orebo Teglværk[1]	4293 Dianalund
	Tychsen's Teglværk[1]	6310 Broager
	Nordtegl[1]	9881 Bindslev
	Ydby Teglværk[1]	7760 Hurup Thy
	Hellingsø Teglværk	7760 Hurup Thy
	Carl Matzens Teglværk	6320 Egernsund
	Gråsten Teglværk	6300 Gråsten
	Wienerberger Petersminde	6320 Egernsund
	Gandrup Teglværk	9362 Gandrup
	Hammershøj Teglværk	8830 Tjele
	Højslev Teglværk	7840 Højslev
	Monier Volstrup Teglværk	9300 Sæby
	Villemoes Teglværk[1]	6690 Gørding
Expanded clay products	LECA Danmark	8900 Randers
	Imerys Mors	7900 Nykøbing Mors
	Imerys Fur	7884 Fur

[1] Production has been closed down.

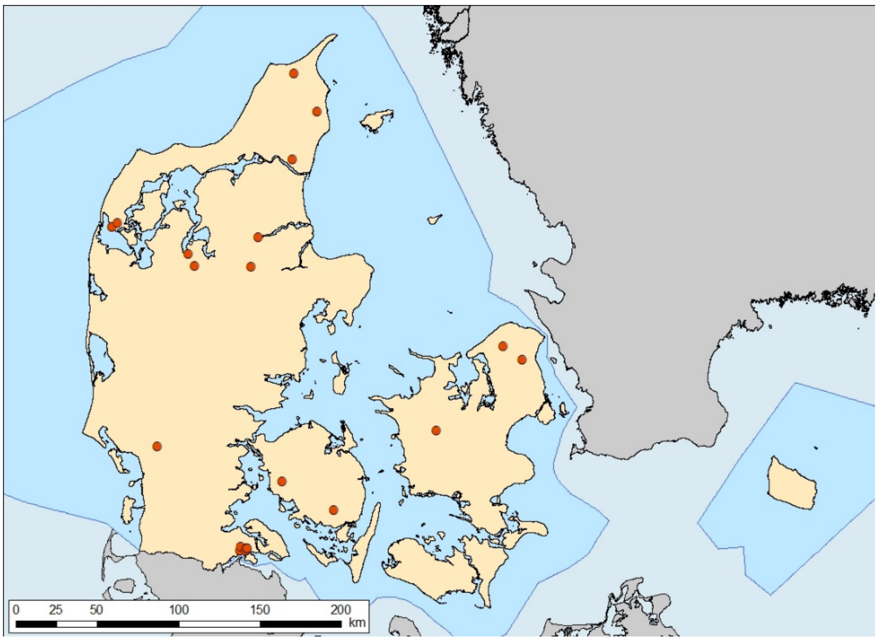


Figure 3.5.1 Location of production sites of bricks, tiles and expanded clay products in Denmark.

The expanded clay products are presented in Table 3.5.2.

Table 3.5.2 Products from different producers of expanded clay products.

Company	Location	Products
Imerys	Fur, Nykøbing Mors	Cat litter (e.g. Amigo)
		Soil improvers (e.g. Terramol)
		Insulators (e.g. Insumol)
		Filtrators (e.g. Purimol)
		Carriers (e.g. Absomol)
		Fillers (e.g. Danamol)
		Auxiliaries and binders for the feed industry (e.g. Diamol)
		Absorbants (e.g. Absodan)
		Oil absorbants (e.g. Oil Dri, Ekoperl)
		Bedding (e.g. Animol)
LECA Danmark	Randers, Gadbjerg	Filtralite
		Leca

3.5.2 Methodology

The emission of CO_2 and SO_2 is related to the carbon and sulphur content in the raw materials, whereas the emission of NO_x and other pollutants is related to fuel consumption/process conditions. A typical composition of clay used for bricks is presented in Table 3.5.3.

Table 3.5.3 Typical composition of clay used for bricks (Tegl Info, 2004).

	Red bricks, %	Yellow bricks, %
Silicic acid (SiO_2)	63.2	49.6
Aluminium oxide (Al_2O_3)	17.9	14.2
Iron(III)oxide (Fe_2O_3)	7.1	5.1
Calcium carbonate ($CaCO_3$)	0.5	19.8
Magnesium oxide (MgO)	1.3	1.4
Alkali oxides (e.g. Na_2O, K_2O)	2.9	2.9
Chemical bound water and organic substances	7.1	7.0

The emission estimation is based on the total carbon content of the raw material. Since 2006, the producers of ceramics have measured and reported process carbon consumption and CO_2 emissions to EU-ETS and production statistics are known from Statistics Denmark (VARER1 08/08-2022) for the entire time series. From these two datasets, implied CO_2 emission factors (i.e. tonne $CaCO_3$ per tonne product) are calculated for 2006-2013 and emissions are calculated for the years back to 1990.

EU-ETS CO_2 emission data from LECA includes carbonates in the clay raw material from 2013 onwards. To increase time series consistency, the $CaCO_3$ equivalent contribution from clay is estimated and included for 1990-2012.

The SO_2 emission and fuel consumption are known for nine different producers of ceramics for 2007-2014 (and also 2015-2021 for expanded clay production at LECA). The SO_2 emission from the fuel consumption is calculated using Danish standard emission factors, and this is subtracted from the total SO_2 emission. The remaining emission is used to calculate two SO_2 emission factors for brickworks and expanded clay production, respectively, for 1980-2006 based on IEF (2007-2010) and two based on IEF (2012-2014) for 2015 onward. These factors are used for all producers of bricks/tiles and for all expanded clay producers, respectively. However, from 2006 onward the expanded clay producer LECA is reported as a large point source with its own (implied) emission factors for SO_2. These emission factors are calculated using the same method as described above; i.e. the difference between total emission and fuel emission. The PCDD/F emission factor is known from national literature.

Activity data

National statistics on production of bricks, tiles and expanded clay (together called ceramics) contain a broad range of different products, most of them in units of numbers (no.). The consumption of limestone is therefore used as alternative activity data for these source categories; available for 2006-2021 (EU-ETS data). The national production statistics for ceramics are used as surrogate data; available for 1985-2021. Prior to 1985 activity data are estimated as the 1985-1989 average.

Data on consumption of lime and produced amounts of ceramics are presented in Table 3.5.4 and Annex A4-1.

Table 3.5.4 Statistics for production of bricks/tiles and expanded clay products.

		1980	1985	1990	1995	2000	2005	2010	2015	2020	2021
Bricks and tiles											
Produced[1]	million pieces	407.6	441.7	315.2	385.6	436.3	426.5	223.0	226.7	311.9	333.2
Consumed lime[2]	kt $CaCO_3$	75.7	82.1	58.6	71.7	81.1	79.2	35.1	46.2	61.1	60.6
Expanded clay products											
Produced[1]	kt	370.0	363.2	331.8	340.9	316.2	310.9	157.4	155.0	247.6	263.0
Consumed lime[2]	kt $CaCO_3$-eq	51.5	50.6	46.2	47.5	44.0	43.3	19.1	19.5	37.5	60.9

[1] Statistics Denmark (VARER1, 08/08-2022).

[2] 1980-2005: Calculated from production data and the average implied emission factor for 2006-2013.

The consumption of limestone equivalents in the production of ceramics is also presented in the following figure.

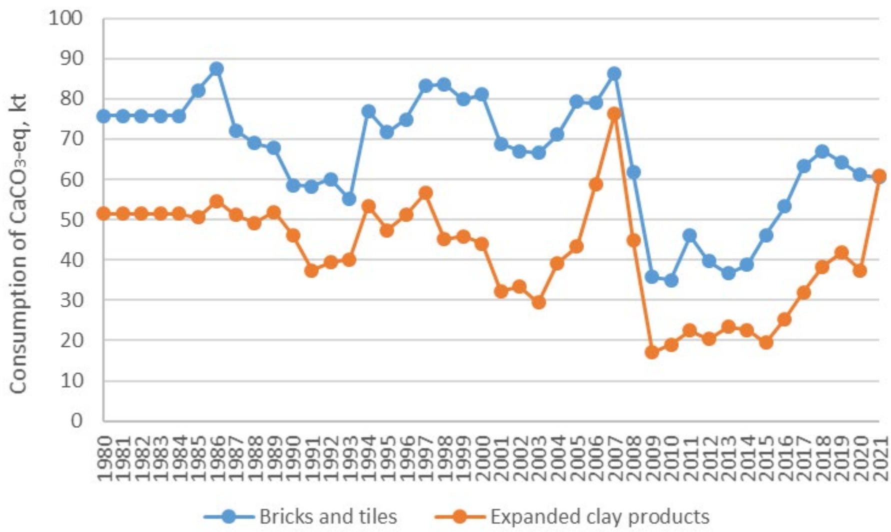


Figure 3.5.2 Consumption of $CaCO_3$ equivalents in the production of ceramics.

Both the brickworks and expanded clay productions displays a significant decrease from 2007 to 2009 that can be explained by the global financial crises. The decreases correspond to 59 % and 71 %, respectively, for brickworks and expanded clay production. The number of brickworks has been decreasing; in 2006, 19 brickworks reported to EU-ETS, by 2014 this number had decreased to 13. Two brickworks closed down in 2008, further two in 2009 and another two in 2013. There are still 13 brickworks reporting emissions for 2021.

Emission factors

The CO_2 emission factor for calcination of limestone is 0.4397 kg per kg $CaCO_3$ based on stoichiometry. The calcination factor is assumed to be 100 % for all years and all producers.

Since 2006, CO_2 emissions are reported by the brickworks to EU-ETS (confidential reports). The reported emissions are calculated from measured lime contents of the raw materials and the stoichiometric emission factor 0.4397 kg CO_2 per kg $CaCO_3$.

Producers of expanded clay products also report CO_2 emissions to EU-ETS for the years since 2006 (Imerys, 2022; LECA, 2022). The reported emissions are calculated from the difference in C contents measured in the raw materials and products and the stoichiometric emission factor 3.664 kg CO_2 per kg C. The reported emissions are recalculated to match the activity data for brickworks using the stoichiometric factors.

The SO_2 emission factors for the production of bricks/tiles and expanded clay products are determined from the individual companies reporting of SO_2 emission (environmental reports) for the years 2007-2014 and the activity for the corresponding years. The years 2015-2021 are also included for the large point source LECA. The SO_2 emissions have been adjusted for fuel related emissions to derive the process emissions.

The SO_2 emissions attributed to the process have been adjusted for the fuel related emissions from coal, petroleum coke and residual oil according to EU-ETS reporting. The fuel related SO_2 emission was calculated by using the general EF_{SO2} for the relevant fuels (Nielsen et al., 2022b). The applied emission factors are presented in Table 3.5.5.

Table 3.5.5 Applied emission factors for S-containing fuels.

Fuel	Emission factor, g SO_2/GJ
Coal	397-513*
Petroleum coke	605
Residual oil	344

* Varies annually.

The total emissions of SO_2 from the plants considered were reduced by the amount related to fuel before calculating the emission factor seen in Table 3.5.6.

The PCDD/F emission factors are calculated from 0.018 µg per tonne product (Hansen og Hansen, 2003), using the total carbonate consumption (environmental reports), national production statistics (Statistics Denmark, VARER1 08/08-2022) and assumption of 2.5 kg per brick/tile (DCE assumption).

The PCDD/F emission factor of 0.018g I-TEQ/ton product is recalculated to match the activity data of used $CaCO_3$ equivalents. This requires a fraction of product produced per carbonate consumption. For brickworks, the calculation is based on the average production of bricks/tiles (tonnes) per $CaCO_3$-eq consumption for 2006-2013; i.e. 13.7 tonnes per tonne $CaCO_3$-eq. For expanded clay products, the calculation is based on the average production of expanded clay products (tonnes) per $CaCO_3$-eq consumption for 2006-2013; i.e. 7.27 tonnes per tonne $CaCO_3$-eq. The resulting emission factors are 0.25 µg and 0.13 µg PCDD/F per tonne $CaCO_3$-eq for brickworks and expanded clay products, respectively.

The applied emission factors for ceramics are presented in Table 3.5.6.

Table 3.5.6 Emission factors for ceramics excluding emissions from fuel, units are per ton $CaCO_3$ equivalent.

Pollutant	CO_2	SO_2	SO_2	PCDD/F
Applied for the years	All	1980-2006	from 2015	All
Unit	kg	kg	kg	µg
Brickworks	0.44	9.9	4.4	0.25
Expanded clay				
- LECA	0.44	51.5	-[2]	0.13
- other	0.44	51.5	109.9	0.13
Source	Stoichiometric	Average IEF[1] (2007-2010)	Average IEF[1] (2012-2014)	Hansen og Hansen (2003)

[1] Calculated using data from the companies' environmental reports.
[2] Process emissions of SO_2 are available for LECA since 2008, hence no IEF in necessary.

3.5.3 Emission trend

Emissions of CO_2, SO_2 and PCDD/F from production of ceramics are presented in Table 3.5.7, Figure 3.5.3, Figure 3.5.4 and Annex A4-2.

Table 3.5.7 Process emissions from production of ceramics.

Pollutant	Source	Unit	1980	1985	1990	1995	2000	2005	2010	2015	2020	2021
CO_2	Total	kt	-	-	46.1	52.4	55.0	53.9	23.8	28.9	43.4	53.4
	Brickworks	kt	-	-	25.8	31.5	35.6	34.8	15.4	20.3	26.9	26.6
	Expanded clay	kt	-	-	20.3	20.9	19.4	19.0	8.4	8.6	16.5	26.8
SO_2	Total	kt	3.4	3.4	3.0	3.2	3.1	3.0	1.5	0.7	0.9	0.6
	Brickworks	kt	0.7	0.8	0.6	0.7	0.8	0.8	0.4	0.2	0.3	0.3
	Expanded clay	kt	2.7	2.6	2.4	2.4	2.3	2.2	1.1	0.5	0.6	0.3
PCDD/F	Total	mg	-	-	20.6	24.1	26.0	25.4	11.2	14.1	20.2	23.1
	Brickworks	mg	-	-	14.6	17.9	20.3	19.8	8.8	11.6	15.3	15.1
	Expanded clay	mg	-	-	6.0	6.2	5.7	5.6	2.5	2.5	4.9	7.9

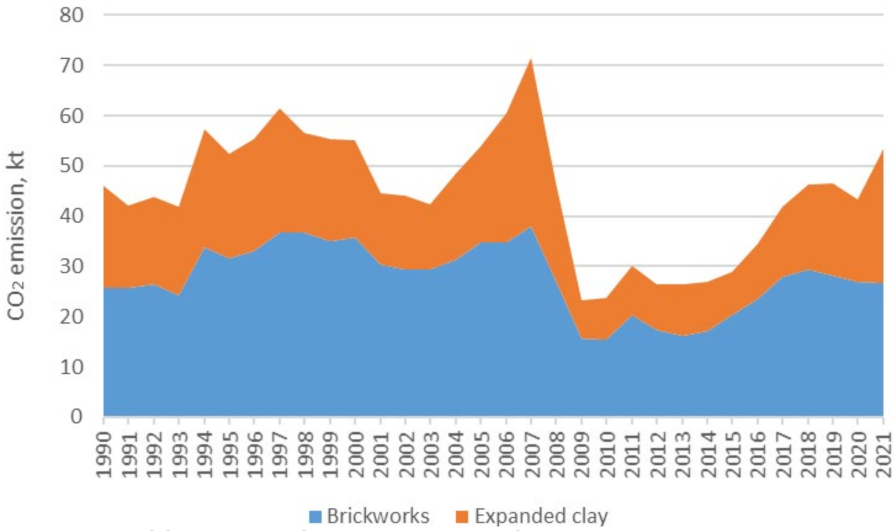


Figure 3.5.3 CO_2 emissions from the production of ceramics.

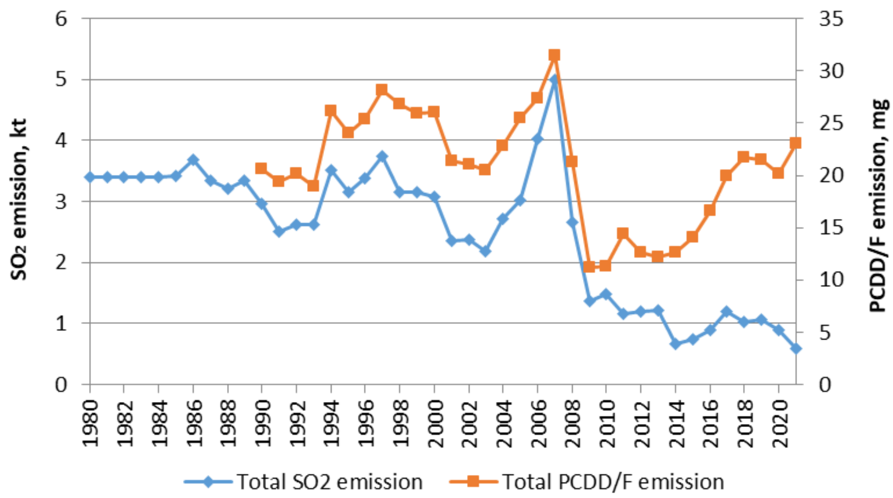


Figure 3.5.4 Total SO_2 and PCDD/F emissions from the production of ceramics.

Emissions from this source category are very dependent on new houses being built as well as old ones being renovated. The significant decline in emissions from 2007-2009 was caused by a reduced production resulting from the economic recession caused by the global financial crisis.

3.5.4 EU-ETS data for ceramics

The applied methodologies for brickworks and expanded clay producers are specified in the individual monitoring plans that are approved by the Danish competent authority, which is the Danish Energy Agency (DEA) prior to the reporting of the emissions. The production of ceramics applies the ETS Tier 2 methodology for calculating the CO_2 emission.

The CO_2 emission for ceramics production at brickworks is based on measured carbonate content in all raw materials and consumption of the individual carbonate containing raw materials (Tier 2; ± 5.0 %). For carbonates used at LECA is applied a Tier 3-4 (± 0.5-1 %) and at Imerys is applied a Tier 1 (± 7.5 %). The implied CO_2 emission factors for the production facilities are based on stoichiometry and 100 % calcination is assumed.

3.5.5 Verification

For 2013-2019, the brickwork companies have reported production of brick/tile products (tonnes) and thereby making it possible to verify the applied production data from Statistics Denmark for these years. A comparison of the two datasets is presented in Table 3.5.8.

Table 3.5.8 Verification of production data from Statistics Denmark against EU-ETS data.

	Unit	2013	2014	2015	2016	2017	2018	2019
Statistics Denmark[1]	t product	466790	498335	566685	626698	702303	717085	720270
EU-ETS	t product	474512	493691	566640	620238	713620	745533	761548
Difference	t product	-7722	4644	45	6459	-11317	-28448	-41278
Difference	-	-1.63 %	0.94 %	0.01 %	1.04 %	-1.59 %	-3.82 %	-5.42 %

[1] VARER1 08/08-2022. Data are calculated into tonnes (from pieces) using the assumption of 2.5 kg per brick or tile.

The data presented in Table 3.5.8 show a good agreement between the two data sources with an average difference of 1.5 % for 2013-2019. This comparison indicates that all Danish brickworks report to EU-ETS and that this source is therefore complete.

For 2006-2021, the implied emission factors have been derived from CO_2 emissions reported by the producers of ceramics to EU-ETS and production statistics (Statistics Denmark, VARER1 08/08-2022). Figure 3.5.5 presents the calculated implied emission factors for ceramics and for the individual product types bricks/tiles and expanded clay products.

The implied emission factors for the production of bricks/tiles are calculated to 26.5-41.5 kg CO_2 per tonne bricks/tiles (average: 34.7 kg CO_2 per tonne product) for 2006-2021 and the IEF for expanded clay products is 53.0-101.8 kg CO_2 per tonne product (average: 69.6 kg CO_2 per tonne product) for the same period. Figure 3.5.5 shows the development of these IEFs for the years 1990-2021. The overall average IEF for ceramics for 2006-2021 is 42.8 kg CO_2 per tonne product. The emission factor for both types of ceramics is 0.4397 tonnes CO_2 per tonne $CaCO_3$.

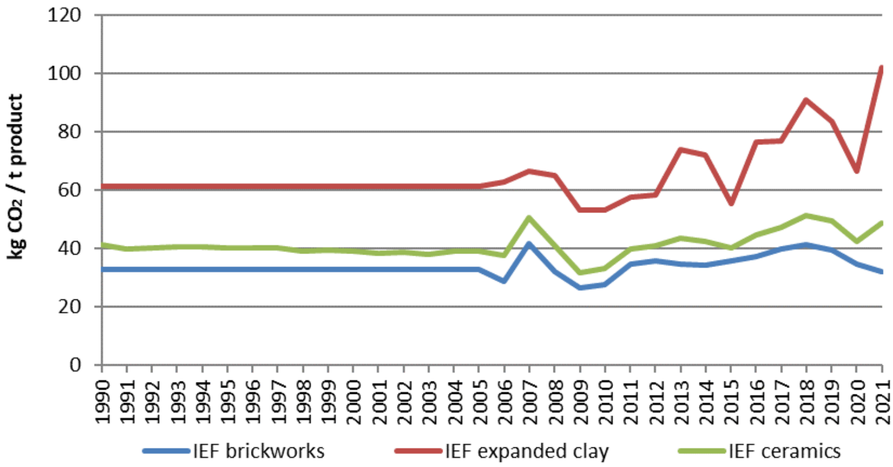


Figure 3.5.5 Implied emission factors for ceramics.

Figure 3.5.5 shows fluctuations in the IEFs for CO_2 as would be expected when comparing sale figures from a national statistics with the consumption of raw material in production given by the producers. The major reason for fluctuations in the IEF time series is most likely due to changes in stocks.

The assumptions applied in order to calculate the default Tier 1 IEF are listed in the following (IPCC, 2006):

- Consumption of clay: 1.1 tonnes clay per tonne product
- Carbon content in clay: 10 % (range from 0 to over 30 %)
- Distribution between carbonates: 85 % limestone/15 % dolomite
- Fraction of calcination: 100 %
- Emission factors: 0.4397 tonnes CO_2 per tonne limestone and 0.4773 tonnes CO_2 per tonne dolomite

The IPCC (2006)[9] default emission factor for ceramics is 49.0 kg CO_2 per tonne product, which is within reasonable compliance with the IEFs of Figure 3.5.5.

[9] Volume 3 Industrial Processes and Product Use, Chapter 2.5.1.3 page 2.36, Chapter 2.5.1.1 page 2.34 and Chapter 2.1 page 2.7 (Table 2.1).

As stated above, the carbon content mentioned in IPCC (2006) is a range from 0 % to 30 % with 10 % as default. Carbon contents of 0 % and 30 % corresponds to emission factors of 0 and 147 kg CO_2 per tonne product, respectively. All Danish implied emission factors are within this range.

The overall IEF for CO_2 for the source category *Ceramics* has been calculated and is compared with the default Tier 1 IEF calculated using production statistics from Statistics Denmark (VARER1 08/08-2022) and default Tier 1 assumptions from IPCC (2006), see Figure 3.5.6.

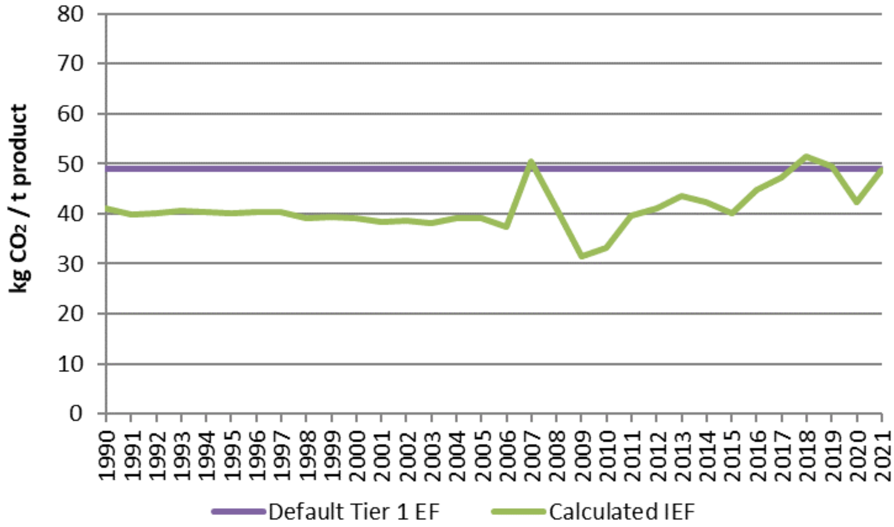


Figure 3.5.6 Development in implied emission factors for CO_2.

The comparison of IEFs shown in Figure 3.5.6 shows good agreement considering the rough assumptions listed above the figure.

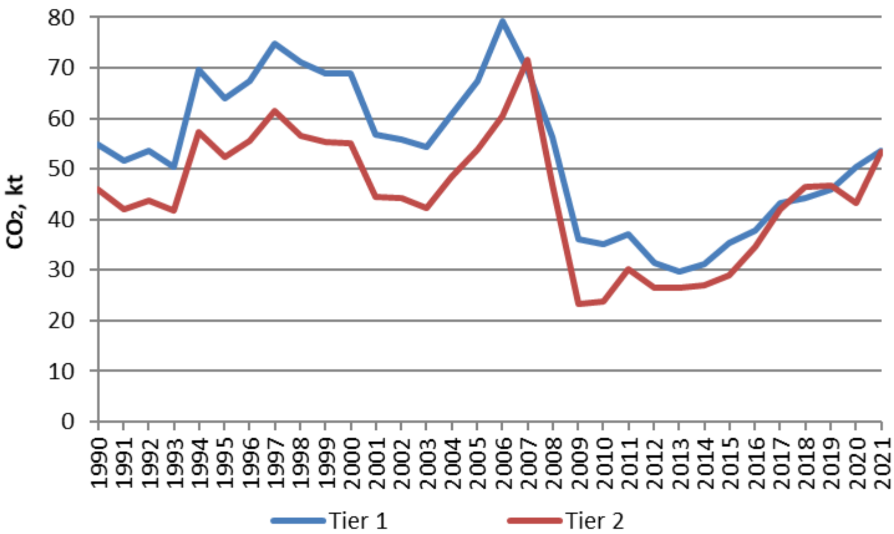


Figure 3.5.7 Comparison of emissions calculated by Tier 1 and Tier 2 method.

Figure 3.5.7 shows the CO_2 emissions from production of ceramics calculated by the Tier 1 method (IPCC, 2006) and the applied Tier 2 method. This shows an acceptable agreement between the methods.

3.5.6 Time series consistency and completeness

Emissions from 2006 onwards are known from the EU-ETS reports and emissions for 1990-2005 are estimated. However, due to the various performed verifications, the ceramics source category is considered consistent.

The inventory is based on companies reporting to EU-ETS and national sales statistics, but clay is also burned in minor scale e.g. ceramic art workshops and school art classes. These miniscule sources are however negligible and the source category of ceramics is considered complete.

3.5.7 Input to CollectER

The actual applied data on production of ceramics are summarised in Table 3.5.9.

Table 3.5.9 Input data for calculating emissions from production of ceramics.

	Year	Parameter	Comment/Source
Activity data	1985-2021	Sale of products	Statistics Denmark; assumptions: 2.5 kg
	1980-1984	Sale of products	Assumed as 1985-1989 average
	1980-2005	Consumption of carbonates	Calculated from sale statistics and average carbonate consumption per product (2006-
	2006-2021	Consumption of carbonates	Company reports to EU-ETS
Emissions	1990-2005	CO_2	Calculated from consumption of carbonates
	2006-2021	CO_2	Company reports under the EU-ETS
	1980-2021	SO_2	EF estimated from environmental reports 2007-2014 (2007-2021 for LECA)
	1990-2021	PCDD/F	Calculated using emission factor from Hansen og Hansen (2003)

3.6 Other uses of soda ash

This section covers the use of soda ash not related to glass production. The following SNAP category is covered:

- 04 06 19 Other uses of soda ash

3.6.1 Process description

When soda ash (Na_2CO_3) is used in processes where it is heated, it decomposes and CO_2 is released. The reaction is:

$$Na_2CO_3 + heat \rightarrow Na_2O + CO_2$$

There are uses of soda ash that are non-emitting since they do not involve heating of the soda ash, e.g. in soaps and detergents.

3.6.2 Methodology

Emissions from other uses of soda ash (Na_2CO_3) are calculated based on national statistics on import/export (subtracted the amount used in the glass industry) and the stoichiometric emission factor. No information is available on the end uses of soda ash and therefore all use is considered emissive. There is no production of soda ash in Denmark.

Activity data

National statistics on import and export and the calculated activity data (supply) are presented in Table 3.6.1 and Annex A5-1.

Table 3.6.1 Statistics for other uses of soda ash, kt.

	1990	1995	2000	2005	2010	2015	2018	2019	2020	2021
Import	54.6	47.6	42.0	59.5	36.5	26.3	50.4	51.4	49.4	54.2
Export	0.09	2.13	0.31	0.01	0.06	0.07	0.14	0.27	0.22	0.30
Glass production	21.4	18.8	19.4	16.6	10.7	8.6	10.9	9.9	9.8	11.9
Supply	33.2	26.7	22.3	42.9	25.7	17.6	39.3	41.2	39.4	42.1

The activity data are calculated using the following equation.

$$Supply = Import - Export - Glass\ production$$

Emission factors

The applied emission factor for other uses of soda ash is 414.92 kg CO_2 per tonne Na_2CO_3 based on the stoichiometry of the chemical conversion. The calculation assumes a calcination factor of 100 %.

3.6.3 Emission trend

The emission trend for the CO_2 emission from *Other uses of soda ash* is presented in Figure 3.6.1 and Annex A0-1.

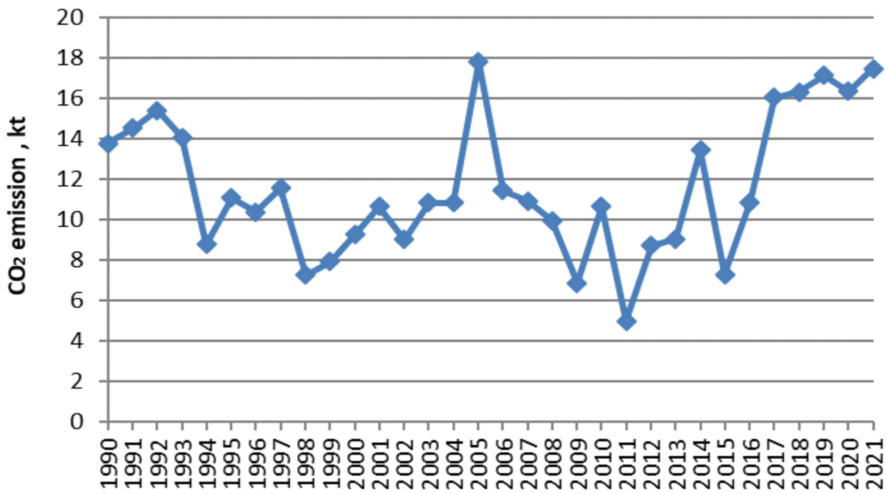


Figure 3.6.1 CO_2 emissions from other uses of soda ash.

Information on the uses of soda ash outside the glass industry is scarce, and explanations of the trend are therefore not available.

3.6.4 Verification

The applied national data collected from Statistics Denmark (KN8Y 17/08-2022) has been checked against data from Eurostat (2014, 2022) for 2000-2020, see Table 3.6.2 and Annex A5-2.

Table 3.6.2 Comparison of statistical data for net import of soda ash, kt.

	2000	2005	2010	2015	2020
Statistics Denmark	41.7	59.5	36.4	26.2	49.2
Eurostat	41.6	50.3	31.3	36.6	44.1
Difference	0.01	9.2	5.1	-10.4	5.1

The comparison shows good agreement for some years but less so for others.

3.6.5 Time series consistency and completeness

The same methodology is used for calculating emissions for the entire time series, the time series of emissions from other uses of soda ash are therefore consistent. Calculations are based on national import/export statistics and are therefore also complete as there is no production of soda ash in Denmark.

There is no information available on how the soda ash in this source category is used, and there is therefore no way of knowing if the use is emissive.

3.6.6 Input to CollectER

The actual applied data on *Other uses of soda ash* are summarised in Table 3.6.3.

Table 3.6.3 Input data for calculating emissions from other uses of soda ash.

	Year	Parameter	Comment/Source
Activity data	1990-2021	Import/export statistics	Statistics Denmark (KN8Y 17/08-2022)
Emissions	1990-2021	CO_2	Calculated using the stoichiometric emission factor

3.7 Flue gas desulphurisation

Flue gas cleaning systems utilising different technologies are primarily installed at large combustion plants i.e. combined heat and power plants as well as waste incineration plants. The following SNAP code is covered:

- 04 06 18 Limestone and dolomite use - Flue gas cleaning, wet, power plants and waste incineration plants

3.7.1 Process description

Three kinds of flue gas cleaning for acidic gases are applied in Denmark (Johnsson, 1999):

- Dry flue gas cleaning
- Semi-dry flue gas cleaning
- Wet flue gas cleaning

However, only wet flue gas cleaning leads to process emissions. The only relevant pollutant is CO_2. The chemistry of the wet flue gas cleaning methodologies is presented below.

3.7.2 Methodology

The emission of CO_2 from wet flue gas desulphurisation can be calculated from the following equation:

$$SO_2\ (g) + ½O_2\ (g) + CaCO_3\ (s) + 2H_2O\ (l) \rightarrow CaSO_4{,}2H_2O\ (s) + CO_2\ (g)$$

The overall equation can be broken down to a number of individual equations. The emission factor depends on how the process is optimised with the following targets: to achieve high degree of desulphurisation, to reduce the consumption of calcium carbonate, and to produce gypsum of saleable quality. From the equation, the emission factors can be calculated to:

- 0.2325 t CO_2/t gypsum
- 0.4397 t CO_2/t $CaCO_3$

The consumed amount of limestone ($CaCO_3$) is used as activity data. Information on limestone consumption at the relevant power plants and waste incineration plants is available from EU-ETS for 2006 onward and used in the calculation of CO_2 emission from flue gas cleaning.

The emission factor for gypsum and data on the generation of gypsum are used in the inventory when information on calcium carbonate consumption by power plants and waste incineration plants is not available (i.e. 1990-2005).

Energinet.dk compile environmental information related to energy transformation and distribution. Since the waste incineration plants with desulphurisation are all power producers, these plants are also included in the data from Energinet.dk (2020). Statistics on the generation of gypsum are available from Energinet.dk (2020) for 1990-2017.

The consumption of other carbonates than limestone (e.g. TASP[10]) is measured by the individual power plants and is added to the limestone consumption in $CaCO_3$ equivalents.

Some information on limestone consumption is available for 1998-2005 from the (at the time) mandatory environmental reports, but this is not applied as the time series is quite short, see section 3.7.5 Verification below.

The power plants equipped with wet flue gas cleaning are:

- Amagerværket*
- Avedøreværket*
- Esbjergværket
- Nordjyllandsværket
- Asnæsværket*
- Enstedværket*
- Grenå Kraftvarmeværk*
- Randersværket (Verdo Produktion A/S)*
- Stigsnæsværket*

  *These operators no longer apply wet desulphurisation.

These plants are, or have been coal fired CHP plants. As some of the plants are rebuilt to combust biomass instead of coal, the need for flue gas desulphurisation will cease.

The waste incineration plants identified to be equipped with wet flue gas cleaning are:

- Affaldscenter Aarhus*
- KARA (Roskilde Forbrænding)*
- Kommunekemi
- L90 Affaldsforbrænding*
- Odense Kraftvarmeværk*
- Reno-Nord*

[10]"Tørt AfSvovlingsProdukt" (Dry desulphurisation product), the by-product from dry flue gas desulphurisation processes.

- Reno-Syd
- Amager Bakke*
- Sønderborg Kraftvarme
- Vestforbrænding*

  *These operators have started measuring total CO_2 emissions, this means that process CO_2 emissions are now included under the energy sector for these operators.

Activity data

During the time series, this source has increased due to more plants being fitted with desulphurisation (1990-1999). However, since the main use is in coal-fired plants, flue gas desulphurisation is decreasing as some of the coal-fired power plants are rebuilt to combust biomass and the need for flue gas desulphurisation ceases. Since 2006, seven of the nine coal fired power plants have changed to alternative fuels and desulphurisation has ceased from these plants.

The Danish waste incineration plants are in general smaller than the coal combustion facilities and owned by smaller companies. Of the approximately 30 waste incineration plants with flue gas desulphurisation only one third uses wet flue gas cleaning. Only three waste incineration plants still report process emissions separately.

For 2006-2021, the consumption of $CaCO_3$ is known. For 1990-2005 however, the production of gypsum is used as surrogate data to estimate lime consumption. The limestone consumption data from the environmental reports (1998-2005) have not been used because this would increase the inconsistency. The applied activity data are presented in Table 3.7.1, Figure 3.7.1 and Annex A6-1.

Table 3.7.1 Activity data for flue gas desulphurisation, kt.

	1990	1995	2000	2005	2010	2015	2018	2019	2020	2021
Gypsum production[1]	41.6	211.5	354.3	220.4	179.7	91.7	NAV	NAV	NAV	NAV
$CaCO_3$ consumption[2, 3]	22.0	111.8	187.3	116.6	95.6	35.3	35.9	22.4	18.4	18.7

[1] Energinet.dk (2020).
[2] 1990-2005: Estimated from surrogate data and stoichiometric relations.
[3] 2006-2021: EU-ETS of the individual plants.
NAV: Not Available.

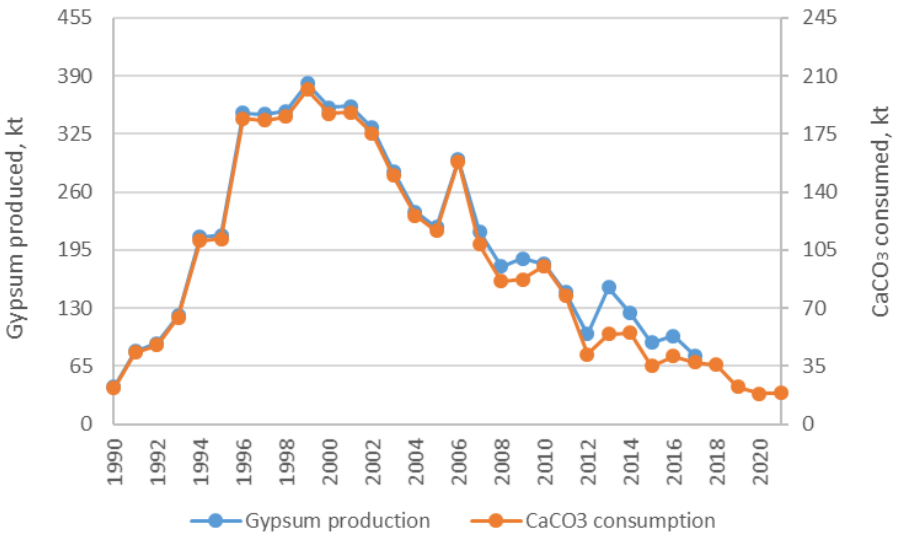


Figure 3.7.1 Activity data for flue gas desulphurisation.

The activity data varies with the coal consumption that again varies depending on electricity import/export. As mentioned above, part of the decreasing trend in this category is caused by the allocation of emissions from some waste incineration plants to the energy sector, but this is of minor influence. A rough estimate is that 10 kt $CaCO_3$ consumption per year has been allocated to the energy sector since 2012.

Emission factors

From the chemical reaction equation presented in the "Methodology" section, the stoichiometric emission factor can be calculated to 0.2325 tonnes CO_2 per tonne gypsum produced. When information on calcium carbonate consumption by power plants and waste incineration plants is not available (i.e. 1990-2005), this emission factor is used in the inventory to estimate the CO_2 emission from gypsum generation, which is then used to estimate the limestone consumption.

The emission factor applied to the limestone consumption is the stoichiometric emission factor 0.4397 tonnes CO_2 per tonne $CaCO_3$.

3.7.3 Emission trend

The trend for the CO_2 emission from flue gas desulphurisation is available in Table 3.7.2 and Annex A6-2.

Table 3.7.2 CO_2 emissions from flue gas desulphurisation, kt.

	1990	1995	2000	2005	2010	2015	2018	2019	2020	2021
Flue gas desulphurisation	9.7	49.2	82.4	51.2	42.0	15.5	15.8	9.9	8.1	8.2

The CO_2 emission from flue gas desulphurisation in CHP plants increased significantly during the 1990s due to the increased use of wet flue gas desulphurisation. Since then the emissions have decreased, primarily due to the decrease in coal consumption.

3.7.4 EU-ETS data for flue gas desulphurisation

The applied methodologies for flue gas desulphurisation are specified in the individual monitoring plans that are approved by the Danish competent authority, which is the Danish Energy Agency (DEA) prior to the reporting of the emissions. The flue gas desulphurisation at the two remaining coal fired CHP plants applies the Tier 1 and Tier 4 methodology, respectively, for calculating the CO_2 emission. Both methodologies are based on weighing the trucks delivering the carbonates. Tier 1 applies standard emission factors (Tier 1) and the obtained uncertainty is ±0.1 %. Tier 4 methodology applies emission factors derived by analysis (Tier 3) and the obtained uncertainty is ±0.04 %.

The CO_2 emission for flue gas desulphurisation at waste incineration plants is based on measured lime consumption Tier 1 and Tier 4 (±2.0 % to ±7.5 %).

Since 2013, nine of the 12 waste incineration plants operating wet flue gas cleaning, have applied a reporting method based on measurements. This means that these plants now estimate the total emissions (process and energy related as one), and that process emissions from these plants are therefore reported under the energy sector.

3.7.5 Verification

Three datasets are available, the gypsum generation from Energinet.dk and the limestone (equivalent) consumption from the environmental reports and EU-ETS, respectively. The consumption data from the environmental reports (1998-2005) are not applied in the emission calculations but are displayed in the figure below for verification purposes. CO_2 emissions are calculated from all three datasets, which generally display a good agreement, see Figure 3.7.2.

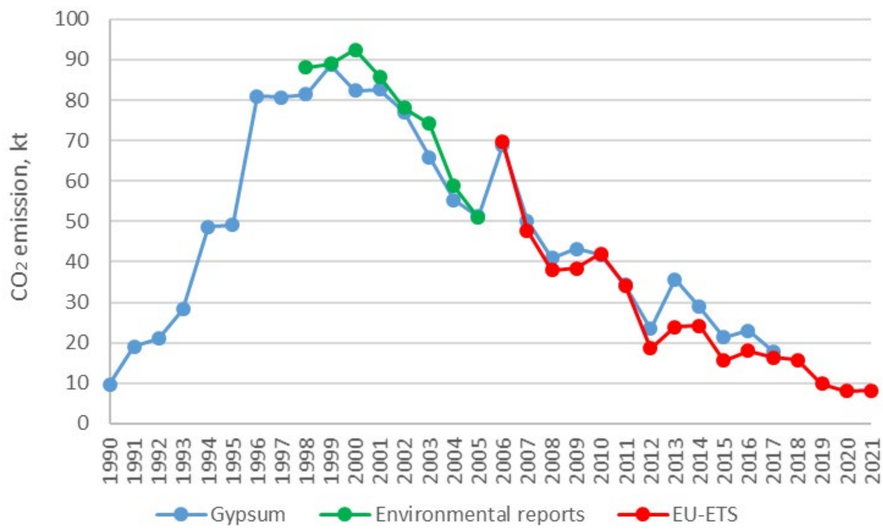


Figure 3.7.2 CO_2 emissions from Flue gas desulphurisation calculated with different methodologies; from gypsum production and limestone consumption compiled by environmental reports and EU-ETS, respectively.

Emissions calculated from the limestone consumption data provided by the environment reports vary with -1 % (2005) to +13 % (2003) from the emission based on gypsum production. Emissions calculated from the limestone consumption data provided by the EU-ETS vary with -33 % (2013) to +1 % (2006) from the emissions based on gypsum production.

3.7.6 Time series consistency and completeness

The methodology for calculating emission from flue gas desulphurisation is consistent in spite of varying methods; please refer to the verification section above. The source category is complete.

3.7.7 Input to CollectER

The input data/data sources are presented in Table 3.7.3.

Table 3.7.3 Input data for calculating emissions from flue gas desulphurisation.

	Year	Parameter	Comment/Source
Activity data	1990-2017	Gypsum generation	Energinet.dk (2020)
	2006-2021	Limestone consumption	EU-ETS
Emission	1990-2021	CO_2	Estimated by use of stoichiometric emission factors

3.8 Stone wool production

Only one company produces stone wool in Denmark, Rockwool situated at three localities: Hedehusene[11], Vamdrup and Øster Doense. The following SNAP categories are covered:

- 03 03 18 Stone wool (except binding)
- 04 06 18 Limestone and dolomite use

Emissions associated with the fuel use are estimated and reported in the energy sector, and therefore not part of this report.

Emissions of the following pollutants are included for the stone wool production process:

- CO_2
- SO_2
- NMVOC
- CO
- NH_3
- Particulate matter: TSP, PM_{10}, $PM_{2.5}$, BC
- Heavy metals: As
- Persistent organic pollutants: PCDD/F

3.8.1 Process description

Stone wool is produced from mineral fibres and a binder (that is hardened to bakelite). The mineral fibres are produced from stone, bauxite, clay, limestone and cement. In addition to own waste products, a number of other waste products are included in the production: aluminium silicate from the iron industry, slags from steelworks, filter dust from cement industry and also used growing media based on stone wool. The raw materials are melted in a cupola fired by coke and natural gas. Several raw materials contribute to the process CO_2 emission e.g. bottom ash, limestone, dolomite, binder etc. (Rockwool, 2003).

3.8.2 Methodology

Information on emissions from some years are used as implied emission factors to calculate emissions for years where measurements are not available. Production data are used as activity data and raw material consumption is used as surrogate data to complete the time series. The data have been extracted from the environmental reports (Rockwool, 2014), reporting to PRTR (Rockwool, 2022b), EU-ETS (Rockwool, 2022a) and Statistics Denmark (VARER1 13/09-2022). Measured emissions of CO and NH_3 are available for the years 2001, 2004 and 2007-2014, for NH_3 also 2015-2021 and for CO also 2021 (Rockwool, 2022c). Emissions of particulate matter are available for 1995-2014 and 2016-2021 (for Doense), and for NMVOC, As and PCDD/F, the inventory is based on measured emissions for 2012-2014, 2007-2015 and 2004, respectively. CO_2 process emissions are available for the years 2006-2021 (EU-ETS). Emissions of all pollutants for 1985-1994 are estimated as the average of 1995-1999. Process emissions of SO_2 are included in the energy sector for 1980-2020 as Rockwool has been using SO_2 heavy fuels and measured emissions are difficult to separate between energy and process. But since 2021, Rockwool in Vamdrup only uses natural gas and gasoil as fuel, and SO_2 emissions are

[11] The melting of minerals (cupola) was closed down in 2002.

therefore reported in this sector. SO_2 emissions from the Rockwool production site in Doense is still included under Energy.

Calculations are performed for the three factories individually.

The consumption of raw material as well as amount of produced stone wool from EU-ETS is confidential.

Activity data

Data on the produced amount of stone wool is known for 1995-2004 (Statistics Denmark, VARER1 13/09-2022) and 2014-2021 (Rockwool, 2022a, confidential). Data on the consumption of raw materials (surrogate data) from Rockwool (2014) are known for 1995-2013. Production data for 2005-2013 are estimated based on raw material consumption and the relation between product and raw materials for 2000-2004 (0.83 tonnes product per tonne raw material). The carbonate raw materials and their CO_2 emission is known for 2006-2021 from EU-ETS.

Both activity data and proxy activity data are presented in Table 3.8.1, Figure 3.8.1 and Annex A7-1.

Table 3.8.1 Activity data for stone wool production.

	Unit	1985	1990	1995	2000	2005	2010	2015	2020	2021
Production of stone wool	kt	153.5	153.5	123.3	152.6	143.6	129.4	c	c	c
Consumption of raw materials	kt	-	-	196.5	190.0	172.0	155.0	-	-	-
Consumption of carbonates	kt $CaCO_3e$	-	16.7	13.5	16.7	18.0	17.1	13.5	12.0	12.4

c: confidential.

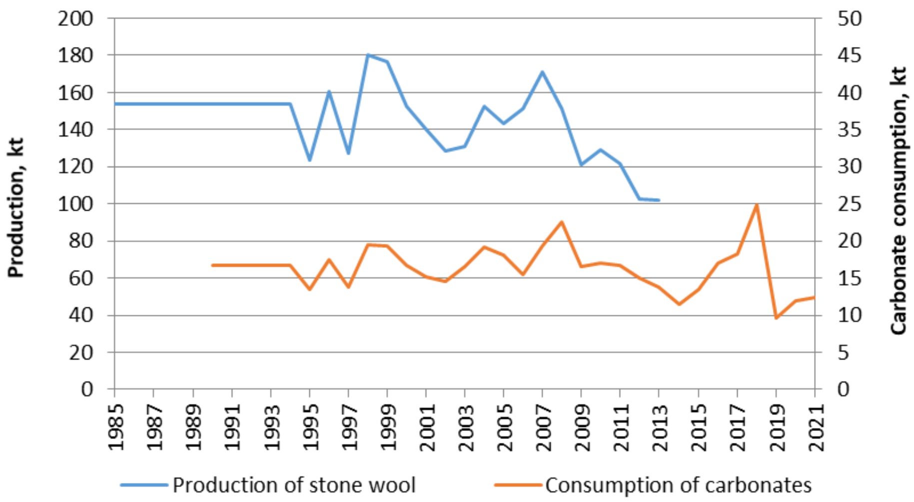


Figure 3.8.1 Activity data for stone wool production.

The consumption of CO_2 emitting raw materials in stone wool production varies, and so does the carbon content of the waste used as raw material. The strong decrease in carbonate consumption (and CO_2 emissions) from 2018 to 2019 is due to a strong decrease in use of dolomite as raw material. Rockwool strides to reduce CO_2 process emissions from production of stone wool by reducing the consumption of dolomite, but the decrease must also be seen as naturally occurring variation in raw material composition.

Emission factors

From 2006, the CO_2 process emission data have been obtained from the company's reportings under the EU-ETS (Rockwool, 2022a). The different carbonate raw materials such as lime, waste, bottom ash, dolomite, binder etc. are all added up to the CO_2 emission reported to EU-ETS. For 1990-2005, the CO_2 emission is estimated from the calculated factor of "CO_2 emission per produced stone wool" (average for 2006-2010) and the stone wool production time series. CO_2 emissions for 1990-1994 are estimated as the constant average of 1995-1999. The applied emission factor for stone wool production is the stoichiometric factor 0.4397 tonnes CO_2 per tonne $CaCO_3$.

Emission factors are calculated from measured emission data; i.e. implied emission factors (see Table 3.8.2 below). Emission factors for CO and NH_3 are average values measured and reported in the annual environmental reports for each Rockwool factory for the years 2001, 2004 and 2007-2014, CO is also known for 2021 and NH_3 is also known for 2015-2021 (Rockwool, 2022b and 2022c). TSP emission data are available for all sites in the environmental reports for 1995-2014. For Doense, TSP is also available for 2016-2021 from PRTR/personal communication for 2016-2021. PM_{10} and $PM_{2.5}$ emission factors are estimated from the distribution between TSP, PM_{10} and $PM_{2.5}$ (1/0.9/0.7) based on an expert judgement from the author of this report. The applied emission factor for BC is actually that of glass wool from EMEP/EEA (2019). NMVOC emissions are known for Doense for 2012-2014, As is measured for 2007-2015, SO_2 is measured for Vamdrup in 2021 and PCDD/F emissions are known from Henriksen et al. (2006). For PCDD/F, measurements of 31 mg and 26 mg from the locations Vamdrup and Doense, respectively, are known for the year 2004. Using the estimated production data for 2004 at the two locations (81.6 kt and 71.0 kt), implied emission factors of 0.380 and 0.366 µg per tonne stone wool produced are calculated; i.e. 0.37 µg per tonne in average.

Implied emission factors are calculated for all years where measured emissions are available; these are used to estimate emissions for all other years in the time series. The implied emission factors are presented in Table 3.8.2.

Table 3.8.2 Emission factors for stone wool production.

Pollutant	Applied for the years	Value	Unit	Source
CO_2	All	43.97	kg/t $CaCO_3$	Stochiometry
NMVOC	All	0.22	kg/t produced	Average IEF[1] (2012-2014)
CO	1985-2000; 2002-2003; 2005-2006	40 - 128	kg/t produced	IEFs[1] (2001; 2004; 2007-2008)
	2015-2021	0.02 - 0.26	kg/t produced	IEFs[1] (2010-2014)
NH_3	1985-2000; 2002-2003; 2005-2006	1.3 - 2.3	kg/t produced	IEFs[1] (2001; 2004; 2007)
TSP	1990-1994	0.38 - 0.89	kg/t produced	IEFs[1] (1995-2002)
	2015-2021[3]	0.54	kg/t produced	Average IEF[1] (2010-2014)
PM_{10}	All	90	% of TSP	DCE judgement
$PM_{2.5}$	All	70	% of TSP	DCE judgement
BC	All	2	% of $PM_{2.5}$	EMEP/EEA (2019)[2]
As	1990-2006 (Vamdrup)	0.51	g/t produced	IEF (2007)
	2013; 2015-2021 (Vamdrup)	0.12	g/t produced	IEF (2012;2014)
	1990-2007;2016-2021 (Doense)	0.33	g/t produced	IEF (2008-2014)
PCDD/F	All	0.37	µg/t produced	Henriksen et al. (2006)

1 Calculated using data from the companies' environmental reports.

2 Valid for glass wool.

3 Only applied for Vamdrup as measurements are available for Doense.

3.8.3 Emission trend

The emission trends for emission of CO_2, SO_2, NMVOC, CO, NH_3, TSP, PM_{10}, $PM_{2.5}$, BC, As and PCDD/F from production of stone wool at all three (from 2006 two) locations are presented in Table 3.8.3 and Annex A7-2.

Table 3.8.3 Emissions from production of stone wool.

	Unit	1985	1990	1995	2000	2005	2010	2015	2020	2021
CO_2	kt	-	7.4	5.9	7.3	7.9	7.5	5.9	5.3	5.5
SO_2	t	IE	IE	IE	IE	IE	IE	IE	IE	18
NMVOC	t	34	34	27	34	32	28	29	31	35
CO	t	11148	11148	8859	11450	11889	11	18	10	9
NH_3	t	274	274	219	278	330	203	242	226	270
TSP	t	-	91	94	71	114	86	60	77	60
PM_{10}	t	-	82	84	64	103	78	54	69	54
$PM_{2.5}$	t	-	64	66	50	80	61	41	54	42
BC	t	-	1.2	1.3	1.0	1.6	1.2	0.9	1.1	0.9
As		-	66	54	65	60	26	130	40	44
PCDD/F	mg	-	57	46	57	54	48	49	53	59

The measurements from Rockwool (2014) show a strong decrease in CO emissions from the two stone wool factories in 2009 and 2010, respectively, due to installation of abatement equipment.

3.8.4 EU-ETS for stone wool production

Stone wool production applies the ETS Tier 3 methodology for calculating the CO_2 process emission for 2006 onwards.

The implied CO_2 emission factors for Rockwool are plant specific and based on the reporting to the EU-ETS. The EU-ETS data have been applied for the years 2006 onwards.

The CO_2 emission for stone wool production is based on measurements of the consumption of carbonates. These measurements fulfil an ETS Tier 1, Tier 2 or Tier 3 methodology (± 1.5 – 2.5 %) depending on the carbonate. The emission factors for dolomite are standard factors (Tier 1), while emission factors for carbonate containing inputs like stone wool waste and cement are based on carbon content measurements for each carbonate (ETS Tier 2-3). (Rockwool, 2022d).

3.8.5 Verification

The data applied for estimating emissions from production of stone wool are verified as best possible. Verification includes comparison of the trends and relation in quantity of stone wool produced versus consumption of raw materials in the production. It also includes an evaluation of the fluctuations of the measured emissions over the time series.

None of the available datasets for stone wool production are available for the entire time series, which complicated the verification process. Figure 3.8.1 presents a comparison of the stone wool production and carbonate consumption. However, the production data are only available for 1995-2004; 2014-2021 and the CO_2 emission for 1998-2002; 2006-2021.

3.8.6 Time series consistency and completeness

The source category of stone wool production is complete. CO_2 emissions for 2006 onward are known (EU-ETS), but emissions for 1990-2005 are estimated via surrogate data. For the air pollutants, a similar shift in methodology occurs in 2014 where after activity data are known from EU-ETS. In spite of this change in data availability, the source category is considered to be consistent.

3.8.7 Input to CollectER

The input data/data sources are presented in Table 3.8.4.

Table 3.8.4 Input data for calculating emissions from stone wool production.

	Year	Parameter	Comment/Source
Activity data	1985-1994	Production data	Average of 1995-1999
	1995-2013		Estimated from Statistics Denmark and raw material consumption (Rockwool 2014)
	2014-2021		Rockwool (2021a)
	1990-1994	Carbonate consumption	Average of 1995-1999
	1995-2005		Estimated using production data as surrogate data
	2006-2021		Estimated from CO_2 emission (Rockwool, 2022a)
Emissions	2006-2021	CO_2	Rockwool (2022a)
	2021	SO_2	Rockwool (2022c)
	2001, 2004, 2007-2014; 2021	CO	Rockwool (2021b, 2022c)
	2001, 2004, 2007-2021	NH_3	Rockwool (2021b)
	2012-2014	NMVOC	Rockwool (2021b)
	1995-2014; 2021 +2016-2020 Doense	TSP	Rockwool (2014, 2021b, 2022c)
	2007-2015	As	Rockwool (2021b)
	2004	PCDD/F	Henriksen et al. (2006)
Emission factor	1990-2005	CO_2	Stoichiometry
	1985-2000; 2002-2003; 2005-2006; 2015-2020	CO	IEFs, interpolated in intermediate years
	1985-2000; 2002-2003; 2004-2006	NH_3	IEFs, interpolated in intermediate years
	1985-2011;2015-2021	NMVOC	IEF (2012-2014)
	1990-1994	TSP	IEF (1995-2006)
	1990-2006; 2016-2021	As	IEFs
	1990-2003; 2005-2021	PCDD/F	IEF from Henriksen et al. (2006)

3.9 Quarrying and mining of minerals other than coal

Quarrying and mining of minerals covers several different types of minerals and occurs all over Denmark. The following SNAP-code is covered:

- 04 06 16 Quarrying and mining of minerals other than coal

The following pollutants are relevant for quarrying and mining:

- Particulate matter: TSP, PM_{10}, $PM_{2.5}$

3.9.1 Methodology

Dust emissions in quarries come from five point emissions sources (EMEP/EEA, 2019):

1. Drilling and blasting
2. Material processing: crushing, screening and transfer
3. Internal transport
4. Material handling operation: loading and unloading
5. Wind erosion from stockpiles

The annual amounts of different extracted minerals are available from national statistics. These resource extraction data cover "sand and gravel", "chalk and dolomite", "marble, granite, sandstone, porphyry, basalt and building stone, etc." and "other".

Emission factors are calculated using the Tier 2 methodology spreadsheet available from EMEP/EEA (2019).

Activity data

Activity data for quarrying and mining of minerals are presented in Table 3.9.1; the full time series is available in Annex A8-1.

The activity data from Statistics Denmark (MRM2 11/08-2022) called "marble, granite, sandstone, porphyry, basalt and building stone, etc." is believed to be mostly granite chippings, this category is entered in the Tier 2 model as "crushed rock". The categories "sand and gravel" and "chalk and dolomite" are entered as "sand and gravel". The category "other" is entered as "Recycled aggregates" due to the lack of information on this category.

Statistical data on quarrying for the latest reporting year are not made available yet. Therefore, the two latest reported years are the same. Activity data for the latest reporting year in this report will be updated with the correct statistical data in the next update.

Table 3.9.1 Extracted minerals, kt.

	1990	1995	2000	2005	2010	2015	2018	2019	2020	2021
Crushed rock	945	1103	332	315	240	234	537	233	175	175
Sand and gravel[1]	43534	51581	63184	73805	44147	57456	63991	65553	64174	64174
Recycled aggregates	908	908	947	813	1052	1090	1306	1100	1315	1315

[1] Incl. chalk and dolomite

Emission factors

The applied emission factors are shown in Table 3.9.3. Emission factors are calculated based on the Tier 2 methodology calculation model spreadsheet (EMEP/EEA, 2019). All Danish quarries are small quarries (<100,000 kt annual production). Being a small country, Danish emission factors are calculated as one region. The average wind speed is 4.72 m per second (2011-2019 average), number of days per year with at least 1 mm natural precipitation is 155 (2016) and number of days with a wind speed > 19.3 km per hour is 105 (2016). All weather related data are collected from DMI (2020). All additional country specific data entered into the model, are presented in Table 3.9.2.

Table 3.9.2 Country specific data used in the Tier 2 methodology calculation model.

	Crushed rock	Sand and gravel	Recycled aggregates
General data			
Number of quarries	2	100	35[a]
Material processing			
Percentage of wet processing	0 %	42 %[b]	42 %[b]
Internal transport			
Distance travelled on unpaved road	2400 km[c]	2400 km	0 km

[a] Auto-calculated from the production (i.e. activity data), [b] It rains a minimum of 1mm per day in Denmark 42 % of the year, [c] Denmark is a small country with small distances and the default value is considered far too high

Emission factors presented in Table 3.9.3 are sums of the individually calculated contributions from the five particle emission sources listed under 3.9.1 Methodology, above. Drilling/blasting and material handling operations are minor contributions.

Table 3.9.3 Emission factors for quarrying and mining of minerals other than coal.

	Unit	TSP	PM_{10}	$PM_{2.5}$
Crushed rock	g/t	77	29	6.4
Sand and gravel	g/t	18	7.4	2.0
Recycled aggregates	g/t	33	15	4.1

Material processing has significant contributions to larger particle emissions from all three mineral product categories (35-37 % of TSP, 30-34 % of PM_{10} and 19-26 % of $PM_{2.5}$), while wind erosion from stockpiles is the largest contributor to small particles (44 % of $PM_{2.5}$ from crushed rock and 68-69 % of $PM_{2.5}$ from sand/gravel and recycled aggregates).

3.9.2 Emission trend

Emissions of $PM_{2.5}$ are presented in Figure 3.9.1. Emissions of TSP. PM_{10} and $PM_{2.5}$ are available in Annex A8-2.

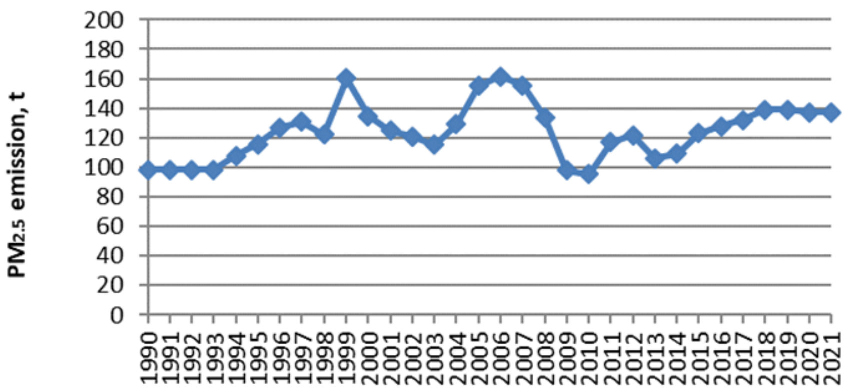


Figure 3.9.1 Emission of fine particles ($PM_{2.5}$) from quarrying and mining of other minerals than coal.

3.9.3 Verification

For verification, emission results from the applied Tier 2 method are compared with those of the simple Tier 1 method (EMEP/EEA, 2019).

Table 3.9.4 Comparison of emissions calculated using the Tier 2 and Tier 1 methods from EMEP/EEA (2019).

	1990	1995	2000	2005	2010	2015	2020	2021
Tier 1								
TSP	4629	5466	6575	7643	4635	5996	6698	6698
PM_{10}	2269	2680	3223	3747	2272	2939	3283	3283
$PM_{2.5}$	227	268	322	375	227	294	328	328
Tier 2								
TSP	898	1058	1211	1400	860	1104	1229	1229
PM_{10}	362	426	490	566	348	447	498	498
$PM_{2.5}$	98	116	134	155	96	123	137	137
Difference								
TSP	3731	4409	5364	6243	3775	4892	5468	5468
PM_{10}	1908	2254	2733	3181	1924	2492	2785	2785
$PM_{2.5}$	129	152	188	219	132	171	191	191
Difference								
TSP, **%**	415	417	443	446	439	443	445	445
PM_{10}, **%**	527	529	558	562	553	558	559	559
$PM_{2.5}$, **%**	131	132	140	141	138	139	140	140

Emission calculations presented in Table 3.9.4 show that the simple Tier 1 methodology results in much higher particle emissions than the applied Tier 2 methodology. The Tier 2 method takes into account local conditions such as quarry size, percentage of wet processing, abatement technology, distance of internal transport on unpaved/paved road, road watering, vehicle weight, surface material silt content, wind speed and precipitation.

3.9.4 Time series consistency and completeness

The time series is both consistent and complete.

3.9.5 Input to CollectER

The input data/data sources for calculating emissions are presented in Table 3.9.5.

Table 3.9.5 Input data for calculating emissions from quarrying and mining.

	Year	Parameter	Comment/Source
Activity data	1990-1992	Extracted minerals	Estimated to equal 1993 data
	1993-2021		Statistics Denmark (2022)
Emission factors	All	TSP, PM_{10}, $PM_{2.5}$	EMEP/EEA (2019)

3.10 Construction and demolition

Construction and demolition covers the following SNAP-code:

- 04 06 24 Construction and demolition

The following pollutants are relevant for construction and demolition:

- Particulate matter: TSP, PM_{10}, $PM_{2.5}$

3.10.1 Methodology

Emissions from construction and demolition are calculated using the Tier 1 methodology from EMEP/EEA (2019) expressed in the following equation:

$$EM_{PM10} = EF_{PM10} \cdot A_{affected} \cdot d \cdot (1 - CE) \cdot \left(\frac{24}{PE}\right) \cdot \left(\frac{s}{9\%}\right)$$

Where: EM_{PM10} is the PM_{10} emission, EF_{PM10} is the emission factors, $A_{affected}$ is the area affected by construction activity, d is the duration of construction, CE is the efficiency of emission control measures, PE is the Thornthwaite precipitation-evaporation index (correction for soil moisture) and s is the soil silt content.

The activity data for construction ($A_{affected}$) are calculated based on national statistics on completed buildings (m^2) (detached houses, undetached houses, apartment buildings and non-residential buildings) and roads (m).

Emission factors (EF_{PM10}) are available from EMEP/EEA (2019).

Activity data

Activity data for construction and demolition are presented in Table 3.10.1. The full time series is available in Annex A9-1.

Table 3.10.1 Activity of construction and demolition, million m^2.

	1990	1995	2000	2005	2010	2015	2018	2019	2020	2021
Construction of houses	2.3	1.3	2.5	3.6	2.2	2.2	3.0	3.3	3.4	3.5
Construction of apartment	0.7	0.5	0.4	0.9	0.3	0.4	1.4	1.6	2.0	1.6
Construction of non-residential	5.3	4.0	6.1	4.6	3.7	2.9	2.9	2.6	2.1	2.2
Construction of road	1.8	1.7	1.6	2.2	2.9	0.8	2.0	0.4	1.0	0.9

Emission factors

The default emission factors are shown in Table 3.10.2.

Table 3.10.2 Default emission factors for different types of constructions.

Pollutant	Unit	Houses	Apartment buildings	Non-residential buildings	Roads	Source
TSP	$kg/m^2/year$	0.29	1.0	3.3	7.7	EMEP/EEA (2019)
PM_{10}	$kg/m^2/year$	0.086	0.30	1.0	2.3	EMEP/EEA (2019)
$PM_{2.5}$	$kg/m^2/year$	0.0086	0.030	0.1	0.23	EMEP/EEA (2019)

The default duration (d) of the different construction types and the default control efficiency (CE) are available in EMEP/EEA (2019). The Thornthwaite precipitation-evaporation index was calculated for the years 2015-2017. The average obtained PE index is 75.9, which corresponds to a humid climate. Denmark is a very sandy country, and the silt content (s) is therefore assumed to be 15 % (DCE judgement). Danish road width spans from 3 to 20 meters, an average road width of 12 m is assumed (DCE judgement).

Table 3.10.3 below presents the applied emission factors for the different types of construction. These emission factors corresponds to:

$$EF_{PM10} \cdot d \cdot (1 - CE) \cdot \left(\frac{24}{PE}\right) \cdot \left(\frac{s}{9\%}\right)$$

Table 3.10.3 Applied emission factors for different building type constructions.

Pollutant	Unit	Houses	Apartment buildings	Non-residential buildings	Roads
TSP	kg/m^2	0.076	0.395	0.722	2.030
PM_{10}	kg/m^2	0.023	0.119	0.219	0.606
$PM_{2.5}$	kg/m^2	0.002	0.012	0.022	0.061

3.10.2 Emission trend

Emissions of $PM_{2.5}$ are presented in Figure 3.10.1. Emissions of TSP, PM_{10} and $PM_{2.5}$ are available in Annex A9-2.

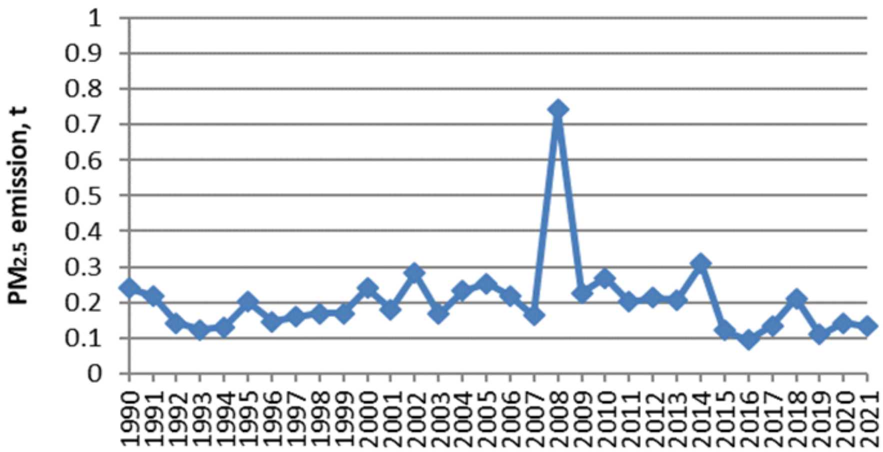


Figure 3.10.1 Emission of particulate matter ($PM_{2.5}$) from construction and demolition.

The peak in 2008 is caused by a large increase in road construction.

3.10.3 Time series consistency and completeness

The time series is consistent and complete according to the EMEP/EEA Guidebook. There is no available method for calculating emissions from demolition.

3.10.4 Input to CollectER

The input data/data sources are presented in Table 3.10.4.

Table 3.10.4 Input data for calculating emissions from construction and demolition.

	Year	Parameter	Comment/Source
Activity data	All	Constructed and demolished buildings m^2	Statistics Denmark (2022)
Emission factors	All	TSP, PM_{10}, $PM_{2.5}$	EMEP/EEA (2019)

3.11 Storage, handling and transport of mineral products

Storage, handling and transport of mineral products covers the following SNAP-code:

- 04 06 90 Storage, handling and transport of mineral products

The following pollutants are relevant for storage, handling and transport of mineral products:

- Particulate matter: TSP, PM_{10}, $PM_{2.5}$

3.11.1 Methodology

The activity data for storage, handling and transport of mineral products covers minerals used in cement production, ceramics production, other uses of soda ash, flue gas desulphurisation and stone wool. The particle emissions from storage, handling and transport of mineral products in lime production, glass production quarrying/mining and construction/demolition are already included in the respective categories.

The activity data for storage, handling and transport of mineral products are gathered from the five included sources (mass mineral).

The emission factor for TSP is assumed to be 0.1 % of activity data, PM_{10} and $PM_{2.5}$ are estimated from the distribution between TSP, PM_{10} and $PM_{2.5}$ (1/0.5/0.05).

Activity data

Activity data for storage, handling and transport of mineral products are presented in Table 3.11.1. The entire time series is available in Annex A10-1.

Table 3.11.1 Activity of storage, handling and transport of mineral products, kt mineral.

	1990	1995	2000	2005	2010	2015	2018	2019	2020	2021
Storage, handling and transport of mineral product	1328	1567	1769	1680	966	905	1149	1134	1226	1314

Emission factors

The applied emission factors are shown in Table 3.11.2.

Table 3.11.2 Emission factors for storage, handling and transport of mineral products.

Pollutant	Value	Unit	Source
TSP	0.1	t/kt	DCE judgement
PM_{10}	0.05	t/kt	Particle distribution from EMEP/EEA (2019)
$PM_{2.5}$	0.005	t/kt	Particle distribution from EMEP/EEA (2019)

3.11.2 Emission trend

Emissions are presented in Figure 3.11.1 and Annex A10-2.

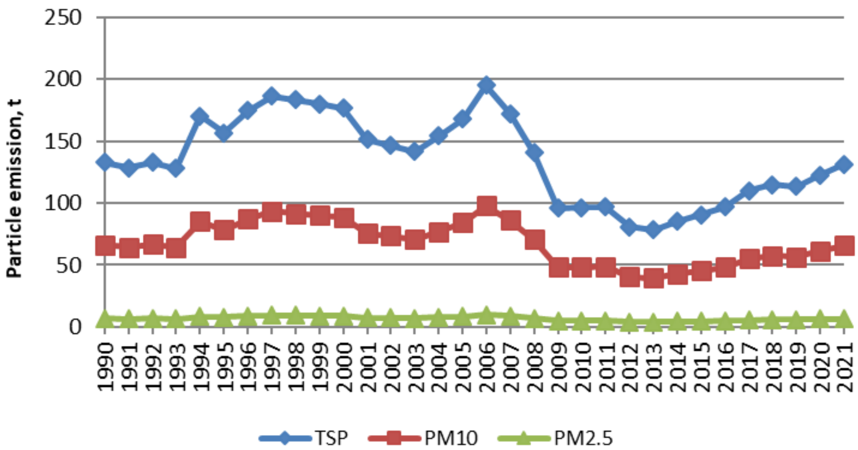


Figure 3.11.1 Emission of particulate matter from storage, handling and transport of mineral products.

3.11.3 Time series consistency and completeness

The time series is both consistent and complete.

3.11.4 Input to CollectER

The input data/data sources for calculating emissions are presented in Table 3.11.3.

Table 3.11.3 Input data for calculating emissions from storage, handling and transport of mineral products.

	Year	Parameter	Comment/Source
Activity data	All	Produced amounts	Activity data from the individual mineral industry sources
Emission factors	All	TSP, PM_{10}, $PM_{2.5}$	Expert judgement and particle distribution from EMEP/EEA (2019)

4 Chemical industry

The Chemical Industry sector (CRF/NRF 2B) covers the following industries relevant for the Danish air emission inventory of greenhouse gases and air pollutants:

- Sulphuric-, nitric acid and fertiliser production (SNAP 040401, 040402, 040407); see section 4.2
- Catalyst and fertiliser production (SNAP 040416, 040407); see section 4.3
- Production of chemical ingredients (SNAP 040500); see section 4.4
- Pesticide production (SNAP 040525); see section 4.5
- Production of tar products (SNAP 040527); see section 4.6

4.1 Emissions

4.1.1 Greenhouse gas emissions

The greenhouse gas emission time series for the source categories within the chemical industries sector are presented in Figure 4.1.1, Annex B0-1 and individually in the subsections below (Sections 4.2 – 4.6). The following figure gives an overview of which source categories contribute the most throughout the time series.

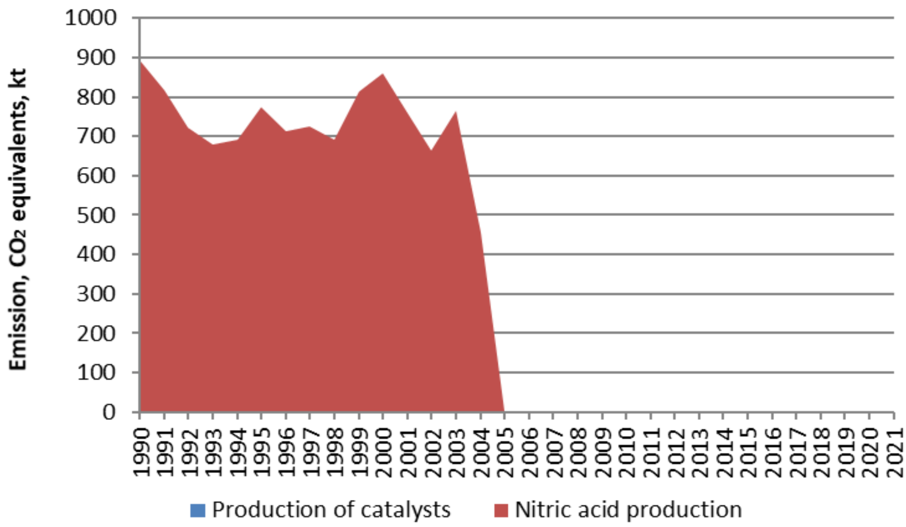


Figure 4.1.1 Emission of CO_2 equivalents from the individual source categories compiling *2B Chemical Industry*, kt.

Greenhouse gas emissions from *Chemical Industry* are made up almost entirely by N_2O emissions from the production of nitric acid; only 0.1 % (1990-2003) to 0.2 % (2004) stems from the production of catalysts, making the emission invisible in the figure above. The production of nitric acid ceased in the middle of 2004.

4.1.2 Air pollution emissions

The time series for emissions of acidifying substances, NMVOC, particulate matter, heavy metals, and POPs from *Chemical industry* (NFR 2B) are available in the Annex B0-1. Table 4.1.1 presents an overview of emissions from 2021.

Table 4.1.1 Overview of 2021 emissions from *Chemical industry*.

	Total emission from Chemical industries		Fraction of IPPU, %	Largest contributor in Chemical industries	Emission from largest contributor		Fraction of Chemical industries, %
SO_2	0.29	kt	30.6	2B10a Other chemical industry	0.29	kt	100.0
NO_x	0.02	kt	30.0	2B10a Other chemical industry	0.02	kt	100.0
NMVOC	0.02	kt	0.05	2B10a Other chemical industry	0.02	kt	100.0
NH_3	0.01	kt	2.6	2B10a Other chemical industry	0.01	kt	100.0
TSP	0.01	kt	0.10	2B10a Other chemical industry	0.01	kt	100.0
HM	1.08	kg	0.015	Hg from 2B10a Other chemical industry	1.08	kg	100.0
POPs	0.18	g	0.3	PAH from 2B10a Other chemical industry	0.18	g	100.0

4.2 Nitric and sulphuric acid production

The production of sulphuric acid, nitric acid as well as NPK fertilisers was concentrated at one company; Kemira GrowHow A/S situated in Fredericia. The production of sulphuric acid and nitric acid/fertiliser ceased in 1996/7 and in the middle of 2004, respectively. The following SNAP codes are covered:

- 04 04 01 Sulphuric acid
- 04 04 02 Nitric acid

The following pollutants are relevant for the nitric and sulphuric acid production processes:

- SO_2
- NO_x
- N_2O
- NH_3
- Particulate matter: TSP, PM_{10}, $PM_{2.5}$, BC

4.2.1 Process description

The inputs to the processes are ammonia, potash, raw phosphate, phosphoric acid/sulphuric acid, dolomite, and other unspecified raw materials. The products are fertilisers (nitrogen, phosphate, and potassium), nitric acid, potassium nitrate, phosphates (feedstock for domestic animals). The production facility consists of different plants: nitric acid plant, NPK-plant, potassium nitrate plant, and dicalcium phosphate plant. Up to 1997 sulphuric acid was also produced at Kemira.

A gas turbine and incineration of ammonia supplies the main part of the electricity necessary for the different processes.

Ammonia is incinerated at the nitric acid plant generating nitric acid as well as energy (steam and electricity). The processes are (HNO_3):

(I) $4\ NH_3 + 5\ O_2 \rightarrow 4\ NO + 6\ H_2O$

(II) $2\ NO + O_2 \rightarrow 2\ NO_2$

(III) $3\ NO_2 + H_2O \rightarrow 2\ HNO_3 + NO$

Other reactions:

(IV) $4\ NH_3 + 3\ O_2 \rightarrow 2\ N_2 + 6\ H_2O$

(V) $4\ NH_3 + 4\ O_2 \rightarrow 2\ N_2O + 6\ H_2O$

Air pollutants relevant to be included for fertiliser production are NH_3, N_2O, and NO_x.

The environmental report (Kemira GrowHow, 2005a) presents aggregated emissions for the entire facility. This information is supplemented with direct contact to the company.

4.2.2 Methodology

Information on emissions from the production of nitric acid, sulphuric acid and fertiliser is obtained from environmental reports, contact to the company as well as information from the county (Kemira GrowHow, 2005a and 2005b). Emission measurements are available for some years, see Table 4.2.1. Implied emission factors are calculated for the years where measurements are available; these implied emission factors are then used to calculate emissions for the remaining years. The following table gives an overview of which years measured emissions are available for the different pollutants (Kemira Growhow, 2005a).

Table 4.2.1 Availability of measured process emissions.

Process	Pollutant	Years
Nitric acid	NH_3	1989-2004
	N_2O	2002
	NO_x	1990, 1994-2002
	TSP	1996-2004
Sulphuric acid	SO_2	1990, 1994-1997

The emission for SO_2 and NOx for 1991 to 1993 are estimated by using interpolated emission factors and activity data.

Specific information on the applied technology is not available; however, the N_2O emission factor measured by the Danish nitric acid plant is comparable with the default emission factors for medium to high pressure plants in the IPCC guidelines (2006).

The Danish production of sulphuric acid ceased in 1996/7 and the production of nitric acid in Denmark ceased in the middle of 2004 and the company relocated the production to a more modern facility in another country.

Activity data

The activity data regarding production of nitric- and sulphuric acid are obtained through environmental reports and personal communication with Kemira (Kemira GrowHow, 2005a and 2005b). The data are presented in Table 4.2.2 and Annex B1-1.

Table 4.2.2 Production of nitric- and sulphuric acid, kt.

	1980	1985	1990	1995	2000	2004
Nitric acid	-	350	450	390	433	229
Sulphuric acid	188	188	148	102	NO	NO

NO: Not occurring.

Production of sulphuric acid decreased from 148 kt to 55 kt from 1990 to 1996, and production of nitric acid decreased from 450 kt to 386 kt from 1990 to 2004. Overall, production of fertiliser decreased from 807 kt to 395 kt from 1990 to 2004.

In the time series, the production of nitric acid peaked in 1990 with 450 kt (and 807 kt fertiliser) and then fluctuated around the average of 375 kt nitric acid (694 kt fertiliser) from 1990-2003 until the factory closed down in the summer of 2004; 2004 production of 229 kt nitric acid and 395 kt fertiliser (Kemira GrowHow, 2005a).

Emission factors

The calculated implied emission factors are presented in Table 4.2.3 together with the standard emission factors given by IPCC (2006[12]) and EMEP/EEA (2019).

Table 4.2.3 Plant specific implied emission factors for production of nitric acid and sulphuric acid compared with standard emission factors, kg per t produced.

Process	Pollutant	Mean	Range	Standard EF
Nitric acid	NH_3	0.11	0.03 - 0.26	-
	N_2O	7.48	-	2-2.5[1]
				5[2]
				7[3]
				9[4]
	NO_x	1.36	0.95 - 1.79	3.5-12[5]
				7.5[6]
				3[7]
				0.5[8]
				0.4-0.9[9]
	TSP	0.86	0.56-0.98	-
Sulphuric acid	SO_2	2.07	1.40-2.69	3-9.1[10]
				3.5[11]
				17[12]

[1] Modern, NSCR, process-integrated or tailgas N_2O destruction (IPCC, 2006), [2]Atmospheric pressure plant (low pressure) (IPCC, 2006), [3]Medium pressure combustion plant (IPCC, 2006), [4]High pressure plant (IPCC, 2006), [5]Low pressure (EMEP/EEA, 2019), [6]Medium pressure (EMEP/EEA, 2019), [7]High pressure (EMEP/EEA, 2019), [8]Direct strong acid process (EMEP/EEA, 2019), [9]Modern plant with abatement technology (EMEP/EEA, 2019), [10]Contact process with/with-out intermediate absorption (EMEP/EEA, 2019), [11]Wet/dry process with intermediate condensation/absorption (EMEP/EEA, 2019), [12]Wet contact process (EMEP/EEA, 2019).

The calculated emission factors for both SO_2 and NO_x have decreasing trends.

The emission factors for NO_x and SO_2 (based on actual emissions) are in the low end compared with the standard emission factors, whereas the N_2O factor is in the high end.

Due to the lack of information on the particle distributions PM_{10} and $PM_{2.5}$, these are put equal to TSP for nitric acid production. BC is estimated as 1.8 % of $PM_{2.5}$ according to EMEP/EEA (2019) (chemical industry, average).

4.2.3 Emission trend

Trends in emissions of NH_3, N_2O, NO_x, SO_2, TSP, PM_{10}, $PM_{2.5}$ and BC from production of nitric acid and sulphuric acid are presented in Table 4.2.4, Figure 4.2.1 and Annex B1-2.

[12] Volume 3 Chemical Industry, Chapter 3.3.2.2 page 3.23 (Table 3.3).

Table 4.2.4 Emissions from *Nitric- and sulphuric acid production*.

	Unit	1980	1985	1990	1995	2000	2004
NH_3	t	-	12	12	62	13	33
N_2O	kt	-	2.6	3.4	2.9	3.2	1.7
NO_x	t	-	627	806	612	413	272
SO_2	t	415	415	327	217	NO	NO
TSP	t	-	-	388	336	362	192
PM_{10}	t	-	-	388	336	362	192
$PM_{2.5}$	t	-	-	388	336	362	192
BC	t	-	-	7.0	6.1	6.5	3.5

NO: Not occurring.

The emission trend for the N_2O emission from nitric acid production is presented in Figure 4.1.1 and is therefore not repeated here. The trend for N_2O from 1990 to 2003 shows a decrease from 3.4 kt to 2.9 kt, i.e. -14 %, and a 41 % decrease from 2003 to 2004. However, the activity and the corresponding emission show considerable fluctuations in the period considered and the decrease from 2003 to 2004 can be explained by the closing of the plant in the middle of 2004.

The emission trends for the air pollutants are presented in Figure 4.2.1. The time series for SO_2 follows the amount of sulphuric acid produced, i.e. the fluctuation follows the activity until the activity ceased in 1997. The same is the case for NO_x from production of nitric acid.

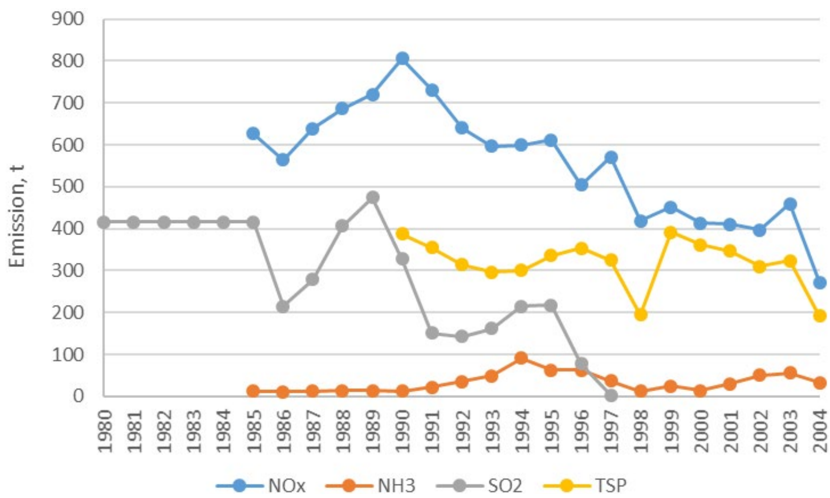


Figure 4.2.1 Emissions from nitric and sulphuric acid production.

4.2.4 Time series consistency and completeness

The activity data are based on information from the specific company/plant. Emissions are either measured by the plant or calculated using implied emission factors, the emission factor applied for N_2O has been constant for the whole time series and is based on measurements performed in 2002. The production equipment has not been changed during the period. The applied methodology is therefore considered consistent. The source category of nitric acid production is complete as the only production plant to ever exist in Denmark is included.

4.2.5 Input to CollectER

The input data/data sources for calculating emissions are presented in Table 4.2.5.

Table 4.2.5 Input data for calculating emissions from *Nitric- and sulphuric acid production.*

	Year	Parameter	Comment/Source
Activity data	1985-2004	HNO_3, H_2SO_4	Kemira GrowHow (2005a, 2005b)
	1980-1984	H_2SO_4	Assumed to equal 1985
Emissions	1980-1989	NO_x, SO_2	IEF 1990
	1990, 1994-2002	NO_x, SO_2	Kemira GrowHow (2005a)
	1980-1988	NH_3	IEF 1989
	1989-2004	NH_3	Kemira GrowHow (2005a)
	1996-2003	TSP	Kemira GrowHow (2005a)
	1980-2001; 2003-2004	N_2O	IEF 2002
	2002	N_2O	Kemira GrowHow (2005a)
	All	PM_{10}, $PM_{2.5}$	Assumed to equal TSP
	All	BC	EMEP/EEA (2019)

4.3 Catalyst and fertiliser production

Production of a wide range of catalysts and potassium nitrate (fertiliser) is concentrated at one company: Haldor Topsøe A/S situated in Frederikssund. The following SNAP code is covered:

- 04 04 16 Other: catalysts

The following pollutants are included for *Catalyst and fertiliser production*:

- CO_2
- NO_x
- NH_3
- Particulate matter: TSP, PM_{10}, $PM_{2.5}$, BC

4.3.1 Process description

The one plant in Denmark is owned and operated by Haldor Topsøe and produces a number of different catalysts, e.g. TK catalysts, CKM catalysts and TertiNOx. The specific processes are naturally commercially sensitive and hence not available. The inputs to the processes are:

- Solid raw materials: salts, oxides, carbonates, metals and intermediates etc.
- Liquid raw materials: acidic and alkaline solutions, dissolved metal salts, methanol etc.
- Gaseous raw materials: ammonia, hydrogen, nitrogen

The products are catalysts for many purposes (for hydro-processing, ammonia, $DeNO_x$, methanol, hydrogen and synthesis gas, sulphuric acid, formaldehyde, and combustion catalysts) and potassium nitrate (fertiliser).

4.3.2 Methodology

The processes involve heating of carbonate compounds i.e. the process leads to emissions of CO_2. There are two available reported CO_2 emissions from the company; PRTR (Haldor Topsøe 2022b) and environmental reports/EU-ETS (Haldor Topsøe, 2013 and 2022a). EU-ETS only contains information on fuel use and emissions from combustion of fuels. CO_2 emissions from natural gas and LPG combustion reported by companies under the EU-ETS are estimated using measured activity data and carbon content of the fuel. Reported CO_2

emission from PRTR is calculated based on stack measurements by the company and hence also includes CO_2 emissions associated with calcination. The PRTR emissions are on average 5 % higher than those from EU-ETS. The difference between the two CO_2 emissions reported by the company is assumed to be from carbonate use.

An average implied CO_2 emission factor was calculated for 2003-2009 using this method, this IEF was used for the entire time series. For the years 1985-1995, the production (activity data) is estimated using linear regression on the years 1997-2012. Potential retention of CO_2 in the flue gas cleaning system has not been taken into account.

The applied methodology for the CO_2 emission calculation corresponds to a country-specific (Tier 3) methodology according to the 2006 IPPC Guidelines.

The emissions of NO_x, NH_3 and PM_{10} from production of catalysts and fertilisers are measured annually from 1996 to 2021 (Haldor Topsøe, 2013 and 2022b). The emissions from 1985-1995 were extrapolated.

The process related NO_x emission has been estimated as 80 % of the measured total NO_x emission; Haldor Topsøe reports this assumption in their environmental report (Haldor Topsøe, 2013). The plant is equipped with a $DeNO_x$ flue gas cleaning system and depending on the efficiency of the cleaning system emissions of NH_3 will occur.

Activity data

The activity data regarding production of catalysts and fertiliser are obtained through environmental reports from Haldor Topsøe (2013) where these are available (2007-2012). For years where environmental reports are unavailable, production data are estimated using the drivers mentioned in Table 4.3.1. Production data are presented in Table 4.3.2 and Annex B2-1, the annex includes the applied surrogate data.

Table 4.3.1 Source of activity data

Years	Determined by
1985-1995	Extrapolation by linear regression of 1997-2012
1996	Total production is available, the average split between the two products from 1997-2001 is applied for estimating the individual productions
1997-2012	Information from the company (Haldor Topsøe, 2013)
2013-2014	Estimated using the consumption of raw materials as surrogate data
2015-2021	Catalyst production is known from Statistics Denmark (VARER1, 08/08-2022), and fertiliser production is estimated using the fuel consumption as surrogate data and the average production for 2003-2012

Table 4.3.2 Production of catalysts and potassium nitrate, kt.

	1985	1990	1995	2000	2005	2010	2015	2020	2021
Catalysts produced	-	-	-	17.2	23.2	20.5	27.2	27.3	24.3
Potassium nitrate produced	-	-	-	19.2	23.3	25.9	35.2	32.2	27.0
Total produced	16.8	23.7	30.5	36.4	46.5	46.4	62.4	59.5	51.2

Emission factors

The average calculated implied CO_2 emission factor for 2003-2009 is 0.0241 tonnes CO_2 per tonne product; this factor is applied for the entire time series. The CO_2 IEF is presented together with those of NO_x, NH_3 and particles in Table 4.3.3.

Table 4.3.3 Implied emission factors for production of catalysts and potassium nitrate.

	CO_2	NO_x	NH_3	TSP	PM_{10}	$PM_{2.5}$	BC
Unit		t/kt	t/kt	t/kt	t/kt	t/kt	kg/kt
Range	0.02-0.03	0.32-1.76	0.11-3.70	0.08-0.70	0.06-0.56	0.05-0.42	0.84-7.54
Mean	0.024[1]	1.21[2]	0.64[2]		0.38[2]		

[1]Average for 2003-2009, [2]Average for 1997-2001 – used for estimating emissions prior to 1997.

TSP and $PM_{2.5}$ are estimated from the distribution between TSP, PM_{10} and $PM_{2.5}$ (1/0.8/0.6) from CEPMEIP (Values for 'Production of nitrogen fertiliser'). BC is estimated as 1.8 % of $PM_{2.5}$ according to EMEP/EEA (2019) (chemical industry, average).

4.3.3 Emission trend

The particle emissions fluctuate, which is typically caused by variations in the performance of the filters. This is quite common for particle abatement. As such the particle emission is not directly correlated to the production, but more influenced by the efficiency of the abatement.

The NO_x emission has been reduced in spite of increasing production due to installation of $DeNO_x$ technology on the stacks. The installation of this abatement occurred in 1999 and 2000. The minor fluctuations in NO_x emission in the years since are caused by variations in the abatement efficiency, e.g. when the system is failing, problems with the dosage of NH_3, etc.

The emission of NH_3 shows an increasing trend throughout the 2000s; from 14 tonnes in 2000 to 165 tonnes in 2009; in the same period, the implied emission factor fluctuates around the average 1.77 tonnes per kt product but shows no trend. For the remaining time series, the NH_3 emission only varies between 16-20 tonnes with the exception of 2010 where 123 tonnes were emitted.

From 1990 to 2021, the emission of CO_2 from the production of catalysts/fertilisers has increased from 0.57 to 1.23 kt (117 %) with maximum in 2015 (1.50 kt), due to an increase in the production as well as changes in raw material consumption.

The trends for emissions of CO_2, NH_3, NO_x, TSP, PM_{10}, $PM_{2.5}$ and BC are presented in Table 4.3.4, Annex B2-2, Figure 4.3.1 and Figure 4.3.2.

Table 4.3.4 Emissions from *Catalyst and fertiliser production*, t.

	1985	1990	1995	2000	2005	2010	2015	2020	2021
CO_2	-	570	735	877	1120	1118	1503	1433	1235
NO_x	20	29	37	39	36	17	23	23	21
NH_3	11	15	20	14	79	123	19	11	11
TSP	-	11	15	24	29	33	7	6	7
PM_{10}	-	9	12	19	23	26	6	4	6
$PM_{2.5}$	-	6.8	8.7	14.3	17.3	19.5	4.0	3.3	4.1
BC	-	0.12	0.16	0.26	0.31	0.35	0.07	0.06	0.07

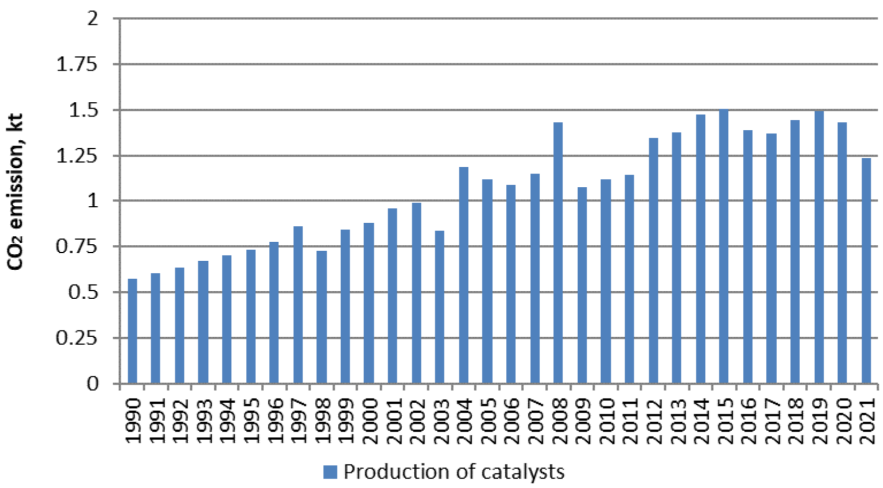


Figure 4.3.1 Emission of CO_2 from catalyst/fertiliser production, kt.

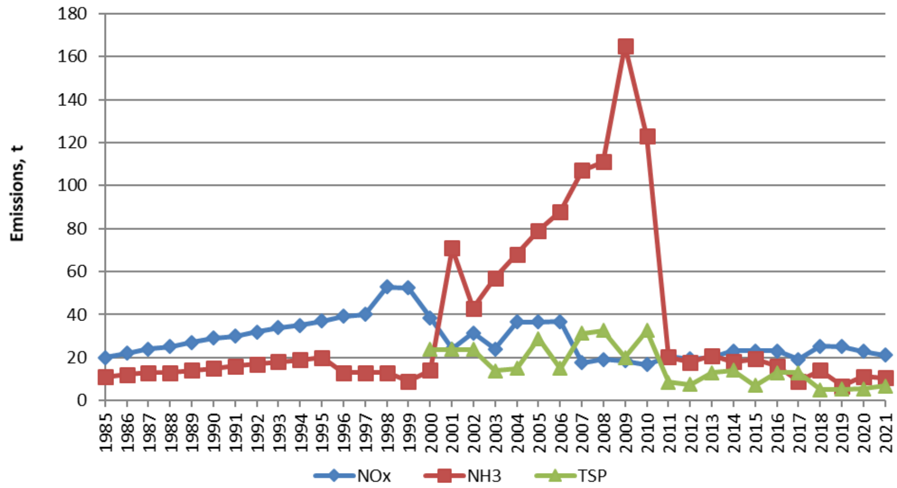


Figure 4.3.2 Emissions of NO_x, NH_3 and TSP from *Catalyst and fertiliser production*.

4.3.4 EU-ETS data for catalyst production

The applied methodology for Haldor Topsøe A/S is specified in the individual monitoring plan that is approved by the Danish competent authority, which is the Danish Energy Agency (DEA) prior to the reporting of the emissions. Catalyst production at Haldor Topsøe applies the Tier 2 methodology for the natural gas consumption activity data (uncertainty ± 3.0 %). The uncertainty for gasoil/diesel and methanol consumption is 7.5 % and 5 %, respectively.

Calorific values and emission factors are a Tier 3 level for natural gas and Tier 2a for gasoil and methanol. Oxidation factors are Tier 1. (Haldor Topsøe, 2022c)

4.3.5 Verification

Activity data for production of catalysts are available from Statistics Denmark (VARER1, 08/08-2022) (1990-2021) and the company's environmental reports (1997-2012). A comparison of the two datasets is presented in Figure 4.3.3.

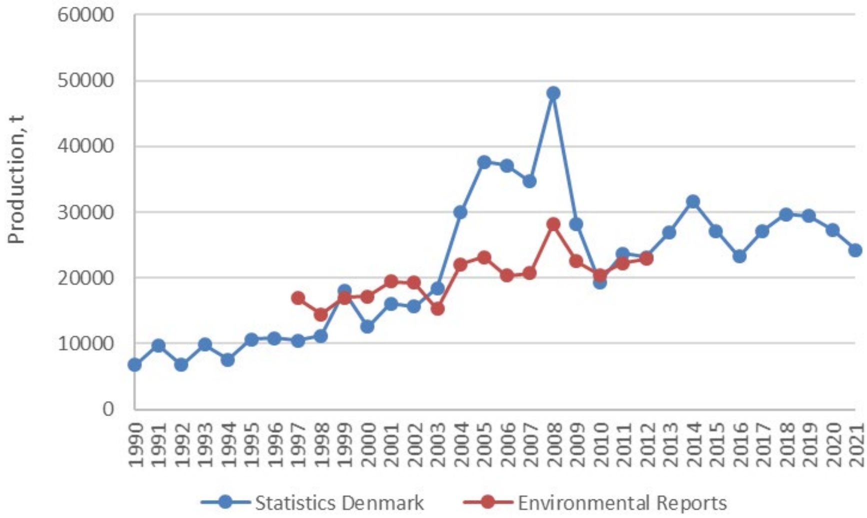


Figure 4.3.3 Activity data comparison for catalyst production.

The two datasets show a similar increase 1998-2012, but data from Statistics Denmark is significantly higher for 2004-2009.

4.3.6 Time series consistency and completeness

There is a change in the applied methodology from 1985-1995 and 1996-onward. Linear regression is used to estimate emissions for 1985-1995, while CO_2 emissions have been provided from the company since 1996. However, the source category is considered to be consistent.

The source category of catalyst production is complete.

4.3.7 Input to CollectER

The input data/data sources for calculating emissions are presented in Table 4.3.5.

Table 4.3.5 Input data for calculating emissions from *Catalyst and fertiliser production*.

	Year	Parameter	Comment/Source
Activity data	1985-1995	Production data	Estimated
	1996-2012	Production data	Haldor Topsøe (2013)
	2013-2021	Production data	Estimated
Surrogate data	1996-2012	Raw material consumption	Haldor Topsøe (2013)
	2013-2014	Raw material consumption	Haldor Topsøe (2022b)
	2014-2021	Fuel consumption	Haldor Topsøe (2022a)
Emissions	1985-1995	CO_2, NO_x, NH_3	Estimated
	1996-2021	CO_2, NO_x, NH_3, PM_{10}	Haldor Topsøe (2013, 2022a, 2022b)
	All	PM_{10}, $PM_{2.5}$	Particle distribution from CEPMEIP
	All	BC	EMEP/EEA (2019)

4.4 Production of chemical ingredients

The production of chemical ingredients takes place in a number of different companies. One of the major companies is IFF Grindsted (previously DuPont (2012-2020) and Danisco (-2012)) located in Grindsted (Danisco Grindsted, 2014). The following SNAP code is covered:

- 04 05 00 Processes in organic chemical industry

The following pollutant is relevant for the production process of chemical ingredients:

- NMVOC

4.4.1 Process description

The following description of the production of chemical ingredients is based on the historical environmental reports from the company (Danisco Grindsted, 2014).

The raw materials are primarily natural or nature identical raw materials/substances: vegetable oils, animal fatty acids, glycerine, other organic substances, mineral acidic and alkaline compounds, solvents etc. The products are emulsifiers, stabilisers, flavours, enzymes, antioxidants, pharmaceuticals, and preservatives.

The chemical processes are not described due to confidentiality.

4.4.2 Methodology

NMVOC emissions are known for the years 1997-2016 and are estimated for 1985-1996. In 2017, the production of pharmaceutical products in Grindsted ceased, but the production of emulsifiers and antioxidants continues. Because of this, Danisco Grindsted is no longer under the VOC executive order, and has therefore ceased the annual VOC emission reporting. From 2017, emissions are estimated using implied emission factors.

Due to confidentiality, no activity data or emission factors are available.

4.4.3 Emission trend

The emission of NMVOC from production of chemical ingredients has been measured from 1997 to 2016 (Danisco Grindsted, 2014 and DuPont, 2017). The emission has in this period decreased from 85 tonnes to 9 tonnes. The emission peaked in 1999 with 103 tonnes. However, no explanation can be given on these conditions, as information on activity is not available. The NMVOC emissions are presented in Table 4.4.1 and Annex B3-1.

Table 4.4.1 Emissions from the production of chemical ingredients, t.

	1985	1990	1995	2000	2005	2010	2015	2019	2020	2021
NMVOC	44	75	87	62	16	12	10	9	9	8

4.4.4 Time series consistency and completeness

There are shifts in methodology in 1996 and 2017. For 1985-1995, emissions are estimated using surrogate data from Statistics Denmark (VARER1 08/08-2022) while emissions have been provided from the company for 1996-2016. Since 2017, emissions have again been estimated data from Statistics Denmark (VARER1 08/08-2022) and implied emission factors. The source category of production of chemical ingredients is complete.

4.4.5 Input to CollectER

The input data/data sources for calculating emissions are presented in Table 4.4.2.

Table 4.4.2 Input data for calculating emissions from production of chemical ingredients.

	Year	Parameter	Comment/Source
Surrogate data	All	Sale of own product, enzymes, emulsifiers etc.	Statistics Denmark (VARER1, 08/08-2022)
Emissions	1985-1996	NMVOC	Estimated
	1997-2013	NMVOC	Danisco Grindsted (2014)
	2014-2016	NMVOC	DuPont (2017)
	2017-2021	NMVOC	Estimated

4.5 Pesticide production

The production of pesticides in Denmark is concentrated at one company: Cheminova A/S situated in Harboøre. The following SNAP code is covered:

- 04 05 25 Pesticide production

The following pollutants are relevant for the pesticide production process:
- SO_2
- NMVOC

Because it is not possible to separate process and fuel emissions reported in the company's environmental reports, SO_2 emissions for this source category includes emissions from fuel consumption.

4.5.1 Process description

Cheminova produces a wide range of pesticides, insecticides and biocides based on organic chemical syntheses. A main group of products is organophosphates and intermediates of organophosphate types to internal as well as external use. Due to the character of the products, the identity of the raw materials is often confidential.

The final formulation of the products is often done at affiliated companies in other parts of the world. Secondary products are P fertiliser and regenerated sulphur.

4.5.2 Methodology

The air emissions from Cheminova are measured from a number of sources:

- Exhaust from process plant I (parameters: odour, organic substances (VOC), hydrogen bromide, hydrogen phosphate, hydrogen chloride, hydrogen sulphide and sulphur dioxide)
- Exhaust from process plant II (parameter: hydrogen sulphide)
- Incineration of sewage water from Glyphosat plant (parameters: hydrogen chloride, metals, TOC, TSP, nitrogen oxide, carbon monoxide)
- Sulphur recovery plant ("Claus plant") (parameter: sulphur dioxide and hydrogen sulphide)
- Biological sewage treatment plant, sludge de-watering plant (parameters: organic substances (VOC))
- Combined heat and power plant (parameters: nitrogen oxides, carbon monoxide)

The produced amount of pesticides is known for 1996-2009 (Cheminova, 2010). Only some of the emissions are available and they are only presented as aggregated data. Emissions of SO_2 and NMVOC are measured yearly and are available for 1990-2021 and 1990-2000+2013-2021, respectively (Cheminova, 2010, 2015 and 2022). For the years where data are not available, activity data are extrapolated and emissions are calculated using implied emission factors.

It has not been possible to get a response from Cheminova on emissions for 2020. Emissions have therefore been set to equal those of 2019 in this report.

Activity data

Activity data for 1980-1995 are calculated using the national statistics on value of pesticides produced (million DKK) as surrogate data. From 2010 forward, no information on the production is available and activity data are estimated using DCE judgement. The activity data are known for 1996-2009 from Cheminova (2010), including intermediate products that are sold to other companies for further processing as well as flotation agents for the mining industry. As such, the activity data are in a way themselves surrogate data. Activity data for the production of pesticides are presented in Table 4.5.1 and Annex B4-1.

Table 4.5.1 Production of pesticides, t.

	1980	1985	1990	1995	2000	2005	2010	2015	2019	2020	2021
Pesticide production	20796	42010	37671	45320	60284	53504	40000	60000	60000	60000	60000

Emission factors

The calculated implied emission factors for pesticide production are presented in Table 4.5.2.

Table 4.5.2 Implied emission factors for pesticide production, Claus process.

	Substance	Interval[1], kg/t	Average[2], kg/t
Pesticides	SO_2	0.05 – 26.1	6.2
	NMVOC	0.04 - 10.4	1.4

[1]Interval for 1980/1985-2021.

[2]Average only for years where actual emissions and activity data are available; i.e. 1990-2021 for SO_2 and 1990-2000+2013-2021 for NMVOC.

4.5.3 Emission trend

The emission of NMVOC from production of pesticides is reduced significantly from 1989 to 1992. The decrease can be explained by introduction of flue gas cleaning equipment rather than any decrease in activity.

The emission of SO_2 is from the sulphur regeneration plant (Claus plant) decreased drastically from 2006-2007 due to installation of a scrubber in the beginning of 2007 (Cheminova, 2010).

Emissions of NMVOC and SO_2 are presented in Figure 4.5.1 and Annex B4-2.

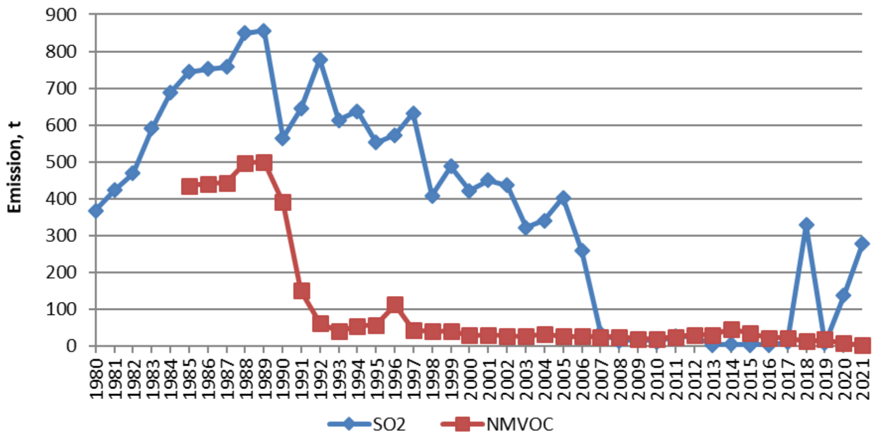


Figure 4.5.1 Emissions of SO_2 and NMVOC from pesticide production.

The SO_2 emission originates from the company's air combustion plant. Two sampling measurements are carried out per year and the annual discharge is calculated from the operating time for the year and the mass flow at sampling. The calculated annual discharge is therefore subject to some uncertainty (Cheminova, 2022).

4.5.4 Time series consistency and completeness

There is a shift in methodology applied for 1990-2019 and the one applied for 1980-1989. For 1980-1989, emissions are estimated using implied emission factors and activity data projected using surrogate data. While emissions have been provided from the company since 1990, with the exception of NMVOC data for 2001-2012. The source category of production of pesticides is complete.

4.5.5 Input to CollectER

The input data/data sources for calculating emissions are presented in Table 4.5.3.

Table 4.5.3 Input data for calculating emissions from production of pesticides.

	Year	Parameter	Comment/Source
Surrogate data	1980-2007	Production of pesticides, value	Statistics Denmark (VARER1, 08/08-2022)
Activity data	1996-2009	Production of pesticides, intermediate products, etc.	Cheminova (2010)
Emissions	1985-1989; 2001-2012	NMVOC	Estimated
	1990-2000	NMVOC	Cheminova (2010)
	2013-2021	NMVOC	Cheminova (2018 and 2022)
	1980-1989	SO_2	Estimated
	1990-2009	SO_2	Cheminova (2010)
	2001; 2004; 2007-2014	SO_2	Cheminova (2015)
	2015-2021	SO_2	Cheminova (2018 and 2022)

4.6 Production of tar products

One Danish factory (Koppers) situated in Nyborg produces tar products. The following SNAP code is covered:

- 04 05 27 Production of tar products

The following pollutants are included in the emission inventory for the production process of tar products:

- SO_2
- NMVOC
- Heavy metals: Hg
- Persistent organic pollutants: Benzo(a)pyrene

4.6.1 Process description

The description of the process is based on the environmental report by the company (Koppers, 2015). The company is a chemical plant that refines coal tar. Coal tar is a residual product from degasification of coal at coking plants. The main products of the company are coal tar pitch, carbon black feedstock, creosote oil and naphthalene.

The production facility where the raw material (coal tar) is separated in fractions and refined consists of the following units:

- Tar distillation plant (Distillation of the coal tar)
- Tar acid washer (TAW) plant (Naphthalene oil is washed with sodium hydroxide)
- Naphthalene distillation plant (Distillation of naphthalene oil)
- Storage tanks (Storage of raw materials and finished products with air ventilation and air cleaning)
- Creosote plant (Reduction of the oils crystallising point by cooling and crystallisation)
- Flacking plant (Crystallisation of naphthalene and packaging)
- Loading plant (Loading of distillates and fuel additives)

The majority of the raw material is imported from other European countries. The finished products are exported globally, but the main product, coal tar pitch, is mainly exported to the aluminium industry in Europe, where it is used for production of anodes. Naphthalene is used as a raw material in the chemical industry, creosote oil for wood preservation and carbon black feedstock in the tyre industry.

Intermediates and finished products are kept in storage tanks, which have a total capacity of approximately 100,000 m^3. In the storage tanks, some products are kept at temperatures up to 220 ºC to prevent solidification. The only exception is the main part of the naphthalene production, which after purification is crystallised in flakes and is sold as solid naphthalene.

The production takes place in a closed system and the storage tanks are run at vacuum to keep releases to the surroundings to a minimum.

The distillation plants are operating around the clock all year with the exception of a few weeks shutdown a year for scheduled maintenance.

4.6.2 Methodology

Activity data are known for 2002-2021 (Koppers, 2017a and 2022) and estimated using surrogate data (Statistics Denmark, VARER1 05/10-2017) for previous years. The emissions are based on measured emissions reported in the environmental reports and PRTR or obtained through direct communication with the company (Koppers, 2017a, 2017b and 2022). Where no emissions are reported, these are calculated using implied emission factors.

Activity data

Activity data for production of tar products are presented in Table 4.6.1 and Annex B5-1 (also presents the surrogate data).

Table 4.6.1 Activity data for production of tar products, kt.

	1980	1985	1990	1995	2000	2005	2010	2015	2019	2020	2021
Tar products	108	108	181	235	199	164	133	236	274	260	263

Emission factors

Calculated implied emission factors are presented in Table 4.6.2.

Table 4.6.2 Implied emission factors for production of tar products.

Pollutant	Unit	Value	Average of	Applied for
SO_2	t/kt	1.0	2002-2006	1980-2000
NMVOC	kg/kt	4.3	2002-2006	1985-2000
Hg	g/kt	67.8	2008	1990-2007
Benzo(a)pyrene	g/kt	0.7	2005	All years

4.6.3 Emission trend

The SO_2 emission varies depending on the sulphur content in the raw tar. The NMVOC emission is fugitive, i.e. the emission is mainly associated with leakages, maintenance work and accidental releases. As such, there is no correlation between the SO_2 and NMVOC emission as the two pollutants are emitted through different processes from different sources. The Hg emission for the later years is based on measured emissions by the plant. The fluctuations are caused by differences in the raw material, differences in production conditions and differences in abatement efficiency.

Emissions are presented in Table 4.6.3 and Annex B5-2.

Table 4.6.3 Emissions from production of tar products.

	Unit	1980	1985	1990	1995	2000	2005	2010	2015	2019	2020	2021
SO_2	t	108	108	181	235	199	212	105	153	14	14	13
NMVOC	t	-	0.5	0.8	1.0	0.9	0.9	1.2	0.9	2.6	2.2	4.8
Hg	kg	-	-	12.3	15.9	13.5	11.1	1.5	1.0	0.2	0.1	1.1
Benzo(a)pyrene	kg	-	-	0.1	0.2	0.1	0.1	0.1	0.2	0.2	0.2	0.2

4.6.4 Time series consistency and completeness

There is a shift in the methodology applied for 1980-2001 (2007 for Hg) and the one applied for 2002 forward. For 1980-2001, emissions are estimated using implied emission factors and activity data projected using surrogate data. While emissions have been provided from the company since 2002 (2008 for Hg). Tar products are only produced at one facility in Denmark, and the source category is therefore complete.

4.6.5 Input to CollectER

The input data/data sources for calculating emissions are presented in Table 4.6.4.

Table 4.6.4 Input data for calculating emissions from *Production of tar products*.

	Year	Parameter	Comment/Source
Surrogate data	1985-2011	Production of tar products	Statistics Denmark (VARER1 08/10-2017)
Activity data	2002-2021	Production of tar products	Koppers (2017a, 2022)
Emissions	1985-2000	NMVOC	Estimated
	2001-2021	NMVOC	Koppers (2017a, 2022)
	1980-2000	SO_2	Estimated
	2001-2021	SO_2	Koppers (2017a, 2017b, 2022)
	1990-2007	Hg	Estimated
	2008-2021	Hg	Koppers (2017b, 2022)

5 Metal industry

The relevant processes within *Metal industry* (CRF/NFR 2C) in Denmark in relation to emission of greenhouse gases and other pollutants are:

- Iron and steel production (SNAP 030303, 040207, 040208); see section 5.2
- Red bronze production (SNAP 040306); see section 5.3
- Magnesium production (SNAP 040304); see section 5.4
- Secondary aluminium production (SNAP 030310); see section 5.5
- Secondary lead production (SNAP 030307); see section 5.6

There are no primary productions of metals in Denmark and no metallurgical coke production.

5.1 Emissions

5.1.1 Greenhouse gas emissions

The time series for emission of greenhouse gasses from *Metal Industry* (2C) is presented in Figure 5.1.1 below.

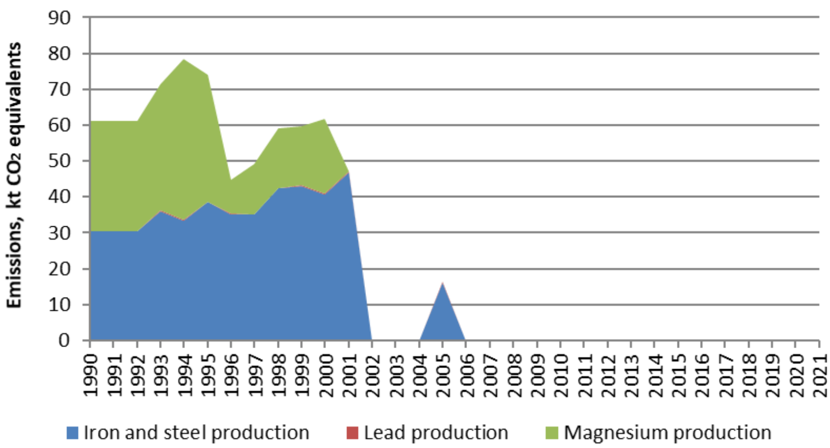


Figure 5.1.1 Emission of greenhouse gasses from the individual source categories compiling *2C Metal Industry*, kt CO_2 equivalents.

From 1990 to 2001, the CO_2 emission from the electro-steelwork increased by 55 % whiles the SF_6 emission from magnesium production decreased with 31 % (1990-2000). The changes in the greenhouse gas emission is similar to the increase and decrease in the activity as the consumption of metallurgical coke per amount of steel sheets and bars produced has almost been constant during the period and the emission factor for magnesium production is constant throughout the time series.

Greenhouse gas emissions from secondary lead production are miniscule (0.3-0.4 % of CO_2 equivalent emissions for 1990-2000), but are the only emissions in the *Metal Industry* sector that occur for the entire time series.

The electro-steelwork was shut down in January 2002 and reopened and closed down again in 2005. In 2000, the SF_6 emission from the magnesium production ceased, due to SF_6 no longer being used as a cover gas.

Grey iron foundries, secondary aluminium production and red bronze production are active for the entire time series but emit no process greenhouse gas emissions.

5.1.2 Air pollution emissions

The time series for emission of SO_2, NMVOC, particulate matter, heavy metals, and POPs from *Metal production* is available in Annex C0-1. Table 5.1.1 presents an overview of emissions from 2021.

Table 5.1.1 Overview of emissions from 2020

	Total emission from Metal industries	Fraction of IPPU, %	Largest contributor in Metal industries	Emission from largest contributor	Fraction of Metal industries, %
SO_2	0.6 t	0.07	2C5 Lead production	0.6 t	100.0
NMVOC	4.8 t	0.01	2C1 Iron and steel production	4.8 t	100.0
TSP	221.5 t	3.1	2C1 Iron and steel production	217.8 t	98.3
HMs	3.1 t	43.9	Pb from 2C5 Lead production	1.5 t	46.2
POPs	0.06 kg	0.1	PCBs from 2C1 Iron and steel production	0.05 kg	92.3

Iron and steel production comprises three activities; an electric arc furnace (EAF) (until 2001/2002 and in 2005), rolling mills (from 2003) and grey iron foundries (whole time series). The most significant activity from an air emission perspective is the EAF. After the closing of the EAF, the site has since 2003 been used for rolling steel slabs imported from steelworks in other countries. This change in production results in large changes in activity data and emissions. In 2005, the EAF was shortly reopened, which explains the higher activity level this year.

Regarding the steelworks that use iron and steel scrap as raw material, the emissions to a large degree depend on the quality of the scrap. This fact may result in large annual variations for one or more of the heavy metals. This may also be the case for iron foundries, as they also use scrap as raw material, but this is not reflected in the current calculations as emissions are based on standard emission factors.

5.2 Iron and steel production

The production of semi-manufactured steel products (e.g. steel sheets/plates and bars) was concentrated at one company: Det Danske Stålvalseværk A/S situated in Frederiksværk. After the closure of the electro steelwork in 2002, the two rolling mills were divided in two companies called DanSteel and Duferco. Multible grey iron foundries exist in Denmark, producing a range of products like e.g. cast iron pipes, central heating boilers and flywheels. The following SNAP categories are covered:

- 03 03 03 Grey iron foundries
- 04 02 07 Electric furnace steel plant
- 04 02 08 Rolling mill

Emissions of the following pollutants are included for *Iron and steel production*:

- CO_2
- SO_2
- NO_x

- NMVOC
- CO
- Particulate matter: TSP, PM_{10}, $PM_{2.5}$, BC
- Heavy metals: As, Cd, Cr, Cu, Hg, Ni, Pb, Se, Zn
- Persistent organic pollutants: HCB, PCDD/F, PAHs, PCB

The steelwork has been closed down in January 2002 and then partly reopened again in November 2002. The production of steel sheets/plates was reopened by DanSteel in 2003, the production of steel bars was reopened by DanScan Metal in March 2004, and the electro steelwork was reopened by DanScan Steel in January 2005. The production at DanScan Metal and Steel ceased in the last part of 2005 and in June 2006 DanScan Metal was taken over by Duferco; the electro steelwork (DanScan Steel) has still not been in operation since 2005. The timeline is presented in Figure 5.2.1.

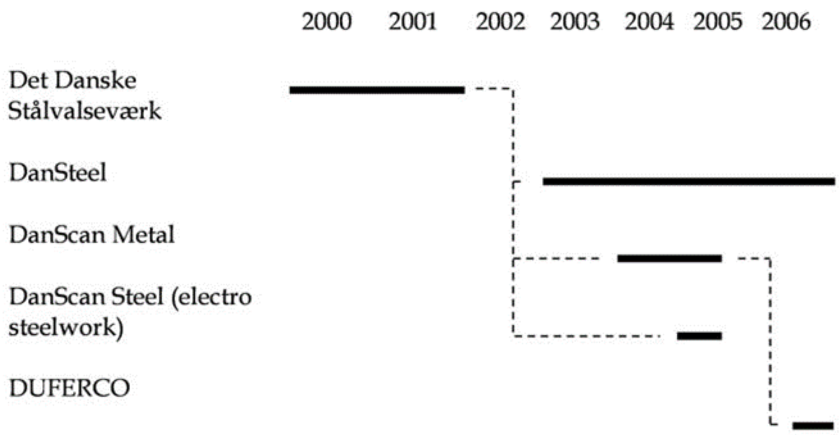


Figure 5.2.1 Timeline for production at the Danish steelwork.

5.2.1 Process description

The primary raw materials in steel production are iron and steel scrap and the secondary raw materials are metallurgical coke, iron, alkali metals, other alloy metals, and oxygen. Trucks, trains or ships deliver the iron and steel scrap. The scrap is controlled before melting in an electric arc furnace. The composition of the molten iron is checked and alloy metals are added depending on the expected quality of the final steel product. The iron is prepared as billets/blooms for bars or slabs for sheets. The final products are made in different rolling mills for bars and sheets, respectively. The cease of the electro steelwork has resulted in import of billets/blooms and slabs for the rolling mills.

The process is presented in Figure 5.2.2.

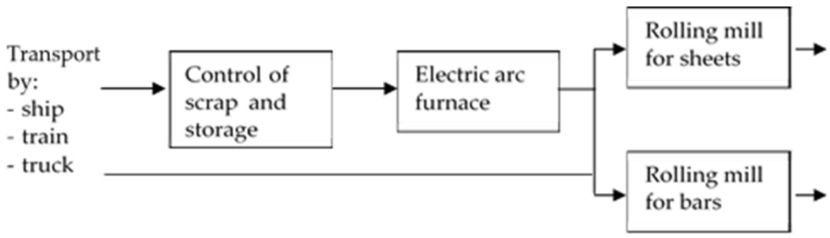


Figure 5.2.2 Overall flow-sheet for "Det Danske Stålvalseværk" (Stålvalseværket, 2002; DanSteel, 2014).

5.2.2 Methodology

In steel production, metallurgical coke is used in the melting process to reduce iron oxides and to remove impurities. The overall process is:

$C + O_2 \rightarrow CO_2$

The emission factors for carbon dioxide from using metallurgical coke in manufacturing of iron and steel from scrap is according to stoichiometry:

- 3.667 tonnes CO_2 per tonne C

Different steel qualities contain carbon from <0.25% (iron/unalloyed steel) to >6% (ferrochromium) and some of the metallurgical coke/carbon can be expected to be retained in the steel. However, the scrap can also be expected to contain a certain amount of carbon. Analysis of the data in the environmental declaration for steel sheets or steel bars indicate that all the metallurgical coke is emitted as carbon dioxide as illustrated in Table 5.2.1.

Table 5.2.1 CO_2 balance for year 2001 for production of 1 tonne steel sheets (Stålvalseværket, 2002).

	Environmental report	Emission factor (2001)	CO_2 emission (estimated)
Input			
Natural gas	73 Nm^3 (2.92 GJ)	57.25 kg CO_2/GJ	167.17 kg CO_2
Metallurgical coke	18 kg	3.667 kg CO_2/kg C	66.01 kg CO_2
Output			
CO_2	229 kg		233.18 kg

The difference between the reported and the estimated CO_2 emission can be explained by choice of calorific value for natural gas and the CO_2 emission factor for natural gas.

The CO_2 emission from the consumption of metallurgical coke at steelworks has been estimated from the annual production of steel sheets and steel bars combined with the consumption of metallurgical coke per produced amount (Stålvalseværket, 2002). The carbon source is assumed to be coke and all the carbon is assumed to be converted to CO_2 as the carbon content in the products is assumed to be the same as in the iron scrap. The emission factor (consumption of metallurgical coke per tonne of product) has been almost constant from 1993 to 2001; steel sheets: 0.012-0.018 tonnes metallurgical coke per tonne and steel bars: 0.011-0.017 tonnes metallurgical coke per tonne.

Steel production data for 1990-1991 and for 1993 have been determined with extrapolation and interpolation, respectively, and data on the consumption of metallurgical coke for 1990-1992 have beenextrapolated.

Emissions of air pollution from steel production are calculated using standard emission factors.

There are about 15 grey iron producers in Denmark; most of these are small producing only 10-1000 tonnes per year. The emissions from iron foundries are based on annual production statistics from Statistics Denmark (VARER1 08/08-2022), emission measurements (implied emission factors) and standard emission factors.

Activity data

Statistical data on steel production activities, i.e. amount of steel sheets and bars produced as well as consumption of metallurgical coke are available in environmental reports from the single Danish steel plant (Stålvalseværket, 2002), the rolling mills factories (DanSteel, 2016 and Duferco, 2014, 2016) supplemented with other literature (Jensen & Markussen, 1993) and personal contact with the plants (DanSteel, 2022 and Duferco, 2021). In 2002, production stopped. For 2005, the production has been assumed to be one third of the production in 2001 as the steelwork was operating between 4 and 6 months in 2005. The activity data are presented in Table 5.2.2 and Annex C1-1.

Table 5.2.2 Overall mass flow for Danish steel production, kt.

		1980	1985	1990	1995	2000	2005	2010	2015	2019	2020	2021
Det danske stålvalseværk												
Raw material	Iron and steel scrap	-	-	-	657	731	-	-	-	-	-	-
Intermediate product	Steel slabs etc.	-	-	-	654	803	-	-	-	-	-	-
Product	Steel sheets	444	444	444	478	380	-	-	-	-	-	-
	Steel bars	170	170	170	239	251	-	-	-	-	-	-
	Products, total	614[1]	614[1]	614[1]	717	631	250[2]	-	-	-	-	-
Dansteel												
Raw material	Steel slabs	-	-	-	-	-	515	457	525	637	582	673
Product	Steel sheets	-	-	-	-	-	433	381	441	538	494	561
Duferco												
Raw material	Steel billets	-	-	-	-	-	-	141	137	164	137	126
Product	Steel bars	-	-	-	-	-	-	129	129	156	130	120

[1] Extrapolation.

[2] Assumed.

The mass balances/flow sheets presented in the annual environmental reports do not tell for all years about the changes in the stock and therefore the balance cannot be completed.

Statistical data on production in grey iron foundries are available from Statistics Denmark (VARER1, 08/08-2022) for the entire time series. The activity data are presented in Table 5.2.3 and in detain in Annex C1-2.

Table 5.2.3 Activity data, iron foundries, kt.

	1990	1995	2000	2005	2010	2015	2018	2019	2020	2021
Grey iron foundries	104.9	100.5	108.0	107.2	86.5	96.2	112.8	99.2	83.5	106.6

Emission factors

The CO_2 emission factor from use of metallurgical coke in manufacturing of steel from scrap is the stoichiometric ratio 3.667 tonnes CO_2 per tonne C.

The applied steel production emission factors for air pollutants are presented in Table 5.2.4. Regarding the electric arc furnace, the emissions for all other pollutants than TSP have been estimated by use of emission factor from literature.

Table 5.2.4 Emission factors for steel production.

	Unit	Electric Arc Furnace	Rolling Mill
SO_2	g/t	60[6]	-
NO_x	g/t	130[6]	-
NMVOC	g/t	46[6]	7[6]
CO	kg/t	1.7[6]	-
TSP	g/t	61-68[4]	2.5-11.1[4]
PM_{10}	g/t	80 % of TSP[6]	2.4-10.5[4]
$PM_{2.5}$	g/t	70 % of TSP[6]	1.5-6.6[4]
BC[7]	g/t	0.36 % of $PM_{2.5}$[6]	0.36 % of $PM_{2.5}$[6]
As	mg/t	15[6]	-
Cd	mg/t	10-80[2]	0.1-0.4[4]
Cr	mg/t	100[6]	-
Cu	mg/t	20[6]	-
Hg	mg/t	50-400[2,6]	-
Ni	g/t	0.4-1.4[2]	0.004-0.010[4]
Pb	g/t	1.0-5.0[2]	0.005[5]
Se	g/t	0.02[6]	-
Zn	g/t	3.6-19.0[2,6]	0.005[5]
HCB	mg/t	3.2[3]	-
PCDD/F	µg/t	0.01-0.4[4]	-
Total 4 PAHs	g/t	0.48[1,6]	-
PCB	mg/t	2.5[6]	-

[1]Divided by four for an estimate of the individual pollutants, [2]Illerup et al. (1999), [3] Antunes et al. (2012), [4]Implied emission factor, [5]DCE judgement, [6]EMEP/EEA (2019), [7]The Tier 1 (Table 3.1) and Tier 2 EAF (Table 3.15) BC EFs are the same in EMEP/EEA (2019). All though different EFs would be expected from the two process types, no data is available to support this.

The applied emission factors for the grey iron foundries are presented in Table 5.2.5.

Table 5.2.5 Emission factors for grey iron foundries.

	Unit	Grey iron foundries	Reference
TSP	g/t	2000	CEPMEIP[1]
PM_{10}	g/t	600	CEPMEIP[1]
$PM_{2.5}$	g/t	90	CEPMEIP[1]
BC	% of $PM_{2.5}$	10	EMEP/EEA (2019)[2]
As	g/t	0.3	EMEP/Corinair (2007)[3]
Cd	g/t	0.1	EMEP/Corinair (2007)[3]
Cr	g/t	1.0	EMEP/Corinair (2007)[3]
Cu	g/t	1.0	EMEP/Corinair (2007)[3]
Hg	g/t	0.04	EMEP/Corinair (2007)[3]
Ni	g/t	0.3	EMEP/Corinair (2007)[3]
Pb	g/t	3.0	EMEP/Corinair (2007)[3]
Se	g/t	0.01	EMEP/Corinair (2007)[3]
Zn	g/t	5.0	EMEP/Corinair (2007)[3]
HCB	mg/t	0.04	Bipro, 2006
PCB	mg/t	0.5	Bipro, 2006

[1]CEPMEIP & EMEP/Corinair 2007, SNAP 030303, Table 8.1, [2]SNAP 040302 Ferroalloys, [3]SNAP 030303, Table 8.1

5.2.3 Emission trend

The greenhouse gas emission from the steel production is presented in Figure 5.2.3 and Annex C0-1. The production ceased in 2001, reopened, and closed again in 2005; see Figure 5.2.1.

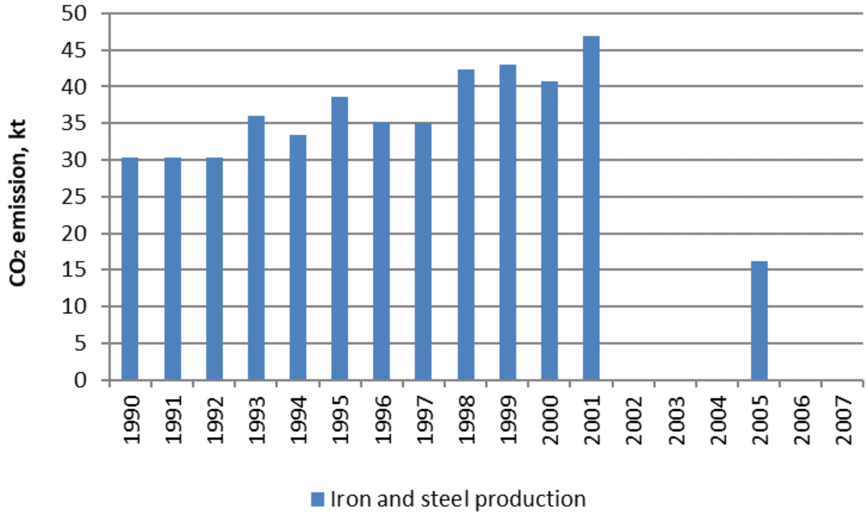


Figure 5.2.3 Emission of greenhouse gases from the production of steel from scrap.

Emissions from steel production (i.e. the electro steelwork and rolling mills) are presented in Table 5.2.6 and Annex C0-1.

Table 5.2.6 Emissions from the electro steelwork and rolling mills.

	Unit	1980	1985	1990	1995	2000	2005	2010	2015	2019	2020	2021
CO_2	t	-	-	30	39	41	16	-	-	-	-	-
SO_2	t	37	37	37	43	38	15	-	-	-	-	-
NO_x	t	-	80	80	93	82	33	-	-	-	-	-
NMVOC	t	-	28	32	37	33	19	6.1	6.9	7.7	6.8	8.2
CO	t	-	1.0	1.0	1.2	1.1	0.4	-	-	-	-	-
TSP	t	-	-	141	153	95	72	45.4	52.9	53.6	44.3	56.8
PM_{10}	t	-	-	71	82	33	15	3.0	5.4	4.8	3.4	4.2
$PM_{2.5}$	t	-	-	62	72	29	12	2.5	4.0	3.8	2.7	3.2
BC	t	-	-	0.22	0.26	0.10	0.05	1.11	1.11	1.35	1.13	1.04
As	kg	-	-	9.2	10.8	9.5	3.8	-	-	-	-	-
Cd	kg	-	-	39	22	16	7.1	0.8	0.8	1.0	0.9	0.8
Cr	kg	-	-	61	72	63	25	-	-	-	-	-
Cu	kg	-	-	12	14	13	5.0	-	-	-	-	-
Hg	kg	-	-	246	143	63	13	-	-	-	-	-
Ni	kg	-	-	757	430	252	104	2.8	1.7	2.4	2.1	1.8
Pb	kg	-	-	2967	1720	669	268	1.9	2.2	2.7	2.5	2.8
Se	kg	-	-	12	14	13	5.0	-	-	-	-	-
Zn	kg	-	-	11492	6547	3085	902	3.0	3.3	4.0	3.6	3.8
HCB	kg	-	-	2.0	2.3	2.0	0.8	-	-	-	-	-
PCDD/F	g	-	-	12.0	7.5	0.5	0.8	-	-	-	-	-
Benzo(b)flouranthene	kg	-	-	74	86	76	30	-	-	-	-	-
Benzo(k)flouranthene	kg	-	-	74	86	76	30	-	-	-	-	-
Benzo(a)pyrene	kg	-	-	74	86	76	30	-	-	-	-	-
Indeno(1,2,3-c,d)pyrene	kg	-	-	74	86	76	30	-	-	-	-	-
PCB	kg	-	-	1.5	1.8	1.6	0.6	-	-	-	-	-

Due to the change in production process in the beginning of the 00's, the emissions (and even more so the implied emission factors) change drastically from 2001 to 2002 and from 2002 to 2003. Please refer to Figure 5.2.1 and Table 5.2.2 (Annex C1-1).

Emissions from grey iron foundries are presented in Table 5.2.7 and Annex C0-1.

Table 5.2.7 Emissions from grey iron foundries.

	Unit	1990	1995	2000	2005	2010	2015	2018	2019	2020	2021
TSP	t	210	201	216	214	173	192	226	198	167	213
PM_{10}	t	63	60	65	64	52	58	68	60	50	64
$PM_{2.5}$	t	9	9	10	10	8	9	10	9	8	10
BC	t	0.9	0.9	1.0	1.0	0.8	0.9	1.0	0.9	0.8	1.0
As	kg	31	30	32	32	26	29	34	30	25	32
Cd	kg	10	10	11	11	9	10	11	10	8	11
Cr	kg	105	100	108	107	86	96	113	99	83	107
Cu	kg	105	100	108	107	86	96	113	99	83	107
Hg	kg	4.2	4.0	4.3	4.3	3.5	3.8	4.5	4.0	3.3	4.3
Ni	kg	31	30	32	32	26	29	34	30	25	32
Pb	kg	315	301	324	322	259	289	338	298	250	320
Se	kg	1.0	1.0	1.1	1.1	0.9	1.0	1.1	1.0	0.8	1.1
Zn	kg	524	502	540	536	432	481	564	496	417	533
HCB	g	4.2	4.0	4.3	4.3	3.5	3.8	4.5	4.0	3.3	4.3
PCB	g	52	50	54	54	43	48	56	50	42	53

5.2.4 Time series consistency and completeness

The time series for both secondary steel and iron production are consistent as the same methodology has been applied for the whole period. The time series are also considered to be complete.

5.2.5 Input to CollectER

The input data/data sources for calculating emissions are presented in Table 5.2.8.

Table 5.2.8 Input data for calculation of emissions from iron and steel production.

	Year	Parameter	Comment/Source
Activity	1992, 1994-2001	Scrap, semi manufactured products, final products	Stålvalseværket (2002)
	1990, 1991, 1993	Final products	Estimated with interpolation and extrapolation
	2003-2021	Final products	DanSteel (2016, 2022) and Duferco (2014, 2016, 2021)
	All	Sales statistics for grey iron products	Statistics Denmark (VARER1, 08/08-2022)
Emissions	1992-1997	Heavy metal EFs	Illerup et al. (1999)
	1993-2001	CO_2	Estimated from information on consumption of metallurgical coke (Stålvalseværket, (2002)
	1993-2000	TSP	Stålvalseværket (2002)

5.3 Red bronze production

This section covers the production of red bronze which is the only ferroalloy (i.e. allied metal) produced in Denmark. The following SNAP category is covered:

- 04 03 06 Allied metal manufacturing

Emissions of the following pollutants are included for the red bronze production processes:

- Heavy metals: Cd, Cu, Pb, Zn

5.3.1 Process description

In Denmark, casting of brass and bronze primarily occurs in clay bonded sand or chemically bonded sand with or without core. These production processes are usually used in small production and are suitable for series of 1-100 pcs, e.g. for prototypes, test series and small production series.

In addition, lost-wax precisions casting is used for e.g. sculptures and shell molding (aka. Croning casting) for large or medium-sized batches.

Products vary from valves and propellers to headstone ornaments and sculptures. The weight of these products is known to vary from 5 grams up to 2.5 tonnes.

5.3.2 Methodology

Production data are available for 1991-1997 (Illerup et al., 1999), 1998-2009 (DSBF, 2010) and 1990-2021 (Statistics Denmark, VARER1, 09/08-2022). Data from the Danish Foundry Industry Association (DSBF) are assumed to be most reliable but only includes production from members, production from non-members is estimated by Illerup et al. (1999). Data from Statistics Denmark shows good agreement with data from DSBF for the years 2001-2009, and have therefore been applied for 2010-2021 as a direct extension to the 1990-2010 time series. The activity for 1990 is set to equal that of 1991.

Activity data

The activity data for calculating emissions are presented in Table 5.3.1 and Annex C2-1.

Table 5.3.1 Activity data for red bronze production, kt.

	1990	1995	2000	2005	2010	2015	2018	2019	2020	2021
Red bronze production	3.9	4.5	4.3	5.5	4.6	3.8	4.0	3.7	3.1	3.1

Emission factors

The applied emission factors are presented in Table 5.3.2 and are all referenced to Illerup et al. (1999). These emission factors are based on Danish measurements and are valid for foundries working with copper alloys (including brass and bronze), aluminium/aluminum alloys and zinc/zinc alloys.

Table 5.3.2 Emission factors for red bronze production.

Pollutant	Unit	Value
Cd	g/t	1
Cu	g/t	10
Pb	g/t	15
Zn	g/t	140

5.3.3 Emission trend

Emissions trends for Cd, Cu, Pb, and Zn from red bronze production are presented in Table 5.3.3 and Annex C2-2.

Table 5.3.3 Emissions from red bronze production, kg.

	1990	1995	2000	2005	2010	2015	2018	2019	2020	2021
Cd	3.9	4.5	4.3	5.5	4.6	3.8	4.0	3.7	3.1	3.1
Cu	39	45	43	55	46	38	40	37	31	31
Pb	58	67	65	82	69	58	60	56	47	46
Zn	545	630	603	769	648	538	557	521	437	428

5.3.4 Time series consistency and completeness

Data from DSBF is only available for 1998-2009. However, the time series is checked against data from Statistics Denmark to ensure as much consistency as possible. The time series for red bronze production is considered both complete and consistent.

5.3.5 Input to CollectER

The input data/data sources for calculating emissions are presented in Table 5.3.4.

Table 5.3.4 Input data for calculation of emissions from *Red bronze production*.

	Year	Parameter	Comment/Source
Activity	1991-2009	Production statistics	Illerup et al. (1999) and DSBF (2010)
	1990, 2010-2021	Production statistics	Estimated using surrogate data (Statistics Denmark)
Emission factors	All	Heavy metal EFs	Illerup et al. (1999)

5.4 Magnesium production

For the production of magnesium in Denmark, the following SNAP-category is covered:

- 04 03 04 Consumption of SF_6 in magnesium foundries

Emissions of SF_6 are included for the magnesium production processes.

5.4.1 Process description

There is no primary production of magnesium in Denmark, hence only magnesium casting has taken place. Magnesium casting processes involve handling of molten pure magnesium and/or molten high magnesium content alloys. Molten magnesium may be cast by a variety of methods including gravity casting, sand casting, die-casting and others.

All molten magnesium spontaneously burns in the presence of atmospheric oxygen. Production and casting of all magnesium metal therefore requires a protection system to prevent burning. Among the various protection systems commonly used are those that use gaseous components with high GWP values, such as SF_6, which typically escape to the atmosphere.

5.4.2 Methodology

The consumption of SF_6 as cover gas in the magnesium production is known from information directly from the industry (Poulsen, 2023[13]). The emission

[13] Information on magnesium production is not included in the report, but in the accompanied Excel spreadsheet.

is calculated from the SF_6 consumption and the default Tier 2 methodology, which is a release of 100 %; i.e. consumption equals release (IPCC, 2006). The use of SF_6 for this purpose exists in Denmark for 1990-2000 after which alternative cover gasses were used in the productions.

The Tier 1 default emission factor of 1 kg SF_6 per tonne produced magnesium (IPCC, 2006) is applied only to achieve tonnes of produces magnesium activity data, but the applied methodology is as stated above a Tier 2.

Activity data

Table 5.4.1 presents the estimated activity data.

Table 5.4.1 Production of magnesium, tonnes.

	1990	1991	1992	1993	1994	1995	1996	1997	1998	1999	2000
Magnesium produced	1300	1300	1300	1500	1900	1500	400	600	700	700	891

1.1.1 Emission trend

The greenhouse gas emissions from the production of magnesium are presented in Figure 5.4.1 below. The consumption of SF_6 ceased after 2000.

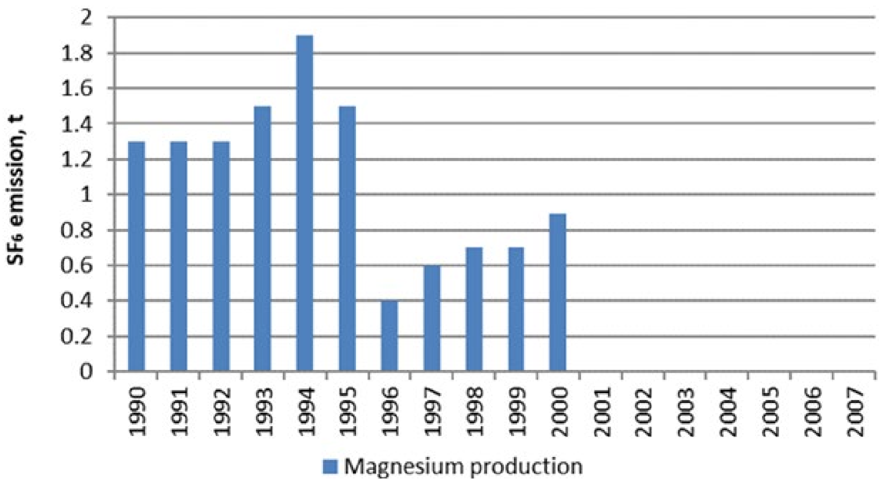


Figure 5.4.1 Emission of greenhouse gases from magnesium production.

5.4.3 Time series consistency and completeness

The time series for magnesium production is both consistent and complete.

5.4.4 Input to CollectER

The input data/data sources for calculating emissions are presented in Table 5.4.2.

Table 5.4.2 Input data for calculation of emissions from *Magnesium production*.

	Year	Parameter	Comment/Source
Activity/ Emission	1990-2000	Magnesium production	Poulsen (2023), spreadsheet

5.5 Secondary aluminium production

Only one Danish producer of secondary aluminium exists; "Stena Aluminium". The following SNAP code is covered:

- 03 03 10 Secondary aluminium production

The following pollutants are relevant for the secondary aluminium production:

- Particulate matter: TSP, PM_{10}, $PM_{2.5}$, BC
- Heavy metals: Cd, Pb
- Persistent organic pollutants: HCB, PCDD/F, PCBs

5.5.1 Process description

Secondary aluminium production is when aluminium scraps or aluminium-bearing materials; other than aluminium-bearing concentrates (ores) derived from a mining operation, is processed into aluminium alloys for industrial castings and ingots. The furnace used for melting aluminium scrap depends on the type of scrap and there is a wide variety of scraps and furnaces used. In general, for fabrication scrap and cleaner materials, reverberatory and induction furnaces are used. For more contaminated grades of scrap, rotary furnaces, tilting or horizontal furnaces are used. The scrap may also be pre-treated, depending on type of scrap and contamination. Coated scrap, like used beverage cans, is de-coated as an integrated part of the pre-treatment and melting process. The metal is refined either in the holding furnace or in an inline reactor to remove gases and other metals generally in the same way as for primary aluminium. If magnesium needs to be removed, this is done by treatment with chlorine gas mixtures.

It is difficult to obtain information on the specific technology used in Denmark as the production closed down in the end of 2008.

5.5.2 Methodology

Secondary aluminium industries were identified from a list of companies with the relevant environmental approvals acquired from the Danish Environmental Agency. All producers were contacted when necessary to determine if they use scrap aluminium in their production. The only secondary aluminium producer (called Stena Aluminium) closed in the end of 2008.

Activity data

The activity data are known from the company's environmental reports (Stena, 2008) for 1996-2008 and are presented in Table 5.5.1 and Annex C3-1.

Table 5.5.1 Activity data for secondary aluminium production, kt.

	1990[1]	1995[1]	2000	2005	2006	2007	2008
Stena Aluminium	30.2	30.2	32.9	23.4	31.3	35.1	36.2

[1]1990-1995: Calculated average of 1996-2000.

Emission factors

Emission factors for the production of secondary aluminium are presented in Table 5.5.2.

Table 5.5.2 Emission factors for secondary aluminium production.

Pollutant	Unit	Value	Applied for years	Source
TSP	kg/t	0.12	All	Average IEF (1998-2000)
PM_{10}	% of TSP	70.0	All	EMEP/EEA (2019)
$PM_{2.5}$	% of TSP	27.5	All	EMEP/EEA (2019)
BC	% of $PM_{2.5}$	2.3	All	EMEP/EEA (2019)
Cd	g/t	0.03	All	Average IEF (1998-2000)
Pb	g/t	0.15	All	Average IEF (1998-2000)
HCB	mg/t	20.0	All	Bipro, 2006
PCDD/F	mg/t	0.035	All	EMEP/EEA (2019)
PCB	mg/t	3.4	All	Bipro, 2006

5.5.3 Emission trend

Emissions from secondary aluminium production are available in Table 5.5.3 and Annex C3-2.

Table 5.5.3 Emissions from Secondary aluminium production.

	Unit	1990	1995	2000	2005	2006	2007	2008
TSP	t	3.6	3.6	3.9	2.8	3.8	4.2	4.3
PM_{10}	t	2.5	2.5	2.8	2.0	2.6	2.9	3.0
$PM_{2.5}$	t	1.0	1.0	1.1	0.8	1.0	1.2	1.2
BC	kg	23.0	23.0	25.0	17.8	23.8	26.7	27.5
Cd	kg	0.91	0.9	1.0	0.7	0.9	1.1	1.1
Pb	kg	4.5	4.5	4.9	3.5	4.7	5.3	5.4
HCB	kg	0.60	0.60	0.66	0.47	0.63	0.70	0.72
PCDD/F	g	1.1	1.1	1.2	0.8	1.1	1.2	1.3
PCB	kg	0.10	0.10	0.11	0.08	0.11	0.12	0.12

5.5.4 Verification

Activity data from the sole producer, available from the environmental reports (Stena, 2008) have been validated by comparing with sales statistic from Statistics Denmark (VARER1, 02/09-2015). These two data sets show good agreement with only smaller fluctuations; see Figure 5.5.1.

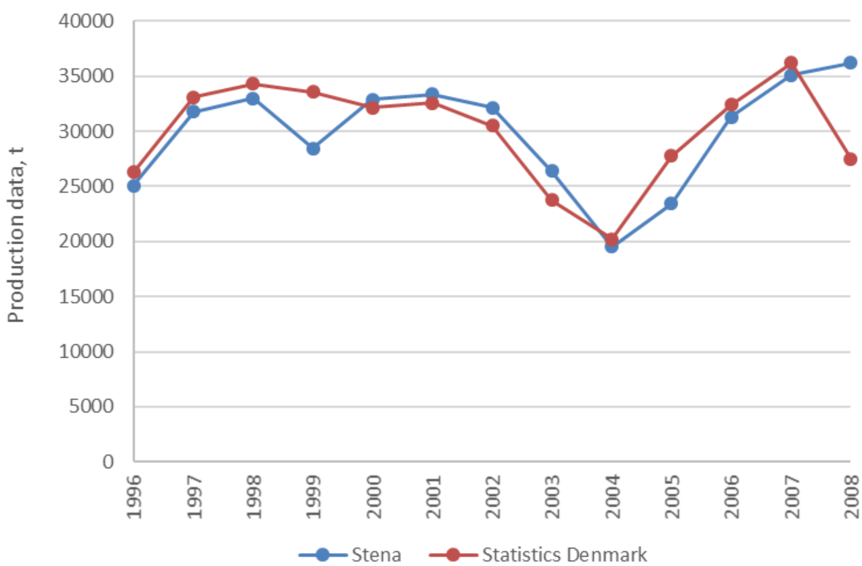


Figure 5.5.1 Comparison of production data from Stena and Statistics Denmark.

5.5.5 Time series consistency and completeness

The time series for *Secondary aluminium production* is both consistent and complete.

5.5.6 Input to CollectER

The input data/data sources for calculating emissions are presented in Table 5.5.4.

Table 5.5.4 Input data for calculation of emissions from aluminium production.

	Year	Parameter	Comment/Source
Activity	1996-2008	Aluminium production	Stena (2008)
	1990-1995	Aluminium production	Estimated
Emission	1990-2008	Emission factors	Stena (2008), EMEP/EEA (2019), Bipro, 2006

5.6 Secondary lead production

The production of secondary lead occurs at one point source (Hals Metal) and as area source from a number of smaller artisans. The following SNAP code is covered:

- 03 03 07 Secondary lead production

Emissions of the following pollutants are included for secondary lead production:

- CO_2
- SO_2
- Particulate matter: TSP, PM_{10}, $PM_{2.5}$
- Heavy metals: As, Cd, Hg, Pb, Zn
- Persistent organic pollutants: HCB, PCDD/F, PCBs

5.6.1 Process description

Only one Danish company; Hals Metal, has been identified as producing secondary lead from scrap metal. Hals Metal closed down during 2021, and 2021 will therefore be the last year with reported emissions from Hals Metal. In addition to Hals metal, old lead tiles from castles, churches etc. are melted and recast on site during preservation of the many historical buildings in Denmark.

The process of secondary lead production is usually subdivided as follows: battery breaking and processing (scrap preparation), smelting of battery scrap materials and refining. The Danish plant was recycling e.g. transformers and land and sea cables containing lead. The cables are stripped to isolate the lead and with other lead-bearing materials, it is melted in a furnace and new lead items are casted for sale.

5.6.2 Methodology

Production data for Hals Metal are provided by the company for the entire time series (Hals Metal, 2021). A clause affected in 2002 meant that Hals Metal could no longer burn cables containing lead. The processing of cables was therefore ceased and the company's activity changed to smelting. This transition resulted in a low activity in 2003.

The activity of recasting lead tiles is not easily found because it is spread out on many artisans and poorly regulated. However, an estimate by Lassen et al.

(2004) states that 200-300 tonnes lead tiles were recast in 2000. Since the building stock worthy of preservation is constant, it is assumed that the activity of recasting of lead tiles is constant.

Activity data

Activity data for secondary lead production are shown in Table 5.6.1 and Annex C4-1.

Table 5.6.1 Activity data for secondary lead production, t.

	1990	1995	2000	2005	2010	2015	2018	2019	2020	2021
Hals Metal	540	750	540	691	635	745	348	322	194	97
Lead tiles	250	250	250	250	250	250	250	250	250	250
Total	790	1000	790	941	885	995	598	572	444	347

Emission factors

The applied emission factors are presented in Table 5.6.2.

Measurements of SO_2, Hg, PCDD/F and PCB are available for Hals Metal for 2008-2010. These measurements are used to calculate plant specific emission factors. For Hg, the calculated implied emission factor (IEF) is also applied to the unabated production as a country specific emission factor. Hals Metal is a modern secondary lead production facility, and emission factors for "current technology" are therefore chosen for emission factors found in literature.

Table 5.6.2 Emission factors for secondary lead production.

		Current technology		Unabated	
Pollutant	Unit	Value	Reference	Value	Reference
CO_2	t/t	0.2	IPCC (2006)[3]	0.2	IPCC (2006)[3]
SO_2	kg/t	6.4[4]	Average IEF (2008-2010)	NA	
TSP	kg/t	0.012	Cusano et al., 2017, Table 5.13	14.8	EMEP/EEA (2019)[1]
PM_{10}	kg/t	0.010	Visschedijk et al. (2004)	11.8	EMEP/EEA (2019)[1]
$PM_{2.5}$	kg/t	0.005	Visschedijk et al. (2004)	8.8	EMEP/EEA (2019)[1]
As	g/t	0.09	Cusano et al., 2017, Table 5.13	47	EMEP/EEA (2019)[1]
Cd	g/t	0.03	Cusano et al., 2017, Table 5.13	15	EMEP/EEA (2019)[1]
Hg	g/t	0.46[4]	Average IEF (2008-2010)	0.46	Average IEF (2008-2010)
Pb	g/t	2.3	Cusano et al., 2017, Table 5.13	5800	EMEP/EEA (2019)[1]
Zn	g/t	0.04	Cusano et al., 2017, Table 5.13[2]	35	EMEP/EEA (2019)[1]
HCB	µg/t	300	Bipro, 2006	300	Bipro, 2006
PCDD/F	µg/t	2.0[4]	Average IEF (2008-2010)	8.0	EMEP/EEA (2019)[1]
PCB	µg/t	981[4]	Average IEF (2008-2010)	3.2	EMEP/EEA (2019)[1]

[1] Chapter 2.C.5, Table 3.4, [2] Value for Ausmelt/ISASMELT, [3] Volume 3: Industrial Processes and Product Use, Chapter 4.6.2.2: Choice of emission factors, Table 4.21, page 4.73. Default Tier 1, [4] Value applied for all years in the time series.

5.6.3 Emission trend

Emissions from secondary lead production are presented in Table 5.6.3 for air pollutants, Figure 5.6.1 for greenhouse gasses (i.e. CO_2) and in Annex C4-2 for all emissions.

Table 5.6.3 Emissions from secondary lead production.

	Unit	1990	1995	2000	2005	2010	2015	2018	2019	2020	2021
SO_2	t	3.5	4.8	3.5	4.4	4.1	4.8	2.2	2.1	1.2	0.6
TSP	t	3.7	3.7	3.7	3.7	3.7	3.7	3.7	3.7	3.7	3.7
PM_{10}	t	3.0	3.0	3.0	3.0	3.0	3.0	3.0	3.0	3.0	3.0
$PM_{2.5}$	t	2.2	2.2	2.2	2.2	2.2	2.2	2.2	2.2	2.2	2.2
As	kg	11.8	11.8	11.8	11.8	11.8	11.8	11.8	11.8	11.8	11.8
Cd	kg	3.8	3.8	3.8	3.8	3.8	3.8	3.8	3.8	3.8	3.8
Hg	kg	0.4	0.5	0.4	0.4	0.4	0.5	0.3	0.3	0.2	0.2
Pb	kg	1451	1452	1451	1452	1451	1452	1451	1451	1450	1450
Zn	kg	8.8	8.8	8.8	8.8	8.8	8.8	8.8	8.8	8.8	8.8
HCB	g	0.2	0.3	0.2	0.3	0.3	0.3	0.2	0.2	0.1	0.1
PCDD/F	mg	3.1	3.5	3.1	3.4	3.3	3.5	2.7	2.6	2.4	2.2
PCB	g	0.5	0.7	0.5	0.7	0.6	0.7	0.3	0.3	0.2	0.1

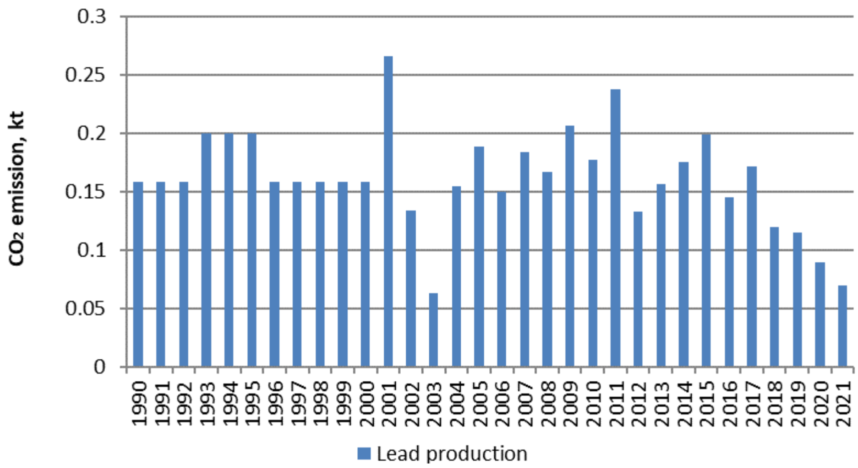


Figure 5.6.1 Emission of greenhouse gases from secondary lead production.

5.6.4 Time series consistency and completeness

The time series for *Secondary lead production* is both consistent and complete.

5.6.5 Input to CollectER

The input data/data sources for calculating emissions are presented in Table 5.6.4.

Table 5.6.4 Input data for calculation of emissions from lead production.

	Year	Parameter	Comment/Source
Activity	All	Production data	Hals Metal (2021), estimated from Lassen et al. (2004)
Emission	All	Emission factor	IPCC (2006), Hals Metal (2021), EMEP/EEA (2019) Bipro, 2006, Visschedijk et al. (2004), Cusano et al., 2017

6 Non-energy products from fuels and solvent use

The sector *Non-energy products from fuels and solvent use* (CRF/NRF 2D) covers the following product uses relevant for the Danish air emission inventory:

- Lubricant use (SNAP 060604); see section 6.2
- Paraffin wax use (SNAP 060606); see section 6.3
- Solvent use (SNAP 0601, 0602, 0603, 0604); see section 6.4
- Road paving with asphalt (SNAP 040611); see section 6.5
- Asphalt roofing (SNAP 040610); see section 6.6
- Urea-based catalysts (SNAP 060607); see section 6.7

The creosote treatment of wood is not occurring in Denmark. It would require a special permission in order to use creosote for wood treatment in Denmark, no such permission has been granted.

Bitumen blowing is the process of polymerising and stabilising asphalt to improve its weathering characteristics, and it may take place in a bitumen processing or roofing plant, or in a refinery. It is unknown to what extent bitumen blowing is occurring in Denmark. There is no Tier 1 methodology available in the EMEP/EEA Guidebook to estimate the occurrence.

6.1 Emissions

6.1.1 Greenhouse gas emissions

The time series for emission of greenhouse gases from *Non-Energy Products from Fuels and Solvent Use* (2D) is presented in Annex D0-1 and in Figure 6.1.1 below.

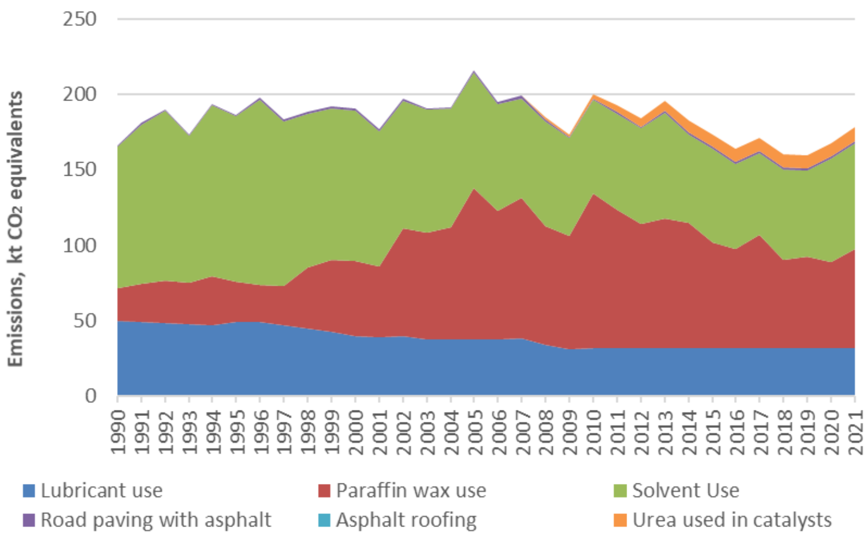


Figure 6.1.1 Emission of greenhouse gases from the individual source categories compiling Non-Energy Products from Fuels and Solvent Use, kt CO_2 equivalents.

The largest source of greenhouse gas emissions from *Non-Energy Products from Fuels and Solvent Use* is for 1990-2004 the use of solvents. As the use of solvents decrease (35 % decrease from 2000-2007) and the use of candles (i.e. paraffin wax use) increases (111 % increase from 2001-2005), the use of candles becomes the largest source of greenhouse gas emissions for 2005-2017. Since the peak in emissions from the use of candles in 2010, emissions have decreased with 36 % (2010-2021). Emissions from solvent use have found a more stable level since 2006 (of 55-70 kt CO_2). Solvent use and paraffin wax use contribute about equally to greenhouse gas emissions from *Non-Energy Products from Fuels and Solvent Use* in 2018-2019. With the occurrence of Covid-19, the use of solvents (disinfectants) increased, making solvent use the dominant source in 2020-2021.

6.1.2 Air pollution emissions

An overview of the 2021 emission of NMVOC, CO, particulate matter and POPs from *Non-energy products from fuels and solvent use* is available in Table 6.1.1. The time series are presented in Annex D0-2.

Table 6.1.1 Overview of 2021 emissions from Non-energy products from fuels and solvent use (2D).

	Total emission from 2D	Fraction of IPPU	Largest contributor in 2D	Emission from largest contributor	Fraction of 2D
NMVOC	30.70kt	92.8 %	Other solvent use	17.76kt	57.9 %
CO	0.66kt	18.0 %	Road paving with asphalt	0.43kt	65.8 %
TSP	0.22kt	3.1 %	Road paving with asphalt	0.18kt	83.4 %
$PM_{2.5}$	0.05kt	7.2 %	Paraffin wax use	0.03kt	55.7 %
POPs	0.21kg	0.2 %	Paraffin wax use (PAH)	0.21kg	100.0 %

6.2 Lubricant use

The category Lubricant use (CRF 2D1) covers the following SNAP category:

- 06 06 04 Oxidation of lubricants during use

Only emission of CO_2 is relevant for *Lubricant use*.

Lubricants consumed in machinery i.e. that is combusted during use, and collection of waste lubricants with subsequent combustion, are reported as part of the *Energy* sector. These emissions are not included in this report.

6.2.1 Process description

Lubricants can be motor oils, industrial oils or greases. Lubricants vary in both physical characteristics (e.g. viscosity), commercial application and environmental fate.

The use of lubricants in engines is primarily for their lubricating properties and associated emissions are therefore considered as non-combustion.

6.2.2 Methodology

The emission of CO_2 from oxidation of lubricants during use is calculated according to the following equation (IPCC, 2006):

$$E_{CO2} = LC \bullet CC_{\mathrm{lub}ricant} \bullet ODU_{\mathrm{lub}ricant} \bullet 44/12 \qquad \text{(Eq. 6.2.1)}$$

Where E_{CO2} is the CO_2 emission, LC is the consumption of lubricants, $CC_{lubricant}$ is the carbon content factor, $ODU_{lubricant}$ is the Oxidised During Use factor and 44/12 is the mass ratio of CO_2/C.

This method represents a Tier 1 approach where LC is the total amount of lubricant consumed in Denmark with no differentiation between greases and oils.

Activity data

The time series for consumption of lubricant oil in TJ is obtained from the Danish Energy Agency (DEA, 2022) along with the calorific value of 41.9 GJ per tonne. The consumption of lubricant oil has been kept constant by DEA since 2010. The consumption is presented in Table 6.2.1 and the complete time series in Annex D1-1.

Table 6.2.1 Consumption of lubricants, kt.

	1990	1995	2000	2005	2010	2015	2018	2019	2020	2021
Lubricants	80.5	79.1	64.3	60.9	51.3	51.3	51.3	51.3	51.3	51.3

Emission factors

The emission factor is calculated as the product: $CC_{lubricant} \cdot ODU_{lubricant} \cdot 44/12$ in equation 6.2.1 above, and yields an emission factor of 14.7 kg CO_2 per TJ or 0.617 tonnes CO_2 per tonne lubricant used. This is constant for the entire time series.

Table 6.2.2 Factors for calculation of the lubricant use emission factor.

Factor	Description	Source	Value	Unit
$CC_{lubricant}$	The default carbon content factor	IPCC (2006), page 5.9	20.1	kg C/GJ
$ODU_{lubricant}$	The oxidised during use factor for grease	IPCC (2006), Table 5.2 page 5.9	0.2	-
CO_2/C	Mass ratio, 44/12	IPCC (2006), page 5.5	3.7	kg CO_2/kg C

6.2.3 Emission trend

The time series for CO_2 emission from oxidation of lubricants during use is presented in Table 6.2.3 and Annex D0-1.

Table 6.2.3 Emissions from oxidation of lubricants during use, kt.

	1990	1995	2000	2005	2010	2015	2018	2019	2020	2021
Lubricants	49.7	48.8	39.7	37.6	31.7	31.7	31.7	31.7	31.7	31.7

6.2.4 Time series consistency and completeness

The applied methodology has been the same for all years in the time series, with activity data based on information from the Danish Energy Agency and using the same emission factor. The emission time series is therefore consistent. Since activity data are available from the energy statistics (DEA, 2022) the time series is also considered complete.

6.2.5 Input to CollectER

The input data/data sources for calculating emissions are presented in Table 6.2.4.

Table 6.2.4 Input data for calculating emissions from *Lubricant use*.

	Year	Parameter	Comment/Source
Activity data	All	Consumption	DEA (2022)
Emission factor	All	Emission factor based on default factors	IPCC (2006)

6.3 Paraffin wax use

The category *Paraffin wax use* (CRF 2D2/NFR 2G4[14]) covers the following activity:

- 06 06 06 Use of paraffin wax candles

Emissions of the following pollutants are relevant for *Paraffin wax use*:

- Greenhouse gases: CO_2, CH_4, N_2O
- CO
- Particulate matter: TSP, PM_{10}, $PM_{2.5}$
- Persistent Organic Pollutants: PCDD/F, benzo(k)fluoranthene, benzo(a)pyrene, indeno(1,2,3-cd)pyrene

6.3.1 Process description

Paraffin waxes are used in applications such as candles, corrugated boxes, paper coating, board sizing, adhesives, food production, packaging, wax polishes, surfactants (used in detergents or in wastewater treatment), and many others. Emissions from the use of paraffin waxes occur primarily when they are combusted during use, e.g. candles, or when otherwise incinerated. The latter case should be reported in the *Energy* sector (IPCC, 2006) and is therefore not included in this report.

6.3.2 Methodology

In the Danish inventory, emissions are only included from the main emission source; i.e. use of candles. The methodology corresponds to a Tier 2 (IPCC, 2006), and assumes an oxidation factor of 100 %.

Activity data

The activity data are derived from import, export and production data for candles from Statistics Denmark (VARER1/KN8Y, 05/09-2022) and are expressed in kt used candles. The activity data are presented in Table 6.3.1 and Annex D2-1.

Table 6.3.1 Activity data for paraffin wax use, kt.

	1985	1990	1995	2000	2005	2010	2015	2019	2020	2021
Paraffin wax	10.9	7.4	9.1	16.9	34.4	35.2	24.0	20.7	19.4	22.5

Emission factors

The emission factors presented in Table 6.3.2 are constant for the entire time series and are compiled from the scientific literature. The IPCC (2006) CO_2 emission factor is valid for shale oil and is therefore not used[15].

[14] The NFR system places paraffin wax use in category 2G4. However, in this report, air emission pollutants and greenhouse gasses from paraffin wax use are reported together, i.e. under 2D2 according to the CRF system.

[15] In IPCC (2006) V3 Ch5 page 5.12 states a combustion emission factor of 73.3 kg CO_2 per GJ. However, the referenced source of this value clearly states that the emission factor is valid for shale oil and not for paraffin wax. Another source was therefore used for the CO_2 emission factor for paraffin wax use in the present report.

Table 6.3.2 Emission factors for *Paraffin wax use*.

	Unit	Paraffin wax use	Source
CO_2	kt/kt	2.91	Shires et al. (2004)
CH_4	t/kt	0.121	Campbell et al. (2021)
N_2O	t/kt	0.024	Campbell et al. (2021)
CO	t/kt	10	Hamins et al. (2005)
TSP	t/kt	1.34	Fine et al. (1999)
PM_{10}	t/kt	1.34	DCE judgement
$PM_{2.5}$	t/kt	1.34	DCE judgement
PCDD/F	mg/kt	0.027	Lau et al. (1997)
Benzo(k)fluoranthene	g/kt	4.64	Fine et al. (1999)
Benzo(a)pyrene	g/kt	3.71	Fine et al. (1999)
Indeno(1,2,3-cd)pyrene	g/kt	0.93	Fine et al. (1999)

6.3.3 Emission trend

Emissions from *Paraffin wax use* are presented in Table 6.3.3 and Annex D2-2.

Table 6.3.3 Emissions from the use of paraffin wax candles.

	Unit	1985	1990	1995	2000	2005	2010	2015	2019	2020	2021
CO_2	kt	-	21.7	26.5	49.3	100.2	102.3	70.0	60.3	56.5	65.5
CH_4	t	-	0.9	1.1	2.0	4.2	4.3	2.9	2.5	2.3	2.7
N_2O	t	-	0.2	0.2	0.4	0.8	0.8	0.6	0.5	0.5	0.5
CO_2 eqv	kt	-	21.7	26.6	49.4	100.5	102.7	70.2	60.5	56.7	65.7
CO	t	108.8	74.4	91.0	169.3	344.3	351.6	240.4	207.1	194.2	225.2
TSP	t	-	10.0	12.2	22.7	46.1	47.1	32.2	27.7	26.0	30.2
PM_{10}	t	-	10.0	12.2	22.7	46.1	47.1	32.2	27.7	26.0	30.2
$PM_{2.5}$	t	-	10.0	12.2	22.7	46.1	47.1	32.2	27.7	26.0	30.2
PCDD/F	mg	-	0.2	0.2	0.5	0.9	0.9	0.6	0.6	0.5	0.5
Benzo(k)fluoranthene	g	-	34.5	42.2	78.5	159.8	163.2	111.5	96.1	90.1	90.1
Benzo(a)pyrene	g	-	27.6	33.7	62.8	127.7	130.5	89.2	76.8	72.0	72.0
Indeno(1,2,3-cd)pyrene	g	-	6.9	8.5	15.7	32.0	32.7	22.4	19.3	18.1	18.1

Since the emission factors are constant throughout the time series, any increase or decrease in emissions are caused by an equal development in activity. Emissions increased with 363 % from 1990 to 2005. After 2010, emissions started decreasing (-43 % from 2010-2018). Since 2018, emissions from paraffin wax use has been somewhat steady at 57-66 kt CO_2 eq. The overall development from 1990 to 2021 in an increase of 202 %.

The decrease in the years after 2010 could be attributed to an increased awareness on indoor climate/pollution and an increased sale of LED candles. However, the full effect of this seems to already be implemented.

6.3.4 Time series consistency and completeness

The time series is both consistent and complete.

6.3.5 Input to CollectER

The input data/data sources for calculating emissions are presented in Table 6.3.4.

Table 6.3.4 Input data for calculating emissions from the burning of paraffin wax.

	Year	Parameter	Comment/Source
Activity data	All	Used amount (Import + Production – Export)	Statistics Denmark (2022)
Emission factors	All	Emission factors	Literature study

6.4 Solvent use

The category *Solvent use* (CRF/NFR 2D3 Other) is aggregated according to four main categories (06 01-06 04), which correspond to the grouping in IPCC (2006). Additionally, Printing industry and Domestic solvent use are reported separately from the remaining category of 06 04 Other use of solvents and related activities. Solvent use is allocated to the following six categories in the Danish inventories:

- 06 01 00 Paint application/Coating applications
- 06 02 00 Degreasing, dry cleaning and electronics
- 06 03 00 Chemical products manufacturing or processing
- 06 04 00 Other use of solvents and related activities
- 06 04 03 Printing industry
- 06 04 08 Domestic solvent use (other than paint application)

Only NMVOC, which is subsequently oxidised to CO_2 in the atmosphere, is relevant for these categories. To be consistent with the reporting during the first commitment period of the Kyoto Protocol, Denmark has continued to report these indirect CO_2 emissions under sector 2D rather than reporting them separately under indirect CO_2.

6.4.1 Process description

Only NMVOCs used as solvents are relevant for these categories. Solvents are chemical compounds that are used on a global scale in industrial processes and as constituents in final products to dissolve e.g. paint, cosmetics, adhesives, ink, rubber, plastic, pesticides, aerosols or are used for cleaning purposes, i.e. degreasing. NMVOCs are main components in solvents - and solvent use in industries and households is a significant source of anthropogenic NMVOC emissions (EEA, 2022). In industrial processes, where solvents are produced or used, NMVOC emissions to air and as liquid can be recaptured and either used or destroyed. Solvent containing products are used indoors and outdoors and the majority of solvent sooner or later evaporate. A small fraction of the solvent ends up in waste or as emissions to water and may finally also contribute to air pollution by evaporation from these compartments. Emission inventories for solvents are based on model estimates, as direct and continuous emissions are only measured from a limited number of sources.

6.4.2 Methodology

NMVOC emissions from solvent use are estimated using emission modelling of solvents by estimating the amount of (pure) solvents consumed, thus representing a "chemicals approach", where each pollutant is estimated separately. All relevant solvents must be estimated, or at least those together representing more than 90 % of the total pollutant emission. These emissions are summed up to the national total emissions from solvent use. The model is updated on a yearly basis.

The method is mainly based on the detailed approach and methodology described in EMEP/EEA (2019) and emissions are calculated for industrial sectors, households and for individual pollutants. The included sources are listed in Chapter 6.4 Solvent use above.

The detailed method used in the Danish emission inventory for solvent use, represents a chemical based approach, where the emission from each chemical is estimated separately. The sum of emissions of all estimated chemicals used as solvents equals the total emission from solvent use.

For each chemical or product, a mass balance is formulated:

Consumption = (production + import) – (export + destruction/disposal + hold-up)

Data on production, import and export amounts of solvents and solvent containing products are collected from Statistics Denmark (VARER1/KN8Y, 10/08-2022). Manufacturing and trading industries are required to report production and trade figures to the Danish Customs & Tax Authorities in accordance with the Combined Nomenclature. Import and export figures are available on a monthly basis from 1988 to present. Production figures are reported quarterly as "industrial commodity statistics by commodity group and unit" from 1990 to present.

Destruction and disposal of solvents lower the pollutant emissions. In principle, this amount must be estimated for each solvent in all industrial activities and for all uses of pollutant containing products. At present, the solvent inventory only considers destruction and disposal for a limited number of pollutants. For some chemicals, it is inherent in the emission factor, and for others the reduction is specifically calculated from information obtained from the industry or literature.

Hold-up is the difference in the amount in stock in the beginning and at the end of the year of the inventory also sometimes referred to as stock change. No information on solvents in stock has been obtained from industries. Furthermore, the inventory spans over several years so there will be an offset in the use and production, import and export balance over time.

In some industries, the solvents are consumed in the process, e.g. in the graphics and plastic industry, whereas in the production of paints and lacquers the solvents are still present in the final product. These products can either be exported or used in the country. In order not to double count consumption amounts of pollutants it is important to keep track of total solvent use, solvents not used in products and use of solvent containing products. Furthermore, some chemicals may be represented as individual chemicals and also in chemical groups, e.g. "o-xylene", "mixture of xylenes" and "xylene". Some pollutants are better inventoried as a group rather than individual chemicals, due to missing information on use or emission for the individual chemicals. The Danish inventory considers single chemicals, with a few exceptions.

Solvent list

The definitions of solvents and (NM)VOC that are used in the Danish emission inventory, are as defined in the solvent directive (Directive, 2010) of the EU legislation. This states that: "Organic solvent means any volatile organic compound which is used for any of the following: (a) alone or in combination with other agents, and without undergoing a chemical change, to dissolve raw materials, products or waste materials; (b) as a cleaning agent to dissolve contaminants; (c) as a dissolver; (d) as a dispersion medium; (e) as a viscosity adjuster; (f) as a surface tension adjuster; (g) as a plasticiser; (h) as a preservative". Furthermore, the directive defines VOCs as follows: "Volatile organic compound means any organic compound as well as the fraction of creosote, having at 293.15 K a vapour pressure of 0.01 kPa or more, or having a corresponding volatility under the conditions of use".

This implies that some NMVOCs, e.g. ethylene glycol, that have vapour pressures just around 0.01 kPa at 20 °C, may only be defined as VOCs at use conditions at higher temperature. However, use conditions at elevated temperatures are typically found in industrial processes. Here the capture of solvent fumes is often efficient, thus resulting in small emissions (communication with industries).

In Table 6.4.1, the Danish list of NMVOCs comprises 26 pollutants or pollutant groups representing more than 95 % of the total solvent use.

Table 6.4.1 2021 NMVOC emissions of single pollutants or pollutant groups.

Pollutant	CAS no	Emissions, t
ethanol	64-17-5	10258
turpentine (white spirit: stoddard solvent and solvent naphtha)	64742-88-7 8052-41-3	7375
propyl alcohol	67-63-0	3992
pentane	109-66-0	2362
propylene glycol	57-55-6	1821
methanol	67-56-1	1157
cyanates	79-10-7	1003
acetone	67-64-1	664
1-butanol	71-36-3	292
propane	74-98-6	282
butane	106-97-8	282
phenol	108-95-2	229
xylenes	1330-20-7 95-47-6 108-38-3 106-42-3	174
glycol ethers	110-80-5 107-98-2 108-65-6 34590-94-8 112-34-5 and others	150
butanoles	78-92-2 2517-43-3 and others	146
toluene	108-88-3	124
cyclohexanones	108-94-1	63.4
ethylene glycol	107-21-1	61.4
styrene	100-42-5	52.2
ethyl acetate	141-78-6	50.2
butanone	78-93-3	45.7
formaldehyde	50-00-0	36.9
butyl acetate	123-86-4	20.3
acyclic aldehydes	78-84-2	5.1
tetrachloroethylene	127-18-4	2.3
acrylic acid	79-10-7	0.05
Total		30,650

In Table 6.4.1, the emission for 2021 is split into individual solvents. The most abundantly used solvents are ethanol and turpentine, or white spirit defined as a mixture of stoddard solvent and solvent naphtha and propylalcohol. Ethanol is used as solvent in the chemical industry and as windscreen washing agent. Turpentine is used as thinner for paints, lacquers and adhesives. Propylalcohol is used in cleaning agents in the manufacture of electrical equipment, flux agents for soldering, as solvent and thinner and as windscreen washing agent. Household emissions are dominated by propane and butane, which are used as aerosols in spray cans, primarily in cosmetics. For some solvents the emission factors are precise but for others they are rough estimates. The division of emission factors into four categories implies that high emission factors are applicable for use of solvent containing products and lower emission factors are applicable for use in industrial processes.

Activity data

Activity data for solvents are primarily calculated from the mass balance equation presented in Chapter 6.4.2 Methodology with input from Statistics Denmark. When Statistics Denmark holds no information on production, import and export or when information that is more reliable is available from industries, scientific reports or expert judgements the data can be adjusted or even replaced. The used amounts of products (activity data) in Table 6.4.2 are derived from used amounts of solvents by assessing the amount of solvents that is comprised within products belonging to each of the categories. The complete time series is presented in Annex D3-1.

Table 6.4.2 Activity data for NMVOCs used as solvents, kt.

	1985	1990	1995	2000	2005	2010	2015	2019	2020	2021
Paint applications	94.1	83.5	91.0	104.2	74.6	45.1	43.1	43.6	48.6	50.4
Degreasing, dry cleaning and electronics	1.7	1.4	1.5	0.6	0.4	0.2	0.2	0.2	0.2	0.3
Chemical products manufacturing or processing	415	407	575	585	751	629	513	523	630	596
Other use of solvents and related activities	198	176	212	197	182	143	146	138.6	175.5	161.5
Printing industry	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.4	0.3
Domestic solvent use (other than paint application)	35.2	29.1	43.9	41.0	35.5	25.6	38.8	21.3	24.1	27.9

Emission factors

For each pollutant, the emission is calculated by multiplying the consumption with the fraction emitted (emission factor), according to:

*Emission = consumption * emission factor*

The present Danish method uses emission factors that represent specific industrial activities such as processing of polystyrene, dry cleaning etc. or that represent use categories, such as paints and detergents. Some pollutants have been assigned emission factors according to their water solubility. Higher hydrophobicity yields higher emission factors, since a lower amount ends in wastewater, e.g. ethanol (hydrophilic) and turpentine (hydrophobic).

Emission factors for solvents are categorised in four groups in ascending order:

1. Lowest emission factors in the chemical industry, e.g. lacquer and paint manufacturing, due to emission reducing abatement techniques and destruction of solvent containing waste.
2. Other processes in industry, e.g. graphic industry, have higher emission factors.

3. Non-industrial use, e.g. auto repair and construction, have even higher emission factors.
4. Diffuse use of solvent containing products, e.g. painting, where practically all the pollutant present in the products will be released during or after use.

For a given solvent, the consumed amount can thus be attributed with two or more emission factors; one emission factor representing the emissions occurring at a production or processing plant and one emission factor representing the emissions during use of a solvent containing product. If the chemical is used in more processes and/or is present in several products more emission factors are assigned to the respective chemical amounts.

Emission factors can be defined from surveys of specific industrial activities or as aggregated factors from industrial branches or sectors. Furthermore, emission factors may be characteristic for the use pattern of certain products. The emission factors used in the Danish inventory also rely on the work done in a joint Nordic project (Fauser et al., 2009).

The emission factors are listed in Table 6.4.3 and Annex D3-2. Emission factors are based on values from EMEP/EEA (2019) and adjusted on a country specific basis according to the assessment described above. See more details in Chapter 6.4.4 Verification.

Table 6.4.3 Emission factors for solvent use.

	Pollutant	Unit	1985	1990	1995	2000	2005	2010	2015	2019	2020	2021
Coating applications	NMVOC	t/kt	59	60	63	60	56	59	60	60	60	62
	CO_2	t/kt	-	154	160	152	139	149	145	143	140	151
Degreasing, dry cleaning and electronics	NMVOC	t/kt	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05
	CO_2	t/kt	-	0.03	0.03	0.03	0.03	0.03	0.03	0.03	0.03	0.03
Chemical products manufacturing/processing	NMVOC	t/kt	21	20	17	12	8	8	10	10	10	10
	CO_2	t/kt	-	48	41	30	21	19	24	25	25	24
Other use of solvents and related activities	NMVOC	t/kt	117	120	112	111	90	109	99	103	103	110
	CO_2	t/kt	-	295	271	274	216	253	220	231	224	247
Printing industry	NMVOC	t/kt	40	40	42	40	34	39	39	39	40	39
	CO_2	t/kt	-	81	86	80	70	78	76	77	78	77
Domestic solvent use	NMVOC	t/kt	151	145	157	155	145	137	149	121	125	143
	CO_2	t/kt	-	321	331	328	316	268	308	272	279	307

CO_2 emission factors are calculated for a complete conversion to CO_2 of each NMVOC molecule in units g CO_2 per g NMVOC from:

$$n \cdot 12 \frac{g}{mol} \Big/ (molecular\ weight\ NMVOC) \cdot 3.667 \frac{g\ CO_2}{g\ C}$$

where n is the number of carbon atoms in the NMVOC molecule.

Source allocation

The Danish Working Environment Authority (WEA) is administrating the registrations of chemicals and products to the Danish product register. All manufacturers and importers of products for occupational and commercial use are obliged to register. The following products are comprised in the registration agreement:

- Chemicals and materials that are classified as dangerous according to the regulations set up by the Danish Environmental Protection Agency (EPA).

- Chemicals and materials that are listed with a limit value on the WEA "limit value list".
- Materials, containing 1 % or more of a chemical, which is listed on the WEA "limit value list".
- Materials, containing 1 % or more of a chemical, which is classified as hazardous to humans or the environment according to the EPA rules on classification.

There are the following important exceptions for products, which do not need to be registered:

- Products exclusively for private use
- Pharmaceuticals ready for use
- Cosmetic products

The Danish product register does therefore not comprise a complete account of used solvents. Source allocations of exceptions from the duty of declaration are done based on information from trade organisations, industries and scientific reports.

The database Substances in Preparations in the Nordic Countries (SPIN) holds information on use of various pollutants in product and activities, i.e. Use Categories Nordic (UCN), and on use in industrial categories, i.e. according to the standard nomenclature for economic activities (NACE) system. The use amount from Statistics Denmark is first distributed in SNAP categories according to UCN data, and second according to NACE industrial use in NFR categories.

Use of spray cans

Emissions from use of spray cans (NFR 2D3i Other solvent use) include the propellant (propane and butane) and solvents. Propellants comprise, according to communication with the Association of Danish Aerosol Industries (i.e. "Aerosol Industriens Brancheforening") and Schleicher et al. (2009), approx. 33 vol-% (24 weight-%) of a can. According to Rambøll (2004) the remaining amount is solvents (VOCs), 71 weight-% for spray paint and 51 weight-% for cosmetics, and non-VOCs, 5 weight-% for spray paints and 25 weight-% for cosmetics. 3 % of the Danish marked is spray paints. The rest is cosmetics, which comprises deodorants, hairspray and foam products. 90 % of the use in Denmark is imported. It is assumed that approximately 5 % remains in the can and is destroyed in waste handling. Based on these assumptions the total VOC emissions from use of spray cans in Denmark is 1.79 kt per year. This amount is assigned to all years, as no detailed consumption trend is available. The specific compounds are propane and butane as propellants and ethanol, tert-butanol, acetone, butanone, butylacetate, ethylacetate, propanol, toluene and xylene as solvents.

6.4.3 Emission trend

Table 6.4.4, Figure 6.4.1, Figure 6.4.2 and Annex D3-3 show the emissions of CO_2 and NMVOC, where the used amounts of single pollutants have been assigned to specific products and NFR sectors. The general decrease from 1996 to present is an indication of increased implementation of NMVOC emission reducing measures in production facilities, and a general shift to water soluble and high solid products, in e.g. the graphics-, paint-, plastic- and auto paint and repair industries.

Table 6.4.4 Emissions from solvent use.

	Unit	1985	1990	1995	2000	2005	2010	2015	2019	2020	2021
CO_2 emissions											
Paint application	kt	-	12.9	14.6	15.8	10.3	6.7	6.3	6.2	6.8	7.6
Degreasing, dry cleaning, electronics	kg	-	37.4	40.6	15.8	9.7	5.5	4.1	6.1	5.1	7.3
Chemical products manufacturing/processing	kt	-	19.4	23.3	17.4	15.6	12.1	12.2	13.1	16.0	14.4
Other use of solvents and related activities	kt	-	52.0	57.5	53.9	39.2	36.2	32.0	32.1	39.4	39.8
Printing industry	t	-	16.2	19.8	14.4	13.3	18.0	18.6	18.5	27.8	25.1
Domestic solvent use (not paint application)	kt	-	9.4	14.6	13.5	11.2	6.9	12.0	5.8	6.7	8.6
Total CO_2	kt	-	93.7	110.0	100.5	76.4	61.9	62.4	57.3	68.9	70.4
NMVOC emissions											
Paint application	kt	5.5	5.0	5.8	6.2	4.2	2.7	2.6	2.6	2.9	3.1
Degreasing, dry cleaning, electronics	t	0.09	0.07	0.08	0.03	0.02	0.01	0.01	0.01	0.01	0.01
Chemical products manufacturing/processing	kt	8.6	8.1	9.7	7.1	6.3	4.9	4.9	5.2	6.6	5.8
Other use of solvents and related activities	kt	23.2	21.1	23.7	21.9	16.4	15.5	14.4	14.3	18.1	17.8
Printing industry	t	9.1	8.0	9.7	7.1	6.3	9.1	9.5	9.5	14.2	12.9
Domestic solvent use (not paint application)	kt	5.3	4.2	6.9	6.3	5.1	3.5	5.8	2.6	3.0	4.0
Total NMVOC	kt	42.6	38.4	46.1	41.6	32.1	26.7	27.7	24.7	30.6	30.6

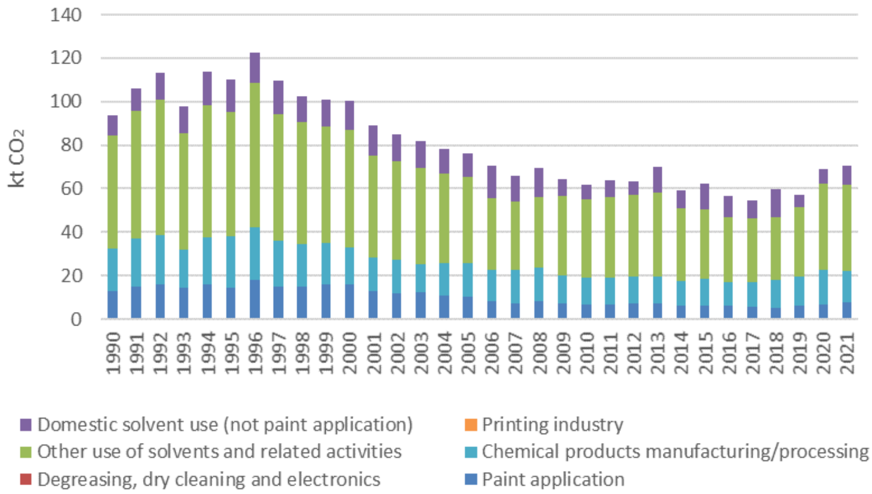


Figure 6.4.1 CO_2 emissions from solvent use, kt.

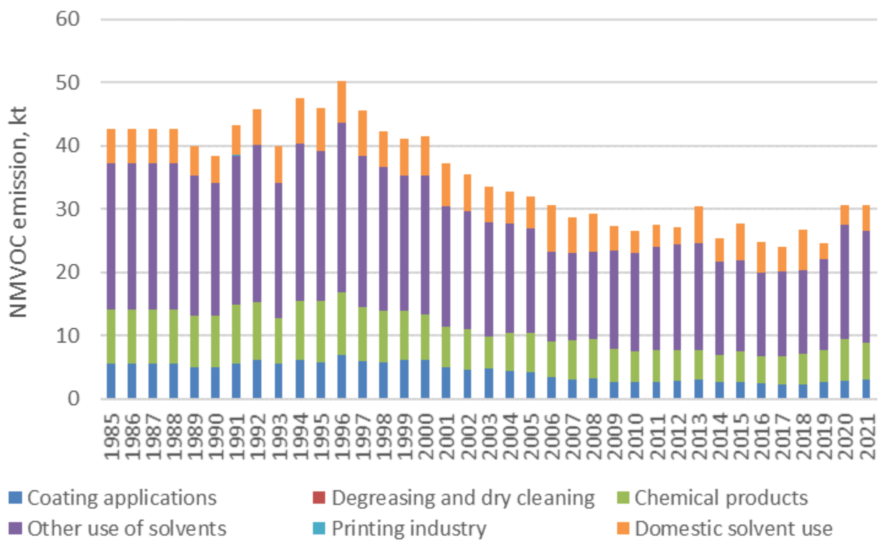


Figure 6.4.2 NMVOC emissions from solvent use, kt.

6.4.4 Verification

Emission calculations performed by IIASA using RAINS codes, are based on a different methodological approach than that used in this report. However, using data for 2000, the total emission values by IIASA using RAINS codes that correspond to the NFR codes used here, are 2.7 % lower than the emissions found in the present approach. This is seen as an indication of good conformity.

Use categories for chemicals in products are found from the Nordic SPIN database. Data for all Nordic countries (Norway, Sweden, Denmark and Finland) are available. For chosen chemicals, a comparison of chemical amounts and use has been made between countries.

The Danish product register (PROBAS) is a joint register for the Danish Working Environment Authority (WEA) and the EPA and comprises a large number of chemicals and products. The information is obtained from registration according to the EPA rules and from scientific studies and surveys and other relevant sources. The product register is the most comprehensive collection of chemical data in products for Denmark and with the availability of data from the other Nordic countries, it enables an inter-country comparison. For each chemical, the data is reported in a uniform way, which enhances comparability, transparency and consistency.

6.4.5 Time series consistency and completeness

The time series is considered to be both consistent and complete.

6.4.6 Input to CollectER

The input data/data sources for calculating emissions are presented in Table 6.4.5.

Table 6.4.5 Input data for calculating emissions from *Solvent use*.

	Year	Parameter	Comment/Source
Activity data	All	Import, Export, Production	Statistics Denmark (2022), DCE judgement
Emission factors	All	Emission factors	EMEP/EEA (2019), DCE judgement

6.5 Road paving with asphalt

The category Road paving with asphalt (CFR/NFR 2D3b) covers the following SNAP category:

- 04 06 11 Road paving with asphalt

Emissions of the following pollutants are relevant for Road paving with asphalt:

- CO_2
- CH_4
- NMVOC
- CO
- Particulate matter: TSP, PM_{10}, $PM_{2.5}$, BC

6.5.1 Process description

Road paving with asphalt is an activity that can be found all over the country and especially in relation to establishing new roads. The raw materials for construction of roads are prepared on one of the plants located near the locality of application to limit the transport distance. The asphalt concrete is mixed and brought to the locality of application on a truck.

Roads are constructed by a number of different layers:

- a load bearing layer (e.g. course gravel)
- an adhesive layer (liquefied asphalt e.g. "cutback" asphalt or asphalt emulsion)
- a wearing coarse (e.g. hot mix asphalt concrete)

6.5.2 Methodology

Different qualities of "cutback" asphalt (e.g. asphalt dissolved in organic solvents/petroleum distillates) and asphalt emulsion contains different kinds and amounts of solvent. Cutback asphalt contains 25-45 %v/v solvent e.g. heavy residual oil, kerosene-type solvent, naphtha or gasoline solvent. Approximately 500.~~000~~ litres solvent evaporates annually from the use of "cutback" asphalt (Asfaltindustrien, 2003). This amount of solvent, which is added to the asphalt, is comprised in the category 2D3 Other: Solvent use, described above with an emission factor of approximately unity. This means that NMVOC emissions from "cutback" asphalt in Road paving with asphalt only include emissions from the asphalt fraction, which is included in Table 6.5.1.

Emissions are calculated as activity data multiplied with emission factors for all pollutants.

Indirect CO_2 emissions are calculated from NMVOC, CH_4 and CO emissions. To be consistent with the reporting during the first commitment period of the Kyoto Protocol, Denmark has continued to report indirect CO_2 emissions from road paving with asphalt under category 2D rather than separately under indirect CO_2.

Activity data

The used amount of asphalt for road paving has been compiled from production, import and export statistics of asphalt products in Statistics Denmark (VARER1/KN8Y, 05/09-2022) and are presented in Table 6.5.1 and Annex D4-1.

Table 6.5.1 Activity data for asphalt in road paving, kt.

	1985	1990	1995	2000	2005	2010	2015	2019	2020	2021
Road paving with asphalt	2743	2535	3144	2933	3879	3005	3440	3508	3833	3606

Emission factors

Default emission and abatement factors are derived from EMEP/EEA (2019) and US EPA (2004).

For NMVOC and particles are used the Tier 1 emission factors from EMEP/EEA (2019). The technology is assumed to be 80 % batch mix hot mix and 20 % batch mix. The abatement applied to batch mix hot mix plants is venture/wet scrubber with an assumed efficiency of 99.6 % for TSP and 98 % for PM_{10} and $PM_{2.5}$. The abatement applied for drum mix hot mix plants could be either venture/wet scrubber (99.7 % efficiency) or fabric filter (99.9 % efficiency), these are assumed to be equally applied. The abatement efficiencies are calculated from these assumptions; i.e. 80 % batch mix with venture/wet scrubbers, 10 % drum mix with venture/wet scrubbers and 10 % drum mix with fabric filters.

Table 6.5.2 Emission factors for road paving with asphalt incl. cutback.

	Unit	Road paving with asphalt	Abatement factors[1], %	Source
CO_2	kg/t	0.23[2]	-	Calculated emission factor: Indirect CO_2 from NMVOC, CH_4 and CO
CH_4	g/t	4.4	-	US EPA (2004), hot mix
NMVOC	g/t	16.0	-	EMEP/EEA (2019)
CO	g/t	120.2	-	US EPA (2004), hot mix
TSP	g/t	50	99.6	EMEP/EEA (2019)
PM_{10}	g/t	49	98.4	EMEP/EEA (2019)
$PM_{2.5}$	g/t	6.6	98.4	EMEP/EEA (2019)
BC	g/t	0.37	98.4	EMEP/EEA (2019)

[1] The abatement factors have already been subtracted from the presented emission factors. [2] Indirect CO_2 emissions calculated from NMVOC, CH_4 and CO (IPCC, 2006)

6.5.3 Emission trend

Emissions from road paving with asphalt are presented in Table 6.5.3 and Annex D4-2.

Table 6.5.3 Emissions from road paving with asphalt, t.

	1985	1990	1995	2000	2005	2010	2015	2019	2020	2021
CO_2	-	583	723	675	892	691	791	807	882	829
CH_4	-	11	14	13	17	13	15	15	17	16
NMVOC	44	41	50	47	62	48	55	56	61	58
CO	330	305	378	353	466	361	414	422	461	433
TSP	-	128	158	148	195	151	173	177	193	182
PM_{10}	-	125	155	144	191	148	169	173	189	177
$PM_{2.5}$	-	16.6	20.6	19.2	25.4	19.7	22.6	23.0	25.1	23.7
BC	-	0.95	1.18	1.10	1.45	1.12	1.29	1.31	1.43	1.35

6.5.4 Time series consistency and completeness

The time series is considered both consistent and complete.

6.5.5 Input to CollectER

The input data/data sources for calculating emissions are presented in Table 6.5.4.

Table 6.5.4 Input data for calculating emissions from *Road paving with asphalt*.

	Year	Parameter	Comment/Source
Activity data	All	Use amounts	Statistics Denmark (2022)
Emission factors	All	Emission factors	EMEP/EEA (2019), US EPA (2004)

6.6 Asphalt roofing

The category Asphalt roofing (CRF/NFR 2D3) covers the following activity:

- 04 06 10 Asphalt roofing

Emissions of the following pollutants are relevant for asphalt roofing:

- CO_2
- NMVOC
- CO
- Particulate matter: TSP, PM_{10}, $PM_{2.5}$, BC

6.6.1 Process description

The asphalt industry produces a number of products, e.g. roofing and siding shingles for use in roofing. Key steps in the total production and roofing process include asphalt storage, asphalt blowing, felt saturation, coating and mineral surfacing. Asphalt blowing is categorised under NFR 2.D.3.g Chemical products which corresponds to Chapter 6.4 Solvent Use of the present report.

6.6.2 Methodology

Emissions are calculated by multiplying activity data and emission factors. Indirect CO_2 emissions from NMVOC and CO emissions from asphalt blowing in asphalt roofing are included. To be consistent with the reporting during the first commitment period of the Kyoto Protocol, Denmark has continued to report indirect CO_2 emissions from asphalt roofing under category 2D rather than separately under indirect CO_2.

Activity data

The used amount of asphalt for roofing has been compiled from production, import and export statistics of asphalt products in Statistics Denmark (VARER1/KN8Y, 05/09-2022). Activity data are presented in Table 6.6.1 and Annex D5-1.

Table 6.6.1 Activity data for asphalt roofing, kt.

	1985	1990	1995	2000	2005	2010	2015	2019	2020	2021
Asphalt roofing	55.7	56.1	57.0	88.5	69.6	43.9	47.0	59.1	60.0	63.9

Emission factors

Default emission and abatement factors are presented in Table 6.6.2. These assume an averaged technology and abatement implementation and integrate all sub-processes within the industry from inputting raw materials to the final shipment of the products off site (EMEP/EEA, 2019).

The TSP abatement efficiencies available from EMEP/EEA (2019) range from 94 % to 98 %. The efficiency chosen in this report is 94 %, chosen as the "worst case scenario".

Table 6.6.2 Emission factors for asphalt roofing (asphalt blowing).

	Unit	Asphalt roofing	Abatement factors[1], %	Source
CO_2	kg/t	0.40[2]	-	Calculated emission factor: Indirect CO_2 from NMVOC and CO
NMVOC	g/t	130	-	EMEP/EEA (2019)
CO	g/t	9.5	-	EMEP/EEA (2019)
TSP	g/t	96	94	EMEP/EEA (2019)
PM_{10}	g/t	24	94	EMEP/EEA (2019)
$PM_{2.5}$	g/t	4.8	94	EMEP/EEA (2019)
BC	mg/t	0.60	94	EMEP/EEA (2019)

[1] The abatement factors have already been subtracted from the presented emission factors. [2] Indirect CO_2 emissions calculated from NMVOC and CO (IPCC, 2006).

6.6.3 Emission trend

Emissions from asphalt roofing are presented in Table 6.6.3 and Annex D5-2.

Table 6.6.3 Emissions from asphalt roofing.

	Unit	1985	1990	1995	2000	2005	2010	2015	2019	2020	2021
CO_2	t	-	22.4	22.8	35.4	27.8	17.6	18.8	23.8	23.6	24.0
NMVOC	t	7.2	7.3	7.4	11.5	9.0	5.7	6.1	7.7	7.8	8.3
CO	t	0.53	0.53	0.54	0.84	0.66	0.42	0.45	0.56	0.57	0.61
TSP	t	-	5.4	5.5	8.5	6.7	4.2	4.5	5.7	5.8	6.1
PM_{10}	t	-	1.3	1.4	2.1	1.7	1.1	1.1	1.4	1.4	1.5
$PM_{2.5}$	t	-	0.27	0.27	0.42	0.33	0.21	0.23	0.28	0.29	0.31
BC	kg	-	0.034	0.034	0.053	0.042	0.026	0.028	0.035	0.036	0.038

6.6.4 Time series consistency and completeness

The time series is considered both consistent and complete.

6.6.5 Input to CollectER

The input data/data sources for calculating emissions are presented in Table 6.6.4.

Table 6.6.4 Input data for calculating emissions from *Asphalt roofing*.

	Year	Parameter	Comment/Source
Activity data	All	Use amounts	Statistics Denmark (2022)
Emission factors	All	Emission factors	EMEP/EEA (2019)

6.7 Urea-based catalysts

The category Urea-based catalysts (CRF 2D3 Other) covers CO_2 emissions from urea-based additives used in catalytic converters in heavy-duty vehicles to bring down NO_x emissions. The category covered is:

- 06 06 07 Use of urea in catalysts

6.7.1 Process description

SCR catalysts are used by Euro V and VI trucks and to a smaller extent by Euro IV trucks as an emission abatement technology in order to bring down NO_x emissions.

6.7.2 Methodology

The consumption of urea by SCR catalysts for heavy-duty vehicles is estimated with the DCE emission model for road transport by using fuel consumption totals and urea consumption rates for relevant engine technologies. The DCE model uses the COPERT 5 detailed methodology. For more details, please refer to Chapter 3.3 of Nielsen et al. (2023a).

Activity data

According to COPERT 5, the consumption of urea is 5-7 % by volume of fuel for Euro IV/V heavy-duty vehicles (6 % is used) and 3-4 % for Euro VI heavy-duty vehicles (3.5 % is used). Activity data for the use of urea is presented in Table 6.7.1 and Annex D6-1.

Table 6.7.1 Activity data for use of urea in catalysts, kt.

	2001	2005	2010	2015	2018	2019	2020	2021
Urea	0.002	0.040	10.6	34.0	38.1	38.4	38.1	40.0

Emission factors

The specifications of commercially available urea solution as an SCR agent for mobile use are regulated by DIN 70070, which specifies that urea should be in aqueous solution at a content of 32.5 % wt (±0.7 %) and a density of 1.09 g per cm^3. If total commercial urea solution sales are known (UC in litres), then total ultimate CO_2 emissions (in kg) by the use of the additive can be calculated by multiplying the urea consumption by 0.26. The coefficient 0.26 (kg CO_2 per l urea solution) takes into account the density of urea solution, the molecular masses of CO_2 and urea, and the content of urea in the solution. If total urea consumption is known in kg, then the coefficient needs to change to 0.238 (kg CO_2 per kg urea solution). In Denmark, the consumption is known in terms of volume and hence for each vehicle layer, the emissions of CO_2 are subsequently estimated as the product of urea consumption and a CO_2 emission factor of 0.26 kg CO_2 per l urea (EMEP/EEA, 2019).

6.7.3 Emission trend

CO_2 emissions from the use of urea in catalysts are presented in Table 6.7.2 and Annex D0-1.

As the use of urea in catalysts only started with EURO IV heavy-duty vehicles, the time series starts in 2001.

Table 6.7.2 CO_2 emissions from the use of urea in catalysts, kt.

	2001	2005	2010	2015	2018	2019	2020	2021
CO_2	0.001	0.010	2.5	8.1	9.1	9.2	9.1	9.5

6.7.4 Time series consistency and completeness

The time series is both consistent and complete.

6.7.5 Input to CollectER

The input data/data sources for calculating emissions are presented in Table 6.7.3.

Table 6.7.3 Input data for calculating emissions from *Urea-based catalysts*.

	Year	Parameter	Comment/Source
Activity data	All	Use amounts	DCE emission model
Emission factor	All	CO_2 emission factor	EMEP/EEA (2019)

7 Electronics Industry

The sector *Electronic Industry* (CRF 2E) covers the use of HFCs and PFCs in the production of fibre optics. There is no production of semiconductors (CRF 2E1), TFT flat panels (CRF 2E2) or photovoltaics with use of F-gases (CRF 2E3) in Denmark. No use of HFCs or PFCs as heat transfer fluids (CRF 2E4) occur in Denmark.

As a result the only relevant category in this sector is:

- Other electronics industry (CRF 2E5); see section 7.2

The description of consumption and emission of F-gases given below is based on an inventory by Poulsen (2023). For further details, please refer to that report.

7.1 Emissions

7.1.1 Greenhouse gas emissions

The use of F-gases in the production of fibre optics did not start until 2001 and no emissions are reported for 2020-2021. Hence the time series covers the years 2001-2019. The emission time series for *Electronics industry* is presented in Figure 7.1.1 and Annex E1-2.

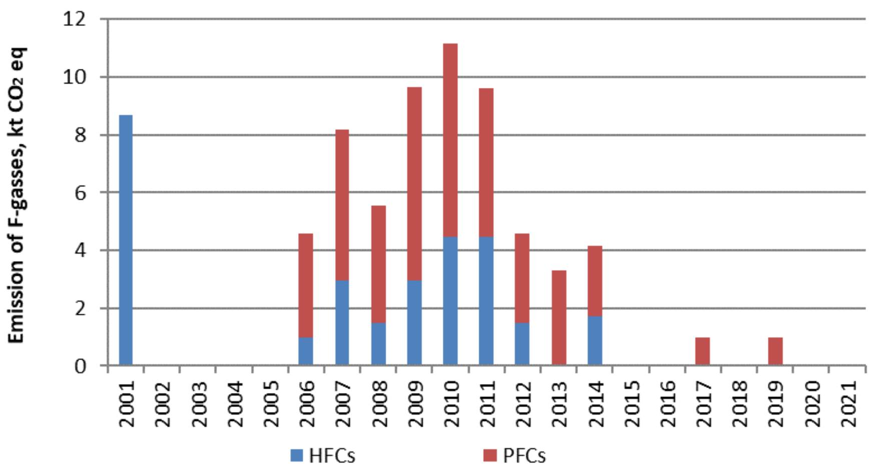


Figure 7.1.1 Emissions of HFCs and PFCs from *Electronics industry*.

7.2 Other electronics industry

As mentioned above, optic fibre production is the only source category relevant for the Danish inventory on electronic industries.

The following pollutants are included for *Other electronics industry*:

- F-gases: HFC-23, PFC-14 (CF_4), PFC-318 ($c\text{-}CF_4F_8$)

7.2.1 Process description

Both HFCs (HFC-23) and PFCs (PFC-14 and PFC-318) are used for technical purposes in Danish optics fibre production for protection and as cleaning gases in the production process.

7.2.2 Methodology

Information on consumption of HFCs and PFCs in production of fibre optics is derived from annual importers' sales report with specific information on the amount used for production of fibre optics. This is believed to represent 100 % of the Danish consumption of F-gases for that purpose. The emission factor is 1, i.e. 100 % release in the production year (i.e. year of consumption). The methodology corresponds to the IPCC Tier 2 method.

Stock displacement is believed to be the main reason for the fluctuations in the time series. However, since F-gasses in this industry are only used for tests or product development and not for industry scale production, the use of F-gasses will also be small and will vary.

Activity data

There has been no use of F-gasses in 2002-2005, 2015-2016, 2018 or 2020-2021. The consumption data are provided in Figure 7.2.1 below and Annex E1-1.

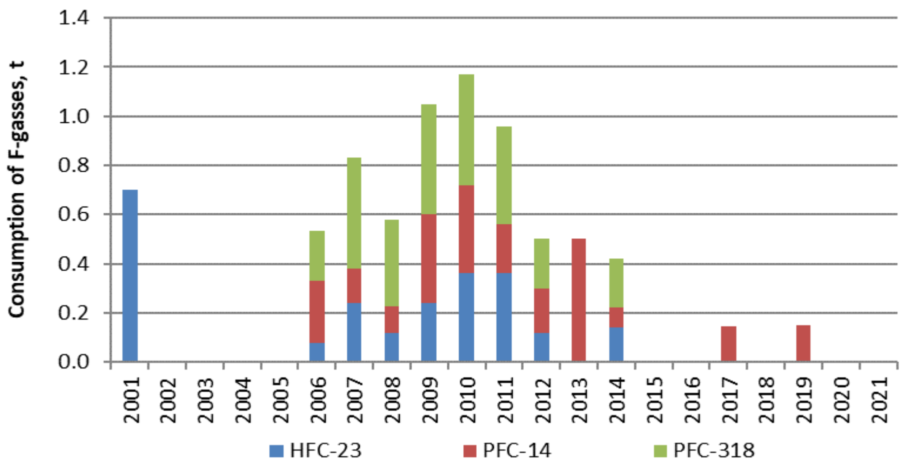


Figure 7.2.1 Consumption of F-gases in production of fibre optics, t.

Emission factors

Since HFC-23 and the PFCs are used as protection and cleaning gases as well as for etching in optics fibre production, the emission factor is defined as 100 % release during the production process.

7.2.3 Emission trend

Emission trends are presented in Figure 7.2.2 below and Annex E1-2.

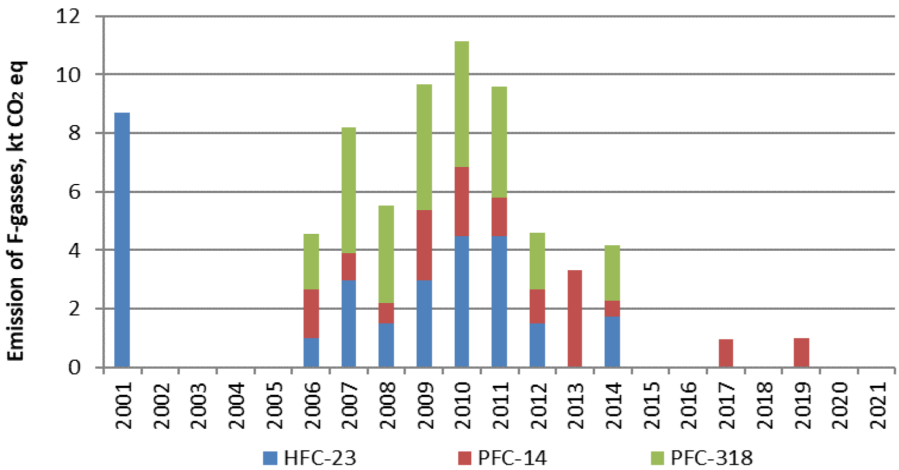


Figure 7.2.2 Emissions from electronic industry, kt CO_2 eqv.

7.2.4 Time series consistency and completeness

The estimates are based on information directly from the importer supplying this sector in Denmark. As Denmark is a small country with a limited consumption of F-gasses, there are only few importers. Data collection for the F-gas report (Poulsen, 2023) is done in close corporation with the industry associations enabling inclusion of any new importers of F-gases or F-gas containing products. The time series is therefore considered both complete and consistent.

8 Product Uses as Substitutes for Ozone Depleting Substances

The sector *Product uses as substitutes for ozone depleting substances (ODS)* (CRF 2F) includes the following source categories:

- Refrigeration and air conditioning (CRF 2F1); see section 8.3
- Foam blowing agents (CRF 2F2); see section 8.4
- Fire protection (CRF 2F3); see section 8.5
- Aerosols (CRF 2F4); see section 8.6
- Solvents (CRF 2F5); see section 8.7

It must be noted that the inventories for the years 1990-1994 might not cover emissions of F-gases in full. The choice of base-year for F-gases under the Kyoto Protocol is 1995 for Denmark.

The description of consumption and emission of F-gases given below is based on Poulsen (2023). For further details, please refer to this report.

8.1 Emissions

8.1.1 Greenhouse gas emissions

The following F-gases are of relevance for the Danish emissions from *Product uses as substitutes for ODS* (2F).

Table 8.1.1 Emission of specific F-gases from the different sub-categories of 2F

CRF	HFC-32	HFC-125	HFC-134a	HFC-143a	HFC-152a	HFC-227ea	PFC-14	PFC-218
2F1	x	x	x	x	x		x	x
2F2			x		x			
2F4			x			x		
2F5								x

The emission time series for *Product uses as substitutes for ODS* (2F) are presented in Figure 8.1.1 and Figure 8.1.2 below as well as in Annex F0-1.

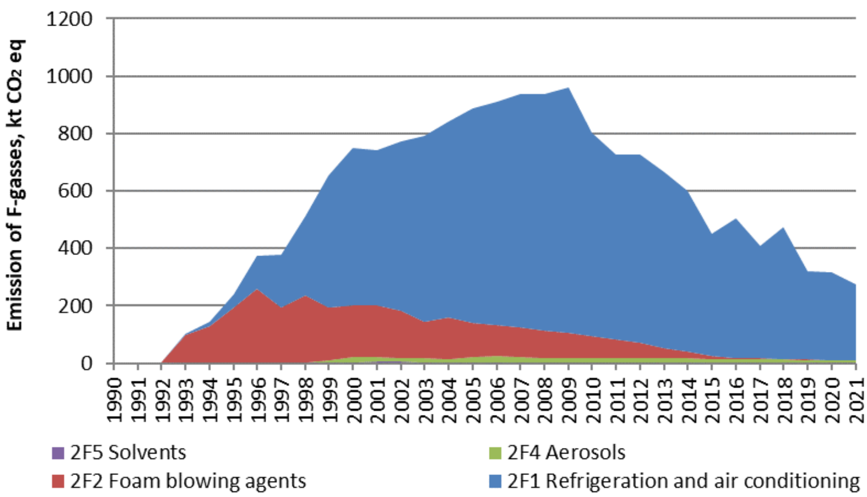


Figure 8.1.1 Emission of F-gases from the individual source categories within *2F Product uses as substitutes for ODS*, kt CO_2e.

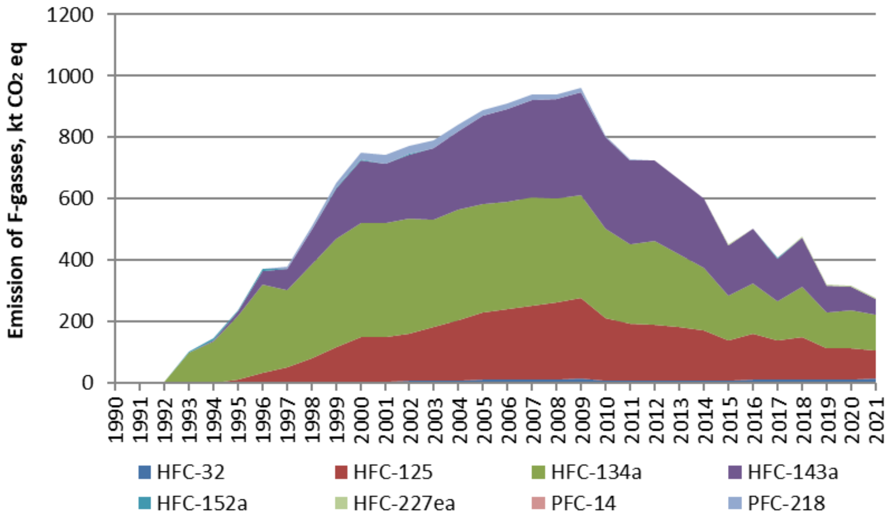


Figure 8.1.2 Emission of F-gases from the individual gases within *2F Product uses as substitutes for ODS*, kt CO_2e. There is no emission of unspecified HFCs.

The emission of HFCs increased rapidly in the 1990s and, thereafter, increased more modestly due to a moderate increase in the use of HFCs as a refrigerant and a decrease in foam blowing. The F-gases have been regulated in two ways since 1 March 2001. For some types of use there is a ban on use of the gases in new installations and for other types of use, taxation is in place. These regulations seem to have influenced emissions so that since 2009, an overall decreasing trend can be observed.

8.1.2 General trends

The phase out of F-gases has in particular been effective within the foam blowing sector and refrigeration and air conditioning installations. Regarding foam blowing, there was a stepwise phase-out of HFC-134a used for foam blowing in closed cell and open cell foam production, during the period 2001-2004. Especially the phase-out of HFCs in open cell foam is significant for the emission in this period.

Since the introduction of taxes on HFCs in 2001, the consumption and emissions from foams has seen a steady decrease and is now almost entirely gone. Emissions still occur form stock in closed cell foams, but no HFCs have been filled into new products (nor imported in new products) since 2016.

The emission of HFCs for refrigeration continued to increase until 2009, especially HFC-404a and HFC-134a increased. This increase is explained with other initiatives in Danish legislation, where new refrigeration systems containing HCFC-22 (ODS) was banned from 2001. It caused a boom in refrigeration systems using HFCs during 2002-2004, because the HFC technology was cheap and well proven. The consumption of HFCs for refrigeration changed significantly after 1 January 2007, where new larger HFC installations with charges exceeding 10 kg were banned. The emission of HFC-134a peaked in 2007, but the peak for HFC-125 and HFC-143a is not seen until 2009. Alternative refrigeration technologies based on CO_2, propane/butane and ammonia are now introduced and available for customers.

The import of PFC-218 (C_3F_8) has been very low since 2006, and as expected, this refrigerant has been phased out of the marked. Emissions have been decreasing since the peak in 2002, and no emissions of PFC-218 are reported after

2014. Emissions from the use of PFC-218 (C_3F_8) as a solvent only occurred from 2000 to 2003.

A quantitative overview is given below (Figure 8.3.1, Figure 8.4.1. Figure 8.6.1 and Figure 8.7.1) for each of the four source categories, showing their emissions in tonnes of CO_2 equivalents through the times series.

8.2 General methodology

The data for emissions of HFCs and PFCs have been obtained in continuation of the work on previous inventories. The determination includes the quantification and determination of any import and export of HFCs and PFCs contained in products and substances in stock form. This is in accordance with the IPCC guidelines (IPCC, 2006).

For the Danish inventories of F-gases, a Tier 2 bottom-up approach is basically used. In Annex 3 to the F-gas inventory report (Poulsen 2023), there is a specification of the approach applied for each sub-source category.

The following sources of information have been used:

- Importers, agency enterprises, wholesalers and suppliers
- Consuming enterprises, and trade- and industry associations
- Danish Environmental Protection Agency
- Recycling enterprises and chemical waste recycling plants
- Statistics Denmark
- Danish Refrigeration Installers’ Environmental Scheme (KMO)
- Previous evaluations of HFCs and PFCs (and SF_6)

Suppliers and/or producers provide consumption data of F-gases. Emission factors are primarily defaults from the IPCC guidelines, which are assessed to be applicable in a national context. In the case of commercial refrigerants and Mobile Air Conditioning (MAC), information from Danish suppliers has been used. The actual amount of F-gas used for refilling is used as an estimate on the actual emission.

Import/export data for sub-source categories where import/export is relevant (e.g. MAC and fridges/freezers for households) are quantified on estimates from import/export statistics of products + default values of the amount of gas in the product. The estimates are transparent and described in Appendix 3 of Poulsen (2023).

The Tier 2 bottom-up analysis used for determination of emissions from F-gasses covers the following activities:

- Screening of the market for products in which F-gases are used
- Determination of averages for the content of F-gases per product unit
- Determination of emissions during the lifetime of products and disposal
- Identification of technological development trends that have significance for the emission of F-gases
- Calculation of import and export is based on defined key figures, and information from Statistics Denmark on foreign trade and industry information

The determination of emissions of F-gases is based on a calculation of the actual emission. The actual emission is the emission in the evaluation year, accounting for the time lapse between consumption and emission. The actual emission includes Danish emissions from production, from products during their lifetimes and from disposal.

Consumption and emissions of F-gases are determined for individual substances, even though the consumption of certain HFCs has been very limited. This has been carried out to ensure transparency of evaluation in the determination of GWP values.

8.2.1 List of F-gasses used in Denmark and their GWP values.

Substance	Chemical formula	Name	GWP
HFC-23	CHF_3	Trifluormethan	12400
HFC-32	CH_2F_2	Difluormetan	677
HFC-125	C_2HF_5	Pentafluoroethane	3170
HFC-134a	$C_2H_2F_4$	1,1,1,2-Tetrafluoroethane	1300
HFC-143a	$C_2H_3F_3$	1,1,1-Trifluoroethane	4800
HFC-152a	$C_2H_4F_2$	1,1-difluoroethan	138
HFC-227ea	C_3HF_7	1,1,1,2,3,3,3-Heptafluoropropane	3350
PFC-14	CF_4	Tetrafluormethan	6630
PFC-218	C_3F_8	Octafluoropropane	8900
PFC-318	c-C_4F_8	Perfluorocyclobutane	9540
SF_6	SF_6	Sulphur hexafluoride	23500

The substances have been accounted for in the annual survey according to their trade names, which are mixtures of different HFCs. In order to report consumption and emissions as pure substances, the ratios provided in Table 8.2.2 have been used.

Table 8.2.2 Content (w/w%)[1] of "pure" HFC in HFC-mixtures, used as trade names (Poulsen, 2023)[2].

HFC mixtures	HFC-32	HFC-125	HFC-134a	HFC-143a	HFC-152a	HFC-227ea
	%	%	%	%	%	%
HFC-365						8
HFC-401a					13	
HFC-402a		60				
HFC-404a		44	4	52		
HFC-407c	23	25	52			
HFC-410a	50	50				
HFC-507a		50		50		

[1]The mixtures also contain substances that do not have GWP values and therefore, the substances do not sum up to 100 %, [2]HFC-401a, -402a, -404a, -407c, -401a and -507a mixtures are in accordance with IPCC (2006) V3 Ch7 Table 7.8.

The national inventories for F-gases are provided and documented in an annual report (Poulsen 2023). Furthermore, detailed data and calculations are available and archived in an electronic version. The report contains summaries of methods used and information on sources as well as further details on methodologies.

8.3 Refrigeration and air conditioning

Refrigeration and air conditioning (CRF 2F1) consists of the following subcategories:

- Commercial refrigeration CRF 2F1a
- Domestic refrigeration CRF 2F1b
- Industrial refrigeration CRF 2F1c - included under 2F1a
- Transport refrigeration CRF 2F1d
- Mobile air conditioning CRF 2F1e
- Stationary air conditioning CRF 2F1f

8.3.1 Process description

The use of HFCs in industrial refrigeration was previously surveyed and the conclusion was that large-scale industrial refrigeration installations in e.g. slaughterhouses, fish factories and medico companies, use ammonia based refrigeration units. This is particularly caused by the tax on HFCs in Denmark that makes HFC based refrigeration units with large charges too expensive, and furthermore the ban from 2007. Smaller HFC based units will occur in industry, but is then similar to commercial refrigeration units. Since it is not possible to separate small-scale industrial and commercial refrigeration units, all consumption and emissions are reported under commercial refrigeration.

8.3.2 Methodology

For refrigeration and air conditioning, Denmark uses mainly the Tier 2 top-down approach (Tier 2b). However, for domestic refrigeration the methodology is a combination of Tier 2a and 2b. For more information on the applied methodology, please refer to Poulsen (2023).

According to Danish law, refrigerators and air conditioning equipment must be emptied before decommissioning by recovery, reuse or destruction of the remaining gases. It is reasonable to assume that this law is upheld in Denmark since waste collection is mandatory and there are no extra charges for e.g. getting rid of a used refrigerator. In addition, to recycling plants where companies and individuals can deliver their waste, there is also a collection scheme where e.g. used refrigerators are collected at the sidewalks and disposed of. Due to this, there is no reason why people would choose to illegally dispose of an appliance when the legal disposal is both free and easy.

For the early period of the time series (1994-2000), transport refrigeration and mobile air conditioning (mobile A/C) were included in one common activity reported under 2.F.1.e Mobile air conditioning. When data became available to allow for the split between these two activities this was implemented. For the transport refrigeration category is used a decommissioning rate of 10 % four years after the consumption. This results in small amounts of HFC-125 and HFC-143a (from HFC-404a) for decommissioning in 1997-2000 in 2.F.1.e. After this period, HFC-404a is no longer reported in 2.F.1.e, but only as used in transport refrigeration (2.F.1.d).

Activity data

The data collection is described in the Chapter 8.2 General methodology.

The activity data expressed as total amount of HFCs and PFCs "filled into new products", "present in operating systems" and "remaining in products at decommissioning" are presented in Table 8.3.1 (Annex F1-1), Table 8.3.2 (Annex F1-2) and Table 8.3.3 (Annex F1-3), respectively. In addition, Annex F1-5 presents data for the recovered amounts of F-gases from refrigeration and air conditioning units.

PFC-14 was used in Denmark for a brief period as refrigerant for specialized low-temperature (-60ºC) freezers for laboratory purposes. Use of PFC-14 for these extreme low temperature laboratory freezers has been registered for 2015-2018, and is placed under 2.F.1.b Domestic refrigeration. By 2019, CF_4 was already substituted with other refrigerants. In 2017 and 2018, the consumption figures were identical.

Heat pumps are part of category 2.F.1.f Stationary air conditioning. There is no production of heat pumps in Denmark and the stock of HFC-32, HFC-125 and HFC-134a in heat pumps therefore increases without any emissions from manufacture. Import of F-gasses in heat pumps is included in "filled into new products" in the table below, this causes the "product manufacturing factor" to be below the 0.2 displayed in Table 8.3.4 (Applied emission factors).

Table 8.3.1 Filled into new manufactured refrigeration products, t.

	Sector	1995	2000	2005	2010	2015	2020	2021
HFC-32	Total	7.0	22.3	23.9	25.4	46.7	96.6	120.9
	Commercial	7.0	12.0	8.2	2.0	10.0	3.6	3.7
	Transport	NO	NO	NO	NO	NO	0.4	1.0
	Stationary A/C	NO	10.3	15.7	23.3	36.7	92.7	116.3
HFC-125	Total	69.1	140.5	99.3	78.2	87.6	62.3	87.1
	Commercial	66.3	107.2	77.5	50.3	47.7	15.7	19.7
	Domestic	0.9	4.0	1.6	0.6	0.4	0.0	0.0
	Transport	0.6	10.2	3.3	2.7	2.2	2.5	2.6
	Mobile A/C	1.3	7.9	NO	NO	NO	NO	NO
	Stationary A/C	NO	11.2	17.0	24.7	37.2	44.2	64.7
HFC-134a	Total	371.9	478.0	252.1	194.0	127.6	109.7	128.6
	Commercial	104.7	179.8	109.5	74.4	55.8	47.9	52.5
	Domestic	267.1	240.4	65.7	6.8	5.6	0.4	0.7
	Transport	NO	0.9	0.8	0.7	0.4	0.1	0.1
	Mobile A/C	0.1	33.7	39.1	67.3	41.3	43.0	55.1
	Stationary A/C	NO	23.2	37.0	44.7	24.5	18.2	20.2
HFC-143a	Total	63.4	133.6	87.2	58.4	46.5	13.2	16.7
	Commercial	60.8	107.5	81.4	54.5	43.3	13.0	16.6
	Domestic	1.0	4.7	1.9	0.8	0.5	0.0	0.0
	Transport	NO	12.1	3.9	3.2	2.7	0.2	0.1
	Mobile A/C	1.6	9.4	NO	NO	NO	NO	NO
HFC-152a	Commercial	NO	1.3	NO	NO	NO	NO	NO
CF_4	Commercial	NO	NO	NO	NO	0.3	NO	0.004
C_3F_8	Stationary A/C	1.5	6.3	0.5	NO	NO	NO	NO

NO: Not occurring

Table 8.3.2 In operating refrigerating systems (average annual stocks), t.

	Sector	1995	2000	2005	2010	2015	2020	2021
HFC-32	Total	NO	54.1	147.8	189.6	271.9	450.4	533.8
	Commercial	NO	39.0	62.8	48.0	22.1	18.3	20.0
	Transport	NO	NO	NO	NO	NO	0.5	0.8
	Stationary A/C	NO	15.1	85.0	141.6	249.8	431.6	513.0
HFC-125	Total	16.2	381.3	700.1	711.7	570.5	536.9	543.3
	Commercial	13.8	313.8	558.4	510.5	273.7	126.9	104.6
	Domestic	0.9	25.9	35.1	38.3	21.2	10.9	9.5
	Transport	NO	3.2	14.5	11.1	13.4	9.1	9.2
	Mobile A/C	1.6	22.1	NO	NO	NO	NO	NO
	Stationary A/C	NO	16.4	92.1	151.8	262.1	390.0	420.0
HFC-134a	Total	248.5	1425.3	2029.5	2013.1	1262.1	800.9	681.9
	Commercial	83.2	575.1	855.6	751.4	285.2	219.5	158.6
	Domestic	165.2	624.2	822.0	804.7	376.7	118.1	90.5
	Transport	NO	NO	4.1	2.0	2.2	0.7	0.7
	Mobile A/C	0.1	191.8	140.4	139.2	188.0	160.3	153.3
	Stationary A/C	NO	34.1	207.5	315.8	409.9	302.3	278.8
HFC-143a	Total	15.7	345.6	614.2	593.4	322.9	132.5	100.7
	Commercial	12.8	289.0	555.5	535.0	281.9	111.8	83.8
	Domestic	1.0	30.6	41.5	45.2	25.1	12.9	11.2
	Transport	NO	NO	17.2	13.1	15.8	7.8	5.8
	Mobile A/C	1.8	26.1	NO	NO	NO	NO	NO
HFC-152a	Commercial	NO	6.3	5.0	2.9	NO	NO	NO
CF_4	Commercial	NO	NO	NO	NO	0.2	0.2	0.2
C_3F_8	Stationary A/C	0.5	21.9	21.2	11.1	NO	NO	NO

NO: Not occurring

Table 8.3.3 Remaining in refrigeration products at decommissioning, t.

	Sector	1995	2000	2005	2010	2015	2020	2021
HFC-32	Total	NO	NO	NO	9.2	9.9	14.5	12.8
	Commercial	NO	NO	NO	9.2	2.8	NO	0.7
	Transport	NO	NO	NO	NO	NO	NO	NO
	Stationary A/C	NO	NO	NO	NO	7.1	14.5	12.2
HFC-125	Total	NO	0.1	NO	51.4	34.8	42.8	25.2
	Commercial	NO	NO	NO	50.4	23.1	25.2	10.9
	Domestic	NO	NO	NO	0.7	3.3	1.3	1.6
	Transport	NO	NO	NO	0.3	0.7	0.8	NO
	Mobile A/C	NO	0.1	NO	NO	NO	NO	NO
	Stationary A/C	NO	NO	NO	NO	7.7	15.5	12.7
HFC-134a	Total	NO	0.0	NO	229.8	132.0	136.1	48.0
	Commercial	NO	NO	NO	137.1	26.6	76.6	0.5
	Domestic	NO	NO	NO	92.5	80.4	26.9	25.9
	Transport	NO	NO	NO	0.2	0.5	0.1	0.0
	Mobile A/C	NO	0.0	NO	NO	NO	NO	NO
	Stationary A/C	NO	NO	NO	NO	24.6	32.6	21.6
HFC-143a	Total	NO	0.1	NO	48.4	28.7	32.3	11.1
	Commercial	NO	NO	NO	47.1	23.9	29.8	9.2
	Domestic	NO	NO	NO	0.9	3.9	1.6	1.9
	Transport	NO	NO	NO	0.3	0.9	0.9	NO
	Mobile A/C	NO	0.1	NO	NO	NO	NO	NO
HFC-152a	Commercial	NO	NO	NO	NO	NO	NO	NO
CF_4	Commercial	NO	NO	NO	NO	NO	NO	NO
C_3F_8	Stationary A/C	NO	NO	NO	2.8	NO	NO	NO

NO: Not occurring

Emission factors

The applied emission factors are presented in Table 8.3.4. The emission factors for commercial refrigerators, mobile air conditioning (MAC) systems and transport refrigeration have been assessed and compared with national conditions (Poulsen, 2003). This has been re-evaluated annually and the values found in Poulsen (2023) are those found to be applicable for Danish conditions.

Table 8.3.4 Applied emission factors for refrigeration and air condition systems.

		Assembly, %	Stock, % per annum	Lifetime, years	Recovery, %
2.F.1.a	Commercial and industrial refrigerators[1]	0.5-1.5	10	15	88.5
2.F.1.b	Household fridges and freezers	2	1	15	100
2.F.1.d	Transport refrigeration	0.5	17	7	88.5
2.F.1.e	Mobile air conditioning systems[2]	4.5	30	3-15	88.5-100
2.F.1.f	Stationary air conditioning[3]	0.2-1.5	3-10	15	88.5-100
	- Heat pumps[4]	0.2	3	10	80

[1] For commercial refrigerators EFs change from 2010 onward, from 1.5 % to 0.5 % for assembly. This is not the case for retail and industrial refrigeration systems.
[2] For pure HFC-134a, EFs are 4.5 % from assembly, 30 % leakage, 15 years and 88.5 % recovery and for HFC-404a, EFs are 4.5 %, 30 %, 3 years and 100 % recovery.
[3] For all HFCs EFs change from 2010 onward, from 1.5 % to 0.2 % for assembly, and from 10 % to 3 % for stock. For PFC-218 recovery is 100 %.
[4] EFs for heat pumps are mentioned separately from the remaining 2.F.1.f category.

2.F.1.a

The reduction in emission factor from 2010 for all sources in 2.F.1.a from 1.5 % to 0.5 % leakage rate at assembly, is implemented based on an expert judgement of when the technologies improved and next generation units were introduced to the market (Poulsen 2023). This reduction in leakage rate has been investigated, and also discussed in the Nordic working group on F-gases. 1.5 % emission at assembly of commercial refrigerators is the correct factor for historic years, while 0.5 % is correct for recent years. While technological development occurs gradually, emission calculations often display a more step wise trend, as is the case here where the year 2010 was chosen as the split line.

2.F.1.b

For domestic refrigeration, the emission from stock presented in Annex F1-4 is a sum of annual emissions in the product lifetime. The product life factor is therefore not exactly equal to 1 % as otherwise stated in Table 8.3.4. The notation key ”Not occurring” (NO) is used in Annex F1-3 for the amounts of HFCs remaining in products at decommissioning because all appliances are either exported or dismantled at specialised facilities where all refrigerants are drawn of and sent to reuse of destruction.

As described in the methodology section above, all Danish household fridges and freezers are collected at end use. Appliances are either exported or treated in Denmark at specialised dissemble plants. F-gasses are drawn off the appliances under a fume hood, and collected gasses are reused or destroyed through incineration. It is therefore reasonable to assume 100 % recovery. Regarding accidents and breakdown in stand-alone fridges (and MACs) where the entire stock might escape is accounted for in the lifetime emissions. Emissions that might potentially escape incineration at the specialised incineration plants with extremely high temperatures, have been estimated and proven insignificant, see Chapter 8.3.4 Time series consistency and completeness below.

2.F.1.e

Detailed information on the amount of HFCs used for refilling of mobile A/C has been available and applied for the years 2009 - 2011, and therefore, a new approach has been implemented in the calculation of emissions from these years onward. Starting from 2009, the refilled and consumed amount of HFC-134a is calculated based on a Tier 2 top-down approach were the importers of HFC-134a for mobile A/C systems are isolated. The consumption of HFC-134a for mobile A/C systems is used solely for refilling. Car manufacturers outside Denmark carry out initial filling. (Poulsen, 2023):

Consumption of HFC for MAC = refilled stock = emission

From 2012 onward, the applied methodology for mobile air conditioning results in a product life factor around 30 % (21-36 %). For years prior to the shift in methodology mentioned above, the product life factor was exactly 30 % as mentioned in Table 8.3.4.

2.F.1.f

The reduction in emission factor from 2010 for 2.F.1.f from 10 % to 3 % leakage rate, is implemented based on an expert judgement of when the technologies improved and next generation units were introduced to the market (Poulsen 2023). This reduction in leakage rate has been investigated, and also discussed in the Nordic working group on F-gases. Based on the discussions among experts, it is clear that the actual level of leakage from stationary air conditioning units is in the range of 1-4 % and that this has been the level for a number of years. Considering the negligible impact on the emissions, it has been decided to use this approach with a sharp drop in 2010, until more detailed knowledge becomes available that can form the basis for recalculations.

Emission resulting from disposal of items and equipment in the applications differs from 0-20 %. For most categories the emission is calculated as 0 % because Danish legislation ensures that management and treatment of refrigerants prevent uncontrolled emissions. For heat pumps the emission at decommissioning is estimated as 20 % due to lack of control measures with decommissioning of air-air heat pumps from private household. (Poulsen, 2023).

For heat pumps, emission from stock is a sum of annual emission over lifetime. This results in varying odd numbers for the product life factor. Emission at decommissioning is 20 % for heat pumps and 11.5 % for stationary air conditioning, the disposal loss factor therefore ends up around 13-14 %.

8.3.3 Emission trend

Figure 8.3.1, Table 8.3.5 and Annex F1-4 present the emissions of F-gases from consumption of HFCs and PFCs in the individual sub-categories of *Refrigeration and air-conditioning* systems.

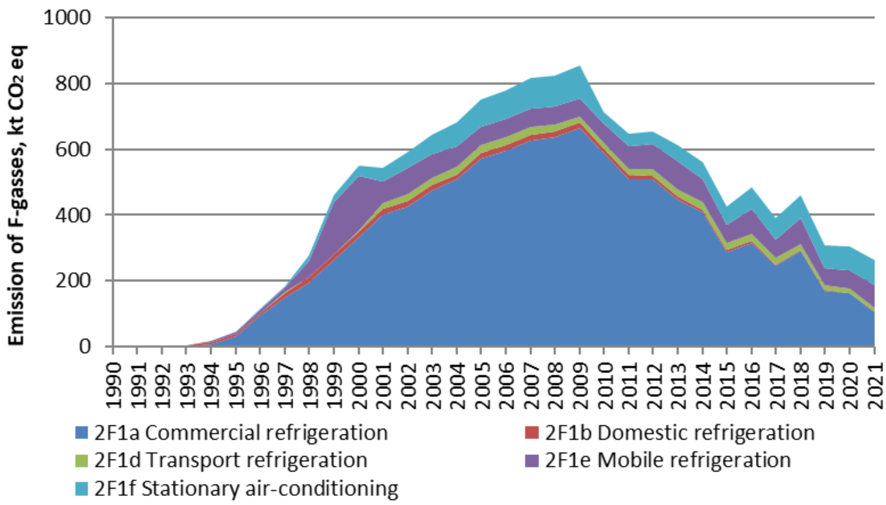


Figure 8.3.1 Emissions from *Refrigeration and air conditioning*.

Table 8.3.5 Emissions from refrigeration and air conditioning, t.

	Sector	1995	2000	2005	2010	2015	2020	2021
HFC-32	Total	0.1	5.7	15.1	10.2	11.1	17.4	20.1
	Commercial	0.1	4.1	6.4	5.9	2.6	1.8	2.1
	Transport	NO	NO	NO	NO	NO	0.08	0.14
	Stationary A/C	NO	1.7	8.7	4.3	8.5	15.5	17.9
HFC-125	Total	3.0	45.9	69.4	64.1	41.8	31.8	28.7
	Commercial	2.4	33.0	57.0	57.1	30.3	15.7	11.8
	Domestic	0.03	0.34	0.40	0.43	0.21	0.11	0.09
	Transport	0.003	0.54	2.49	1.94	2.37	1.65	1.58
	Mobile A/C	0.6	10.2	NO	NO	NO	NO	NO
	Stationary A/C	NO	1.8	9.5	4.6	8.9	14.4	15.2
HFC-134a	Total	16.9	134.2	162.9	154.0	92.5	88.9	83.8
	Commercial	9.9	60.2	87.2	91.3	31.9	31.0	16.2
	Domestic	7.0	11.2	10.1	8.0	3.4	1.0	0.7
	Transport	NO	NO	0.70	0.36	0.44	0.13	0.12
	Mobile A/C	0.05	59.0	43.6	44.8	41.3	43.0	55.1
	Stationary A/C	NO	3.8	21.3	9.6	15.4	13.7	11.7
HFC-143a	Total	2.9	43.0	60.2	62.0	34.2	16.2	10.6
	Commercial	2.2	30.5	56.8	59.2	31.2	14.7	9.5
	Domestic	0.03	0.40	0.48	0.50	0.24	0.12	0.10
	Transport	NO	NO	2.9	2.3	2.8	1.4	1.0
	Mobile A/C	0.7	12.0	NO	NO	NO	NO	NO
HFC-152a	Commercial	NO	0.7	0.5	0.3	NO	NO	NO
CF_4	Commercial	NO	NO	NO	NO	0.002	0.001	0.001
C_3F_8	Stationary A/C	0.1	2.3	2.1	0.3	NO	NO	NO

NO: Not occurring

F-gas emissions from commercial refrigeration are dominating the overall emissions from this source. Hence, the increasing trend from the mid-1990s to 2009 and the subsequent decrease in emissions are explained in Chapter 8.1.1 Greenhouse gas emissions.

The decrease in emissions from mobile air -conditioning in the recent years, is related to the lower consumption of HFC-134a. HFO-1234yf (GWP value of <1) is increasingly being used as a substitute for HFC-134a in new mobile air conditioning systems. HFO-1234yf is not reported under the UNFCCC in accordance with the reporting guidelines and is therefore not included in this report.

EU F-gas Regulation 517/2014, Annex III entered into force on 1 January 2015 placing a ban on sale/installation of domestic refrigeration appliances containing F-gases with a GWP>150. However, for 2015-2021 amounts of HFC-125 (GWP 3170), HFC-134a (GWP 1300) and HFC-143a (GWP 4800) are reported as "filled into new manufactured products" in the Domestic refrigeration subcategory. The single producer responsible for this consumption confirms the consumption of HFC-134a and HFC-404a for domestic appliances and biomedical coolers and freezers. The amounts are decreasing and very small for recent years.

8.3.4 Time series consistency and completeness

Emissions from decommissioning of domestic refrigeration appliances are reported as "Not Estimated" (NE). Direct contact to the Danish industry for destruction of ozone-depleting substances, confirms that no F-gas emissions escape the combustion at extremely high temperatures. However, in acceptance of the possibility of miniscule amounts of F-gases, the notation key is as mentioned "NE".

Estimations of the potential emission from decommissioning show that these are well below 0.05 % of the national total greenhouse gas emission. Using a removal efficiency of 99.99 % and considering that only 50 % of appliances are treated in Denmark, the potential emission at decommissioning is 0.5 - 8.2 t CO_2-eq (0.000001 % - 0.00001 % of national total emission incl. LULUCF) and thereby negligible.

The time series is considered complete and consistent.

8.4 Foam blowing agents

Foam blowing agents (CRF 2F2) consists of the following categories:

- Closed cells (hard polyurethane (PUR) foam plastics and polyether (PE) foam)
- Open cells (soft PUR foam plastics)

In Denmark, five specific processes have occurred during the time series, i.e. foam in household fridges and freezers (closed cell), soft foam (open cell), joint filler (open cell), foaming of polyether (PE) for shoe soles (closed cell) and system foam for panels, insulation etc. (closed cell).

8.4.1 Process description

A blowing agent is a substance with the capability of creating a cellular structure in a liquid of polymers. The cellular structure of the foam reduces density, increasing thermal and acoustic insulation, while increasing relative stiffness of the original polymer.

The difference between open-cell foams and closed-cell foams lies in the way in which the blowing agent is lost from the products. For open-cell foam, HFC emissions used as blowing agents will occur during the manufacturing process and shortly thereafter. Whereas for closed-cell foam, only a minor part of the emission occurs during the production process. For closed-cell foams, the emission will extend into the in-use phase, and most often, the main part of the emission will not occur until end-of-life (decommissioning).

Open-celled foams are most commonly used for mattresses and for cushioning household furniture, automotive seating, office furniture, etc. Closed-cell foams are primarily used for insulating applications in e.g. freezers and refrigerators, where the gaseous thermal conductivity of the chosen blowing agent (lower than air) is used to contribute to the insulating performance of the product throughout its lifetime (IPCC, 2006).

8.4.2 Methodology

The methodology used varies between the different processes. For all processes, the methodology corresponds to the Tier 2 level of IPCC (2006). For some processes, a bottom-up methodology is applied while for others a top-down approach or a combination of top-down and bottom-up is used. For more information on the details of the applied methodology, please refer to Poulsen (2023).

Activity data

The data collection is described in the Chapter 8.2 General methodology.

There is no longer production of HFC-based hard polyurethane (PUR) insulation foam in Denmark. This production has been banned in statutory order since 1 January 2006 (MIM, 2002). Extensions to the phase out were given to a few producers of specialised foam products, e.g. for thermostats (HFC-152a consumption in 2006-2016) and system foams (HFC-134a consumption in 2006-2010).

Activity data are presented in Table 8.4.1 and Annex F2-1.

Table 8.4.1 Activity data for F-gasses used as foam blowing agents, t.

		1995	2000	2005	2010	2015	2020	2021
Filled into new manufactured products								
HFC-134a	Total	298.0	269.0	69.7	0.2	NO	NO	NO
	Closed cells	193.0	225.1	57.8	0.2	NO	NO	NO
	Open cells	105.0	43.9	11.9	NO	NO	NO	NO
HFC-152a	Total	47.0	16.4	5.5	15.0	7.0	NO	NO
	Closed cells	4.0	1.0	5.5	15.0	7.0	NO	NO
	Open cells	43.0	15.4	NO	NO	NO	NO	NO
In operating systems								
HFC-134a	Closed cells	404.7	1353.6	1175.2	690.8	141.3	0.2	NO
HFC-152a	Closed cells	3.6	15.2	24.0	71.8	94.1	66.7	60.0
Remaining in products at decommissioning								
HFC-134a	Closed cells	NO	4.4	7.8	54.1	62.2	0.2	NO
HFC-152a	Closed cells	NO	NO	NO	1.2	0.3	1.6	3.3

NO: Not occurring

Emission factors

The applied emission factors for foam blowing agents are presented in Table 8.4.2 (Poulsen, 2023 – Appendix 3).

Table 8.4.2 Applied emission factors for foam blowing agents (2F2).

	Consumption %	Stock %	Lifetime years
Foam in household fridges and freezers (closed cell)	10[4]	4.5[4]	15[5]
Soft foam (open cell)[1]	100[4]		
Joint filler (open cell)[1]	100[4]		
Foaming of polyether for shoe soles (closed cell)	15[5]	4.5[5]	3[5]
System foam (for panels, insulation, etc.)	0[2]	-[3]	

[1] 100 % emission during the first year after production. [2] HFC is used as a component in semi-manufactured goods and emissions first occur when the goods are put into use. [3] System foam is only produced for export. [4] IPCC (2006) default, [5] Danish default.

System foam is produced in a closed environment and is only produced for export. Therefore, the consumption of HFCs does not contribute to the Danish stock.

The emission factors for foam in fridges and freezers, soft foam and joint filler are default values from (IPCC, 2006[16]). The emission factors for foaming of polyether are country-specific (Poulsen, 2023).

The F-gases remaining in products at decommissioning (closed cell products) are destroyed by incineration and hence there are no F-gas emissions related to disposal of these products.

8.4.3 Emission trend

Figure 8.4.1, Table 8.4.3 and Annex F2-2 presents the emissions of F-gases from consumption of HFCs in foam blowing agents.

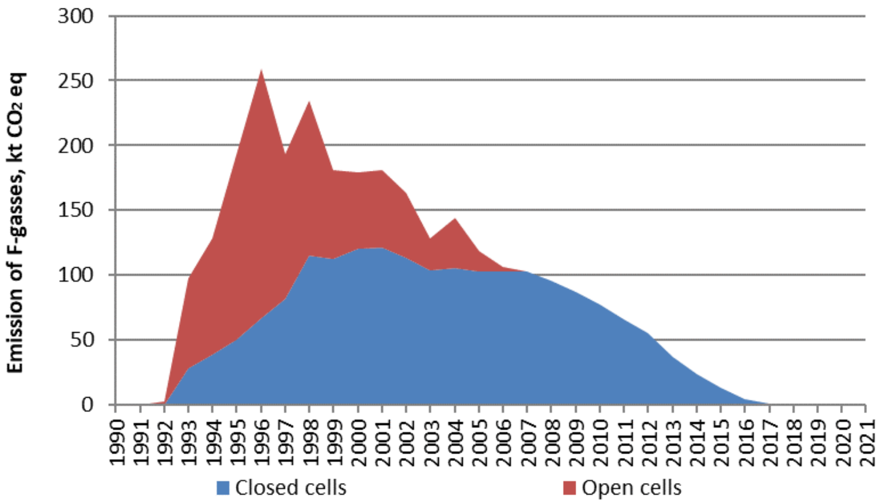


Figure 8.4.1 Emissions from foam blowing agents.

[16] Volume 3: Industrial Processes and Product Use, Chapter 7.4.2.1: Foam blowing agents, Choice of method, Table 7.5, page 7.35 and Chapter 7.4.2.3: Foam blowing agents, Choice of activity data, page 7.38.

Table 8.4.3 Emission of F-gasses used as foam blowing agents, t.

F-gas	Sub-category	Emission	1995	2000	2005	2010	2015	2019	2020
HFC-134a	Total	Total emission	143.3	136.4	91.1	59.2	9.2	2.9	2.9
		From manufacturing	124.3	66.2	12.0	NO	NO	NO	NO
		From stocks	19.0	70.2	79.1	59.2	9.2	2.9	2.9
		Recovery	NO	4.4	7.8	54.1	62.2	45.8	45.8
	Closed cells	Total emission	38.3	92.5	79.2	59.2	9.2	2.9	2.9
		From manufacturing	19.3	22.3	0.1	NO	NO	NO	NO
		From stocks	19.0	70.2	79.1	59.2	9.2	2.9	2.9
		Recovery	NO	4.4	7.8	54.1	62.2	45.8	45.8
	Open cells	From manufacturing	105.0	43.9	11.9	NO	NO	NO	NO
HFC-152a	Total	Total emission	43.6	16.3	1.9	5.4	6.3	6.1	6.1
		From manufacturing	43.4	15.5	0.6	1.5	0.7	0.4	0.4
		From stocks	0.2	0.8	1.4	3.9	5.6	5.7	5.7
		Recovery	NO	NO	NO	1.2	0.3	NO	NO
	Closed cells	Total emission	0.6	0.9	1.9	5.4	6.3	6.1	6.1
		From manufacturing	0.4	0.1	0.6	1.5	0.7	0.4	0.4
		From stocks	0.2	0.8	1.4	3.9	5.6	5.7	5.7
		Recovery	NO	NO	NO	1.2	0.3	NO	NO
	Open cells	From manufacturing	43.0	15.4	NO	NO	NO	NO	NO

NO: Not occurring

The sharp fluctuations in the time series are caused by fluctuations in the consumption of HFCs in production of open cell foam. Fluctuations in production activity data are directly reflected in the emissions as the open cells foams have an emission factor of 100 % at manufacture. For the later part of the time series, the trend reflects the limited use of HFCs and reflects the emission from the stock of previous use of HFCs.

8.4.4 Time series consistency and completeness

Emissions from decommissioning of hard foam (closed cells) are reported as "Not Estimated" (NE). Direct contact to the Danish industry for destruction of ozone-depleting substances, confirms that no F-gas emissions escape the combustion at extremely high temperatures. However, in acceptance of the possibility of miniscule amounts of F-gases, the notation key is as mentioned "NE".

Estimations of the potential emission from decommissioning show that these are well below 0.05 % of the national total greenhouse gas emission. Using a removal efficiency of 95 % and considering that only 50 % of products are treated in Denmark, the potential emission at decommissioning is 0.1 – 3.9 kt CO_2-eq (0.0002 % - 0.007 % of national total emission incl. LULUCF) and thereby negligible.

The time series is considered complete and consistent.

8.5 Fire protection

No HFCs or PFCs are used in fire protection in Denmark. The use of halogen substituted hydrocarbons has been banned since 1977 (MIM, 1977), and this ban is still in place (MIM, 2015).

Halon-1301 has been used in planes, in the military, in server rooms and on ships. New fire protection systems use other technologies, e.g. early fire detection, inert gases or gas mixtures (argon, nitrogen and CO_2) or water vapour. For mobile systems, halon-1211 has been replaced with CO_2 or foam fire extinguishers.

8.6 Aerosols

Aerosols (CRF 2F4) consists of HFCs used for:

- Propellant in aerosols
- Metered dose inhalers

8.6.1 Process description

Aerosol sprays are a dispensing system that creates an aerosol mist of liquid particles. It is used with a can or a bottle that contains a product and a liquefied gas propellant under pressure. The product is forced out through a small hole in the canister by the propellant and emerges as an aerosol or mist. After having been dispersed, the droplets of propellant quickly evaporate.

A metered-dose inhaler (MDI) is an aerosol spray that delivers a specific amount of medication to the lungs, in the form of a mist of aerosolised medicine for inhalation. It is a common delivery system for treating asthma and other respiratory diseases.

8.6.2 Methodology

The general data collection process is described in the Chapter 8.2 General methodology.

For HFC use as propellant in aerosol cans the IPCC (2006) Tier 2a default methodology is used. A default emission factor of 50 % of the initial charge per year is used for aerosols. For metered dose inhalers (MDI) a Tier 2 bottom-up approach is used and an emission factor of 100 % of the initial charge per year is applied.

Information on propellant consumption is derived from reports on consumption from the only major producers of HFC-containing aerosol sprays in Denmark. The import and export are estimated by the producer.

Information on consumption of F-gasses in MDIs is based on data from the national medical trade statistic and information on product content of HFCs from the producers.

As all F-gasses are assumed to be released during the product lifetime for all aerosols, there are no F-gasses remaining in products at decommissioning and therefore no emission from decommissioning and no recovery of F-gasses. The notation key used for these is therefore "NO" (not occurring).

Activity data

From 2019 and forth, the use of HFC-134a is phased out and substituted with HFO-1234ze[17] (GWP value of 7) as propellants in aerosols for specific industrial purposes. 2019 will therefore be the last year of submitted HFC emissions from source category 2.F.4.b Other aerosols.

HFC-134a has been used in medical metered dose inhalers since 1998, and HFC-227ea is introduced from 2015.

The activity data are presented in Table 8.6.1 and Annex F3-1.

Table 8.6.1 Activity data for F-gasses used as aerosols, t.

F-gas	Activity	Sub-category	1995	2000	2005	2010	2015	2020	2021
HFC-134a	Filled into new manufactured products	Total	NO	14.9	20.6	12.4	9.6	5.9	6.0
		Metered dose inhalers	NO	1.6	5.6	7.2	3.8	5.9	6.0
		Propellant in aerosols	NO	13.3	15.0	5.2	5.8	NO	NO
	In operating systems	Total	NO	19.9	23.6	15.4	12.3	5.9	6.0
		Metered dose inhalers	NO	1.6	5.6	7.2	3.8	5.9	6.0
		Propellant in aerosols	NO	18.3	18.0	8.2	8.6	NO	NO
HFC-227ea	Filled into new manufactured products	Metered dose inhalers	NO	NO	NO	NO	0.2	0.8	0.7
	In operating systems	Metered dose inhalers	NO	NO	NO	NO	0.2	0.8	0.7

NO: Not occurring

Emission factors

The applied emission factors are presented in Table 8.6.2 (Poulsen, 2023).

Table 8.6.2 Applied emission factors for aerosols/medical dose inhalers.

	Consumption/filling	Stock	Lifetime
Aerosols	0 %	50 % first year 50 % second year	2 years
Medical dose inhalers	0 %	100 % in year of application	1 year

8.6.3 Emission trend

Figure 8.6.1, Table 8.6.3 and Annex F3-2 presents the emissions of F-gases from consumption of HFCs in *Aerosols*.

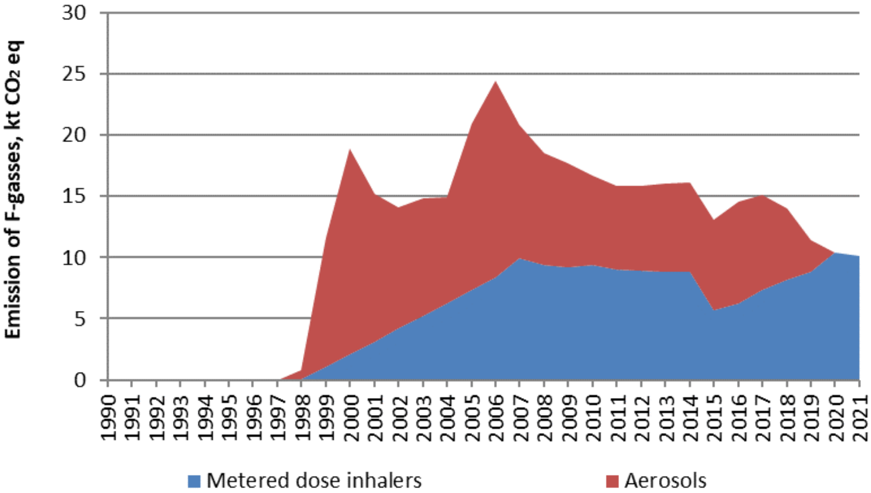


Figure 8.6.1 Emissions from HFCs from *Aerosols*.

[17] HFOs are not reported under the UNFCCC and is therefore not included in this report.

Table 8.6.3 Emissions of F-gasses used as aerosols, t.

F-gas	Emission	Sub-category	1995	2000	2005	2010	2015	2020	2021
HFC-134a	Metered dose inhalers	From stocks	NO	1.6	5.6	7.2	3.8	5.9	6.0
	Propellant in aerosols	From stocks	NO	12.9	10.5	5.6	5.7	NO	NO
	Total	Total	NO	14.5	16.1	12.8	9.4	5.9	6.0
HFC-227ea	Metered dose inhalers	From stocks	NO	NO	NO	NO	0.2	0.8	0.7

NO: Not occurring

Due to the methodology used, the fluctuations in the time series are a result of changes in import, production and export. Baring these fluctuations in mind the emission level has been rather constant at a level between 13 and 21 kt CO_2 equivalents in 2000-2018, but has dropped to 10-11 kt CO_2 equivalents from 2019 due to the phase out of HFC-134a in Aerosols.

8.6.4 Time series consistency and completeness

The time series is considered complete and consistent.

8.7 Solvents

C_3F_8 was used as cleaner from 2000 to 2002 (emissions in 2000-2003) and the use then ceased following the ban in accordance with the Executive Order (MIM, 2002).

8.7.1 Process description

The use of HFCs or PFCs as solvents can occur in precision cleaning, electronics cleaning, metal cleaning and deposition applications.

In general, PFCs have little use in cleaning, as they are essentially inert, have very high GWPs and have very little power to dissolve oils. Accordingly, PFCs only find rare uses in the solvent sector.

8.7.2 Methodology

The methodology used is the IPCC (2006) default, and the fraction of chemical emitted from solvents in the year of initial use is assumed to be 50 % in line with good practice. The other 50 % are assumed to be emitted in the second year and hence there is no subtraction of any F-gasses sent to destruction in the solvents sector.

Activity data

The general data collection process is described in Chapter 8.2 General methodology.

Information on consumption of PFCs in liquid cleaners is derived from two importers' sales reports. This is representing 100 % of the Danish consumption.

Table 8.7.1 Activity data for F-gases used as solvents, t.

F-gas	Activity	2000	2001	2002	2003
C_3F_8	Filled into new manufactured products	0.54	0.50	0.50	NO
	In operating systems	0.54	0.77	0.75	0.25
	Remaining in products at decommissioning	NO	NO	NO	NO

NO: Not occurring.

Emission factors

In accordance with IPCC (2006)[18], the emission factor is 50 % in year 1 and 50 % in year 2.

8.7.3 Emission trend

Figure 8.7.1 and Table 8.7.2 presents the emissions of F-gases from consumption of PFCs used as solvents.

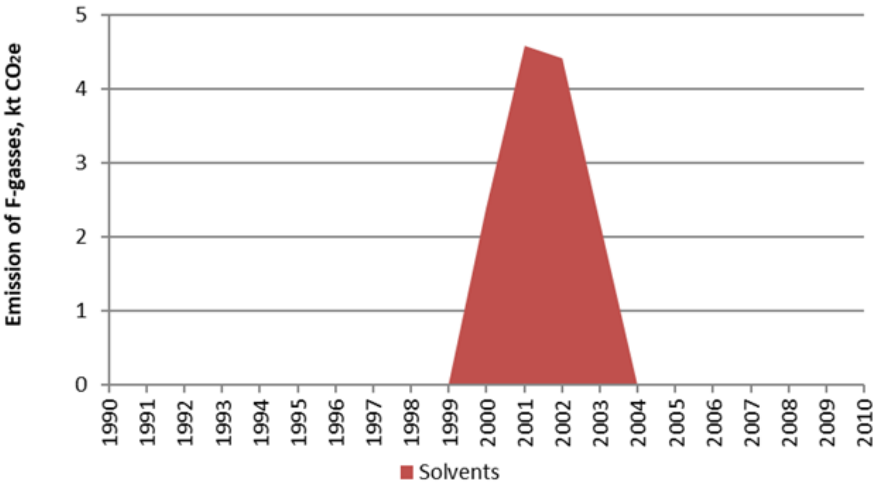


Figure 8.7.1 Emissions from PFCs used as solvents.

Table 8.7.2 Emissions of F-gases used as solvents, t.

F-gas	Emission	2000	2001	2002	2003
C_3F_8	From manufacturing	NO	NO	NO	NO
	From stocks	0.27	0.52	0.50	0.25
	From disposal	NO	NO	NO	NO
	Recovery	NO	NO	NO	NO

NO: Not occurring

As mentioned the use of PFCs as solvent only occurred from 2000 to 2002 and hence emissions only occurred from 2000 to 2003.

8.7.4 Time series consistency and completeness

The time series is considered complete and consistent.

[18] Volume 3: Industrial Processes and Product Use, Chapter 7.2.2: Choice of emission factors.

9 Other Product Manufacture and Use

The sector *Other Product Manufacture and Use* (CRF/NFR 2G) covers the following processes relevant for the Danish air emission inventory:

- Electrical equipment (SNAP 060507); see section 9.2
- SF_6 from other product use (SNAP 060508); see section 9.3
- Medical applications of N_2O (SNAP 060501); see section 9.4
- N_2O used as propellant for pressure and aerosol products (SNAP 060506); see section 9.5
- Other product uses (SNAP 060601, 060602, 060603, 060605); see section 9.6

9.1 Emissions

9.1.1 Greenhouse gas emissions

Total greenhouse gas emissions from the *Other Product Manufacture and Use* (2G) sector are presented in Figure 9.1.1 and Annex G0-1. The emission time series for the source categories within 2G are also presented individually in the chapters below (Chapter 9.2 – 9.6). The following figure gives an overview of which source categories contribute the most throughout the time series.

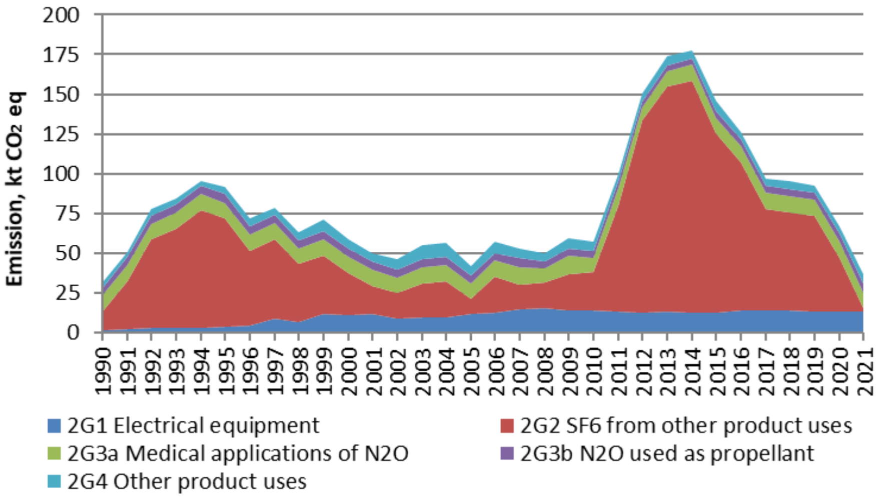


Figure 9.1.1 Emission of CO_2 equivalents from the individual source categories compiling *Other Product Manufacture and Use*.

The significant increase in emissions of SF_6 from other product use from 2010 onwards is caused by the disposal of double-glazed windows containing SF_6. The first windows containing SF_6 were introduced in 1991 and with an estimated lifetime of 20 years, the first disposal emissions are estimated to occur in 2011. As the use of SF_6 in double-glazed windows stopped after 2001, the last emissions from this specific use of SF_6 is reported in 2021.

9.1.2 Air pollution emissions

Air pollution emissions only occur from *Other product use*; i.e. use of fireworks, tobacco, charcoal for barbeques (BBQ) and shoes. The time series for air pollution emissions are available in Annex G0-1 and Annex G3-2. Table 9.1.1 presents an overview of emissions in 2021.

Table 9.1.1 Overview of 2021 air pollution emissions from *Other product use*.

	Total emission from other product use		Fraction of IPPU, %	Largest contributor in other product use	Emission from largest contributor		Fraction of Other product use, %
SO_2	0.05	kt	5.4	Charcoal for barbeques	0.04	kt	76.9
NO_x	0.05	kt	70.0	Charcoal for barbeques	0.04	kt	76.5
NMVOC	0.07	kt	0.2	Charcoal for barbeques	0.04	kt	57.7
CO	3.00	kt	81.7	Charcoal for barbeques	2.65	kt	88.3
NH_3	0.02	kt	6.1	Use of tobacco	0.02	kt	95.1
TSP	0.32	kt	4.5	Use of fireworks	0.20	kt	61.8
HMs	3.87	t	54.1	Use of fireworks (Cu)	3.75	t	97.1
POPs	91.4	kg	99.5	Charcoal for barbeques	90.0	kg	98.5

Emissions of Hg from product uses (such as thermometers, barometers and thermostats) are a difficult area to assess. In Denmark, a lot of Hg used in products, is collected annually and exported for disposal or reuse. In total, 2-4 tons of Hg are collected and exported annually (Skårup et al., 2003). In addition, some of the products containing Hg will end up in the regular waste stream and will be incinerated. The emissions from the incineration of waste are already included in the Energy sector (Stationary combustion). Considering the collection and the emissions already covered by other sectors, the emission estimate included in this report is considered accurate. No other data sources have been identified.

9.2 Electrical equipment

Use of electrical equipment (CRF 2G1b) is the only source relevant for the Danish inventory in the sector *Electrical equipment*.

The following pollutant is included for the *Use of electrical equipment*:

- SF_6

9.2.1 Process description

Power switches in high-voltage power systems is the only use of SF_6 in *Electrical equipment* in Denmark.

High voltage power switches are filled or refilled with SF_6, either for new installation or during service and repair. Filling is usually carried out on new installations and a smaller proportion of the consumption of SF_6 is due to refilling.

9.2.2 Methodology

The methodology uses annual data from importers' statistics with detailed information on the use of the gas. This corresponds to the country-level mass-balance Tier 3c methodology of IPCC (2006). A release of 5 per cent on filling with new gas and a gradual release of 0.5 per cent from the stock are applied. Both figures are averages, covering normal operation and failure/accidents.

No emissions are assumed to result from disposal since the used SF_6 is drawn off from the power switches and re-used internally by the sole Danish supplier (Siemens) or appropriately disposed of through waste collection schemes. The activity for the amount of SF_6 remaining in products at decommissioning of electrical equipment is therefore "not occurring" (NO).

The general data collection process for F-gases is described in Chapter 8.2 General methodology.

Activity data

Information on consumption of SF_6 in high-voltage power switches is derived from importers' sales reports (gas or gas-containing products). The importers account for 100 % of the Danish sales of SF_6 for this purpose.

The electricity sector also provides information on the installation of new plants and thus whether the stock is increasing.

Table 9.2.1 and Annex G1-1 presents the activity data.

Table 9.2.1 Activity data for SF_6 used in electrical equipment, t.

	1995	2000	2005	2010	2015	2020	2021
Filled into new manufactured products	1.4	4.0	3.6	3.2	1.4	1.6	1.5
In operating systems (average annual stocks)	26.2	57.3	68.0	86.3	93.5	100.3	101.2

Emission factors

The applied emission factors are country specific values and are presented in Table 9.2.2. Special attention has been given to use of SF_6 as insulation in high-voltage plants (Poulsen, 2001; ELTRA, 2004).

Table 9.2.2 Applied emission factors for electrical equipment (Poulsen, 2023, page 48).

	Consumption/ filling	Stock, per annum	Disposal	Lifetime
Insulation gas in high voltage switches	5 %	0.5 %	0 %	-[1]

[1] Lifetime unknown.

9.2.3 Emission trend

Figure 9.2.1 and Annex G1-2 presents the emissions of SF_6 from *Electrical equipment*.

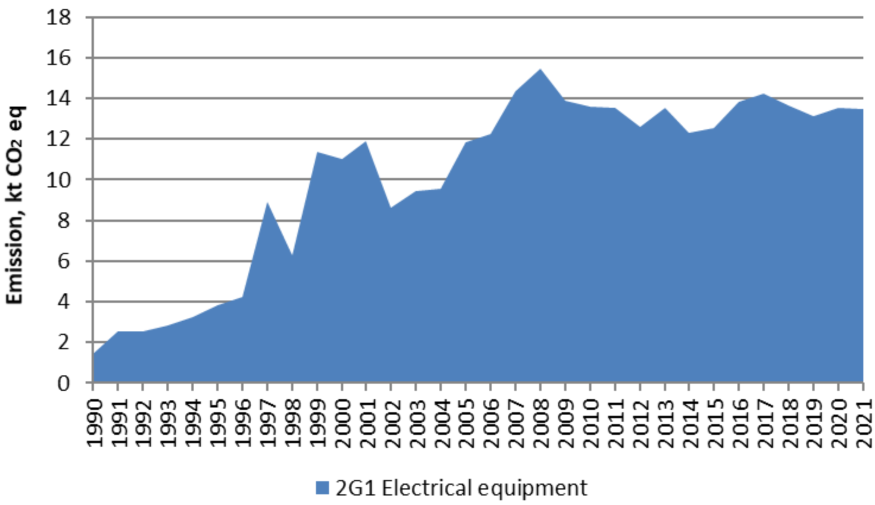


Figure 9.2.1 Emissions from SF_6 from *Electrical equipment*.

The trend in emissions from use of SF_6 in electrical equipment has been increasing. However, significant inter-annual variations occur depending on the specific activity level in a given year.

9.2.4 Time series consistency and completeness

The time series is considered complete and consistent.

9.2.5 Input to CollectER

The input data/data sources for calculating emissions are presented in Table 9.2.3.

Table 9.2.3 Input data for calculation of emissions from *Electrical equipment*.

	Year	Parameter	Comment/Source
Activity	All	Consumption	Poulsen (2023)
Emission	All	Emission factor	Poulsen (2023)

9.3 SF_6 from other product use

SF_6 from other product use (CRF 2G2) consists of the following subcategories:

- Consumption of SF_6 in running shoes
- Consumption of SF_6 in laboratories
- Consumption of SF_6 in double glazed windows

An overview of when emissions from these three sources occurred are available in Table 9.3.1 below.

Table 9.3.1 Occurrence of emissions from the sources compiling 2G2.

	From manufacture	From stocks	From disposal
Running shoes	-	-	1995-2003
Laboratories	1990-1997, 2001-2004, 2006-2021	-	-
Windows	1991-2001	1991-2020	2011-2021

9.3.1 Process description

Consumption of SF_6 in laboratories includes consumption for a particle accelerator, a radiotherapy device, electron microscopes, plasma erosion in connection with the manufacture of microchips in clean-room laboratories and to a limited extend analytical purposes.

9.3.2 Methodology

In general, a mass balance approach is used for laboratory use of SF_6. For double glazed windows and shock-absorption in running shoes, the default IPCC methodology is used with country-specific emission factors. For more information, please refer to Poulsen (2023). Data on the consumption of SF_6 are available from the importers.

Importers/suppliers of SF_6 have been questioned with regard to their knowledge of SF_6 consumption in laboratories, but no further details could be obtained as to the breakdown in consumption between the various activities (plasma erosion, analytical purposes, particle accelerators, radiotherapy and electronic microscopes). The yearly consumption reached a maximum of 1.1 tonnes of SF_6 in 2013 and is below 0.8 tonnes for all other years in the time series. Due to the limited use and lack of data to distinguish between uses of SF_6, it is considered that the resources needed to improve this would be disproportional to the benefit in increased accuracy. The current method is conservative as it assumes that SF_6 is emitted in the year of purchase.

Use of SF_6 in double-glazed windows was phased out in 2002, and the last stock emissions were emitted in 2020. However, there are still emissions from disposal of the last existing double-glazed windows in Danish buildings. The stock is estimated from consumption data from Danish producers of double-glazed windows 1991-2001 and lifetime for double-glazed windows are determined to 20 years. This country specific lifetime was determined in collaboration with the Danish industry and matches the warranty. This is further corroborated by the Association of Danish Window Manufacturers (Vindues Industrien, 2023) who state an expected lifetime of 20 years.

Consumption of SF_6 in production of double-glazed thermal windows started in 1991 and has been banned since 1 January 2003 (MIM, 2002).

Activity data

The data collection is described in the Chapter 8.2 General methodology.

Information on consumption of SF_6 in double-glazed windows is derived from importers' sales reports to the application area. The importers account for 100 % of the Danish sales of SF_6 for double-glazed windows. In addition, the largest producer of windows in Denmark has provided consumption data, with which SF_6 import information is verified.

Importers have estimated imports to Denmark of SF_6 in training footwear.

Activity data are presented in Table 9.3.2 and Annex G1-1.

Table 9.3.2 Activity data for *SF_6 from other product use*, t.

		1995	2000	2005	2010	2015	2020	2021
Soundproof windows	Filled into new manufactured products	13.5	4.1	NO	NO	NO	NO	NO
	In operating systems	25.0	38.3	36.4	34.3	17.0	1.5	0.1
	Remaining in products at decommissioning	NO	NO	NO	NO	4.6	1.4	0.1
Running shoes	Filled into new manufactured products	0.1	0.1	NO	NO	NO	NO	NO
	In operating systems	0.1	0.1	NO	NO	NO	NO	NO
	Remaining in products at decommissioning	0.1	0.1	NO	NO	NO	NO	NO
Laboratories	Filled into new manufactured products	0.5	NO	NO	0.6	0.1	0.02	0.01

NO: Not occurring

Emission factors

The applied emission factors are presented in Table 9.3.3.

Table 9.3.3 Applied emission factors for SF_6 from other product use (Poulsen, 2023).

	Consumption	Stock	Lifetime
Laboratories	100 %		
Insulation gas in double glazed windows	15 %	1 % annual	20 years
Shock-absorbing in Nike Air training footwear	-[1]	-[2]	5 years

[1]No emission from production in Denmark.

[2]Yearly emissions have been estimated to 0.11 t in 1995-2003.

Of the SF_6 filled into new manufactured double-glazed windows, 80 % is assumed to be disposed at decommissioning.

The applied emission factors for double glazed windows follow IPCC for stock (1 % per year), but differs for consumption and lifetime, where the default IPCC (2006)[19] values are 33 % and 25 years, respectively.

9.3.3 Emission trend

Figure 9.3.1 and Annex G1-2 presents the emissions of SF_6 from shoes, double glazed windows and other uses (laboratories etc.).

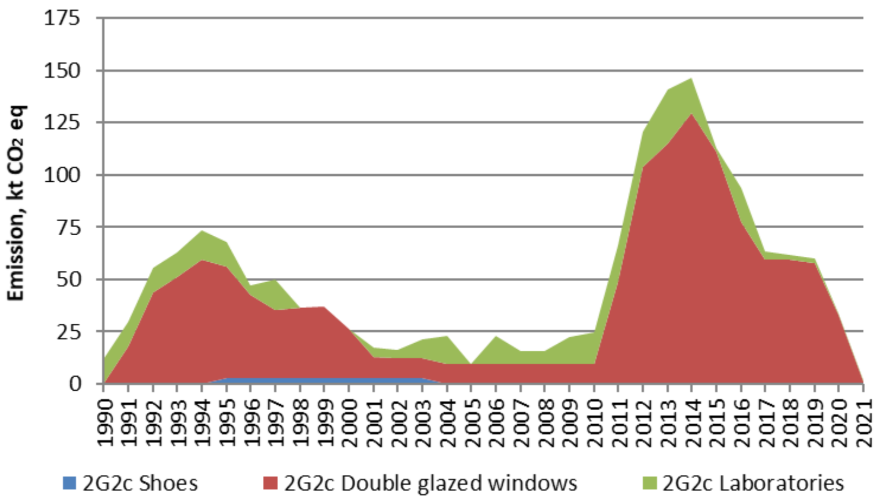


Figure 9.3.1 Emissions from *SF_6 from other product use*.

Double-glazed windows using SF_6 was introduced in 1991 and ceased 10 years later. While there are annual emissions, the lifetime is assumed to be 20 years meaning that all remaining SF_6 contained in the windows is assumed to be emitted 20 years after the last production, i.e. starting from 2011. Emissions of SF_6 from this source is therefore high from 2011 (where the first windows are scrapped) and the following 10 years. However, since the use of SF_6 in double glazed windows was banned in 2002, by 2021 all emissions are assumed to have taken place.

9.3.4 Time series consistency and completeness

The time series is considered complete and consistent.

9.3.5 Input to CollectER

The input data/data sources for calculating emissions are presented in Table 9.3.4.

Table 9.3.4 Input data for calculation of emissions of *SF_6 from other product use*.

	Year	Parameter	Comment/Source
Activity	All	Consumption	Poulsen (2023)
Emission	All	Emission factor	Poulsen (2023)

9.4 Medical applications of N_2O

The category *Medical applications of N_2O* (CRF 2G3a) covers the following SNAP-code:

[19] IPCC (2006), Volume 3, Chapter 8, page 8.31

- 06 05 01 Anaesthesia

9.4.1 Process description

N_2O has been used as anaesthetics for more than a century but has also had other smaller applications in newer times. N_2O in this source category is predominantly used as anaesthesia and a small amount is used as fuel in race cars and in chemical laboratories.

In the mid-1990s, introduction of air-quality limit values for N_2O together with requirements of expensive extraction systems reduced the application of N_2O for anaesthetics at smaller facilities like dentists.

9.4.2 Methodology

Five companies sell N_2O in Denmark and only one company produces N_2O. N_2O is primarily used in anaesthesia by hospitals, dentists and veterinarians and in minor use in laboratories, racing cars and in the production of electronics. Due to confidentiality, data on produced amount are not available and thus the emissions related to N_2O production are not estimated. For 2005-2012, sold amounts are obtained from the respective distributors and the produced amount is estimated from communication with the company. For the remaining years, data are estimated.

Activity data

Data on total sold and estimated produced N_2O for sale in Denmark is only available for the years 2005-2012, activity data for the years 1990-2004 and 2013-2021 have therefore been estimated as the average value of 2005-2012. Activity data for the time series are presented in Table 9.4.1.

Table 9.4.1 Activity data for N_2O mainly used for medical applications, t.

	1990-2004	2005	2006	2007	2008	2009	2010	2011	2012	2013-2021
N_2O consumption	38[1]	37	38	43	33	46	34	42	30	38[1]

[1]Calculated: average 2005-2012.

Emission factors

An emission factor of 1 is assumed for all uses, meaning 100 % release during consumption.

9.4.3 Emission trend

The emission trend for the N_2O emission from medical applications is presented in Figure 9.4.1 below.

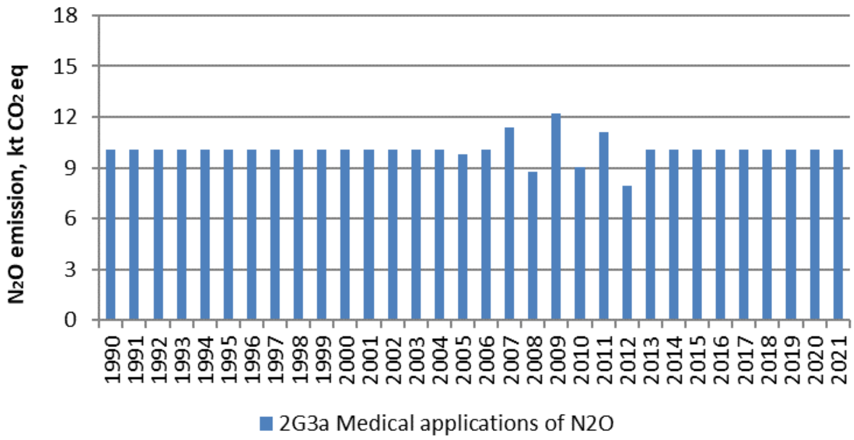


Figure 9.4.1 N_2O emissions from the use of anaesthetics.

9.4.4 Time series consistency and completeness

The methodology is consistent throughout the time series. It is not possible to obtain reliable data prior to 2005, but the source category is considered complete although uncertainties going back from 2005 and forth from 2012 are increasing.

9.4.5 Input to CollectER

The input data/data sources are presented in Table 9.4.2.

Table 9.4.2 Input data for calculation of emissions of N_2O from anaesthetics.

	Year	Parameter	Comment/Source
Activity	2005-2012	Consumption	Direct contact with distributors
	1990-2004; 2013-2021		Estimated as average of years 2005-2012
Emission	All	Emission factor	DCE judgement

9.5 N_2O used as propellant for pressure and aerosol products

The category *N_2O used as propellant for pressure and aerosol products* (CRF 2G3b) covers the following SNAP-code:

- 06 05 06 Aerosol cans

9.5.1 Process description

There is a strong tradition of fresh dairy products in Danish culture and while canned whipped cream is popular for e.g. hot beverages in the winter months this product is not widely used.

9.5.2 Methodology

There are no statistics on production, import/export and/or sales of canned whipped cream in Denmark and the content of propellant is confidential. The consumption of canned cream is therefore estimated using a country specific methodology, where the sale (i.e. consumption) is estimated as 1 % of the regular cream sale. Further assumptions made include five mass% propellant in a can, 250 ml (250 g) cream per can and 95 % release of N_2O.

Activity data

Data on total sold cream and the estimated sale of canned cream are presented in Table 9.5.1 and in Annex G2-1.

Table 9.5.1 Consumption of cream in Denmark, t.

	1990	1995	2000	2005	2010	2015	2020	2021
Fresh cream[1]	37378	46279	39380	37333	34835	31772	41713	46584
Canned cream	374	463	394	373	348	318	417	466

[1]Statistics Denmark (VARER1, 09/08-2022).

Emission factors

The applied emission factor is 47.5 kg N_2O per tonne canned cream sold; 5 % propellant and 95 % release.

9.5.3 Emission trend

The emission trend for the N_2O used as propellant for pressure and aerosol products is available in Annex G2-2 but is also presented in Figure 9.5.1 below.

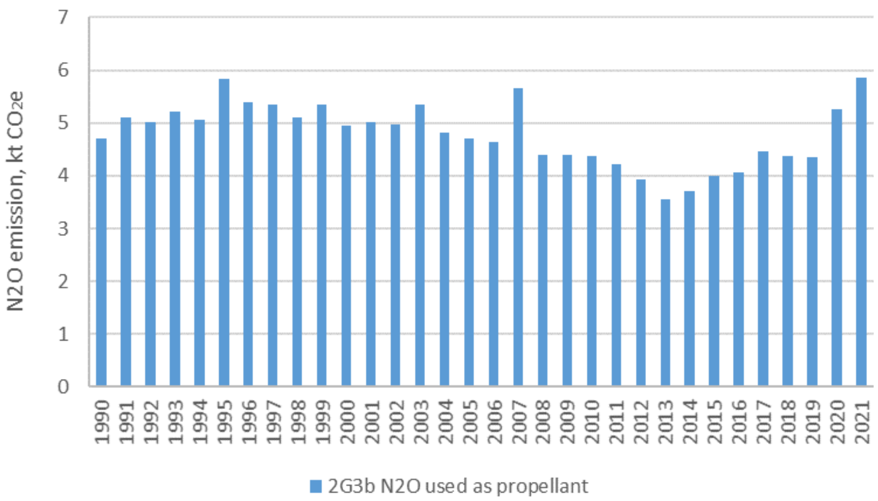


Figure 9.5.1 N_2O emissions from the use of canned whipped cream (Emission 2A from Figure 9.5.2).

9.5.4 Verification

In an attempt to verify the calculated N_2O emissions from canned whipped cream, the same emission is calculated using four assumptions in different combinations. Table 9.5.2 shows the calculated emission for 2012 using the four combinations of assumptions along with the overall assumptions that a can contains 250 ml (250 g) cream and 95 % release of the propellant.

Table 9.5.2 N_2O released as propellant (2012), t

	Assumption 1 1 can used per household per year	Assumption 2 1 % market share of canned cream
Assumption A		
5 % propellant	33.1	14.9
Assumption B		
5 g N_2O per can	13.1	5.9

Using the four assumptions presented in the table above, the time series are calculated; see Figure 9.5.2.

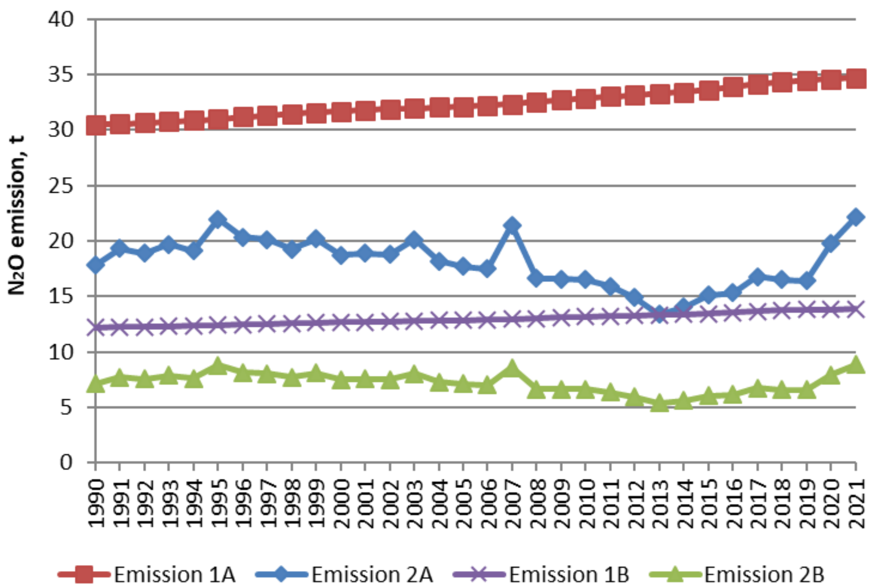


Figure 9.5.2 N_2O emissions from the use of canned whipped cream.

Although the calculated emissions vary over the four estimates, the emission of N_2O from canned whipped cream can generally be said to lie between 5 tonnes and 35 tonnes. Emission 2A has been chosen as the best estimate and used in Figure 9.5.1.

All four estimates are well below 0.05 % of the national greenhouse gas emissions; in 2020 "Emission 1A" is 0.01 % of nationally emitted CO_2 equivalents (excl. LULUCF).

9.5.5 Time series consistency and completeness

The time series is considered complete and consistent.

9.5.6 Input to CollectER

The input data/data sources for calculating emissions are presented in Table 9.5.3.

Table 9.5.3 Input data for calculation of emissions of N_2O used as propellant.

	Year	Parameter	Comment/Source
Activity	All	Consumption	Statistics Denmark (2022), DCE judgement
Emission	All	Emission factor	DCE judgement

9.6 Other product use

The category *Other Product Use* (CRF 2G4/NFR 2G) covers the following categories:

- 06 06 01 Use of fireworks
- 06 06 02 Use of tobacco
- 06 06 03 Use of shoes
- 06 06 05 Use of charcoal for barbeques

The following pollutants are included for *Other product use*:

- Greenhouse gasses: CO_2, CH_4, N_2O
- SO_2
- NO_x
- NMVOC
- CO
- NH_3
- Particulate matter: TSP, PM_{10}, $PM_{2.5}$, BC
- Heavy metals: As, Cd, Cr, Cu, Hg, Ni, Pb, Se, Zn
- Persistent organic pollutants: HCB, PCDD/F, PAHs (benzo(a)pyrene, benzo(b)flouranthene, benzo(k)flouranthene, indeno(1,2,3-c-d)pyrene), PCBs

9.6.1 Process description

Use of fireworks

The use of fireworks is in general limited to a short period around New Year's Eve. This section contains calculations of the annual aggregated emissions.

In general, fireworks consist of a container of paper and polymers, a propellant in form of black powder and for fireworks like e.g. rockets there is a content of different compounds for colours and effects. Black powder consists of about 75 % oxidizer, most commonly potassium nitrate but also potassium perchlorate or, less commonly, chlorate. The remaining components in black powder are a fuel (carbon), and an accelerant (sulphur). The combustion of black powder commonly produces carbon dioxide, potassium sulphide and nitrogen (von Oertzen et al., 2003). Different metal compounds produce different colours and effects. Amongst the pollutants included in this inventory Pb, Cu and Zn are the most important.

All imported fireworks must comply with the standard DS/EN-14035.

Use of tobacco

The use of cigarettes and other tobacco products emit a smoke that contributes to the national emissions. Vast amounts of research focusing on the health risks from tobacco smoke are available, but this inventory only focuses on the impact of environmental tobacco smoke, i.e. releases to the atmosphere.

Use of charcoal for barbeques

The quality of the charcoal depends on the wood species and the process of production. Charcoal is produced by anaerobic heating of the wood, which causes the volatile components in the wood to convert to coke. The heating value for pure dry wood is 19,000 kJ per kg while pure coke has a heating value around 33,000 kJ per kg. The energy content in charcoal is therefore determined by the degree of decomposition of the volatile compounds (FORCE Technology). There is no production in Denmark and all charcoal used in Denmark is therefore imported.

The product called Heat Beads® BBQ briquettes have won market shares from regular charcoal for some years now, but the use of this product is still small compared to regular coal for barbequing. Heat Beads® consist of a certain blend of hardwood charcoal and mineral carbon made by carbonising brown coal and is therefore emitting some non-biogenic CO_2. Due to confidentiality, it is not possible to determine neither the marked share of this product nor if/how much its composition differs from other products. The amount of non-biogenic CO_2 from barbequing is assumed negligible.

Use of shoes

Wear of shoes is a cause of emissions of particles (TSP).

9.6.2 Methodology

Data on the used amounts of product are obtained from Statistics Denmark (2022), emission factors are primarily from international literature and guidelines. The applied methodology follows a Tier 2 technology-specific approach from EMEP/EEA (2019)[20] for calculating emissions from fireworks, tobacco and charcoal for barbeques (BBQ).

Methane and nitrous oxide emissions are calculated for all three product uses, but carbon dioxide is only relevant for fireworks since CO_2 emissions from the two remaining product uses are biogenic.

Use of fireworks

Emissions from fireworks are calculated by multiplying the activity data available from Statistics Denmark (SITC5R3Y/SITC5R4Y, 06/09-2022) with selected emission factors.

Activity data are collected from Statistics Denmark for the years back to 1988; these data are based on information on import and export. Data for the years 1980-1987 are estimated. The cross-border shopping (since most fireworks from e.g. Germany is illegal in Denmark due to the strict Danish laws on the content of net explosive mass) and use of illegal fireworks are assumed negligible. In collaboration with the Danish Pyrotechnical Association, it was decided that any production of fireworks within Denmark is also negligible (Danish Pyrotechnical Association, 2010).

In November 2004, an accidental explosive burning of vast amounts of fireworks occurred in Denmark. It was estimated that the explosion involved around 284 tonnes net explosive mass (NEM). This episode led to a wide evaluation of the laws on use and storage of fireworks (Report Seest, 2005). Since 2005, the amount of total NEM allowed in a single piece of firework has been reduced and the use of fireworks has only been legal to use in the period 1 December to 5 January or with special permission by the local municipality. From 2014, this period was further constricted to only six days (27 December to 1 January).

The heavy metal content in fireworks like Hg, Pb and As and toxic compounds like HCB have been greatly reduced over the time series and are now legally banned, but there are still cases where trace content of HCB has been detected during random checks (DEPA, 2012, 2017). Other compounds like Cu has had increasing application in production of fireworks; Cu has to some extent replaced Pb in its uses. Compounds like Ni and Zn are primarily used in alloys; traces of Cd is assumedly caused by contamination of some ingredients since they have no use in fireworks (Miljöförvaltningen, 1999). Compounds that are still widely used in different amounts and for different applications are: S, C, Cu and Cl (resulting in PCDD/F emissions). Furthermore, N and O are widely used in many different combinations of nitrates, oxides, carbonates, sulphates, chlorates and more.

[20] 2.D.3.i- 2.G Other solvent and product use, Chapter 3.3 Tier 2 technology-specific approach.

The average NEM content in fireworks is estimated to be 20 % (Passant et al., 2003).

Use of tobacco

Emissions from use of tobacco are calculated by multiplying activity data with emission factors from literature.

Activity data on sold amounts of tobacco are known from Statistics Denmark. Data for cross border shopping of tobacco are available from the Danish Ministry of Taxation (Skatteministeriet, 2016 and 2021, Table 7A.2) for 2000-2020 and estimated for the remaining years in the time series. From 2001 to 2009, the cross border shopping of tobacco decreased from 14 % of retail sale to 7 % followed by an increase to 11 % in 2012 and a decrease to 6 % in 2020. Cross border shopping is highly influenced by regulations in the Danish tax system and on e.g. the closure of borders in 2020 caused by the global pandemic of Covid-19. The cross border shopping of tobacco decreased by 28 % from 2019 to 2020. It is assumed that all purchased tobacco is smoked within the same year.

The assumption of the weight of tobacco in cigarettes and cigars of 1 g and 5 g, respectively (EMEP/EEA, 2019, 2.D.3.i-2.G. page 23) was made to derive the activity data presented in Table 9.6.1.

Use of charcoal for barbeques

Emissions from barbequing are calculated by multiplying the net import with selected emission factors.

Activity data for charcoal are gathered from the import/export statistics at Statistics Denmark, which are available for all years back to 1988. The consumption data for 1980-1987 are estimated using extrapolation, i.e. linear regression on the 1998-2009 data and assuming that the development represented by this line is fitting for the description of the 1980-1987 data.

It is assumed that the entire quantity of charcoal is combusted the same year as it is imported. It is further more assumed that the cross-border shopping of charcoal is negligible.

Use of shoes

TSP emissions from the use of shoes are calculated from national population data and an emission factor.

Activity data

Data on consumption of other products are presented in Table 9.6.1, Figure 9.6.1 and Annex G3-1.

Table 9.6.1 Activity data for the use of other products.

	Unit	1980	1985	1990	1995	2000	2005	2010	2015	2020	2021
Fireworks	kt	1.0	1.0	1.3	3.0	4.9	3.7	5.4	5.8	4.2	5.0
Tobacco	kt	14.5	14.3	13.1	11.7	11.4	10.5	9.5	7.3	5.6	5.7
BBQs	kt	1.9	4.4	7.2	7.9	13.4	14.9	7.8	16.3	6.6	12.8
Shoes	million inhabitants	-	-	5.1	5.2	5.3	5.4	5.5	5.7	5.8	5.8

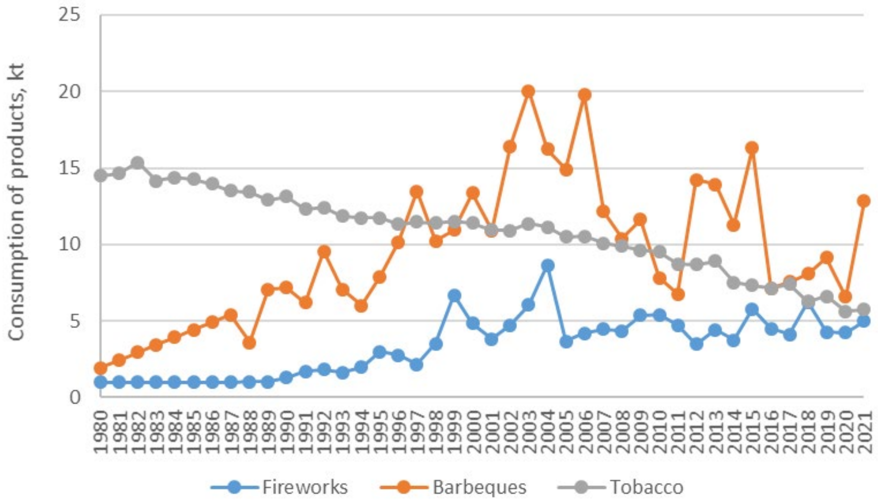


Figure 9.6.1 Activity data for other product use.

The consumption of charcoal for BBQs is highly influenced by the summer season weather, and the number of smokers has been decreasing throughout the time series. For fireworks, two peaks are visible in the time series. The peak in 1999 is caused by the celebration of the new millennia and the peak in 2004 by the Seest incident where 284 tonnes NEM corresponding to a gross weight of about 1.5 kt of fireworks exploded (Report Seest, 2005). From 2005, the new restrictions put on fireworks (see section 9.6.2) meant a lower general consumption than before 2004. Even with the slightly increasing trend since 2005, the level of consumption is still not as high as for 2003.

Emission factors

Table 9.6.2 shows the applied emission factors for calculating the emissions from use of fireworks, use of tobacco, combustion of charcoal for barbeques and use of shoes.

The emission factor for fireworks for Pb was changed in 2000 and Hg and Pb, along with any compounds derived from them, were forbidden in 2003 and 2007, respectively. Emissions are therefore noted as not occurring for these years and forward.

Table 9.6.2 Emission factors for other product use.

Compound	Unit	Fireworks	Tobacco	BBQ	Shoes
CO_2	kg/t	43.25 (a)	NA	NA	-
CH_4	kg/t	0.83 (a)	3.19 (e)	5.9(j)	-
N_2O	kg/t	1.94 (a)	0.06 (e)	0.03(j)	-
SO_2	kg/t	1.94 (a)	0.40 (e)	3.10 (i)	-
NO_X	kg/t	0.26 (f)	1.80 (f)	2.95 (m)	-
NMVOC	kg/t	-	4.84 (f)	2.95 (m)	-
CO	kg/t	6.90 (a)	55.10 (f)	206.5 (m)	-
NH_3	kg/t	-	4.15 (f)	0.10 (e)	-
TSP	kg/t	39.66 (b)	13.67 (g)	3.10 (i)	0.75 (l)[4]
PM_{10}	kg/t	35.69 (b/f)	13.67 (g)	3.10 (i)	NE
$PM_{2.5}$	kg/t	19.83 (b/f)	13.67 (g)	3.10 (i)	NE
BC	% of $PM_{2.5}$	-	0.45 (f)	14.7 (e)	-
As	g/t	1.33 (f)	0.16 (h)	0.10 (i)	-
Cd	g/t	0.67 (c)	0.02 (e)	0.04 (i)	-
Cr	g/t	15.56 (f)	0.15 (h)	0.04 (e)	-
Cu	g/t	444.4 (f)	0.35 (h)	0.15 (e)	-
Hg	g/t	0.06 (f)[1]	0.01 (e)	0.07 (i)	-
Ni	g/t	30 (f)	0.03 (e)	0.13 (i)	-
Pb	g/t	2200 (d)[2] 666.7 (c)[3]	0.64 (e)	4.45 (i)	-
Se	g/t	-	0.01 (e)	0.65 (i)	-
Zn	g/t	260 (f)	1.61 (e)	1.90 (e)	-
HCB	mg/t	-	-	0.10 (e)	-
PCDD/Fs	µg/t	-	0.10 (f)	10.50 (k)	-
Benzo(b)fluoranthene	g/t	-	0.05 (f)	2.14 (e)	-
Benzo(k)fluoranthene	g/t	-	0.05 (f)	1.25 (e)	-
Benzo(a)pyrene	g/t	-	0.11 (f)	2.16 (e)	-
Indeno(1,2,3-cd)pyrene	g/t	-	0.05 (f)	1.46 (e)	-
PCB	mg/t	-	-	0.13 (e)	-

NO: Not occurring, NA: Not applicable - CO_2 emissions from these sources are biogenic and therefore not relevant, [1]The emission of Hg from fireworks was banned in 2002. [2]1980-1999. [3]2000-2006. [4]Unit is g per inhabitant, (a) Netherlands National Water Board (2008), (b) Klimont et al. (2002), (c) Passant et al. (2003), (d) Miljöförvaltningen (1999), (e) Emission factors for wood (111A) combustion in residential plants (1A4b i), SNAP 020200, the energy content used in the calculation is the average of wood pills and wood waste (16.1 GJ/t), (f) EMEP/EEA (2019), (g) Martin et al. (1997), (h) Finstad & Rypdal (2003), (i) Environment Australia (1999), (j) IPCC (2006), calculated using default uncontrolled combustion EFs[21] and net calorific value of 29.5 MJ/kg[22], (k) Hansen (2000), (l) Sambat et al. (2001), (m) IPCC (1997), calculated using default uncontrolled combustion EFs[23] and net calorific value of 29.5 MJ/kg.

[21] IPCC (2006), Volume 2: Energy, Chapter 2.3.2.1 Stationary combustion, Tier 1, Table 2.4, page 2.21, solid biofuels, charcoal.
[22] IPCC (2006), Volume 2: Energy, Chapter 1.4.1.3 Introduction, Activity data sources, Table 1.2, page 1.19, solid biofuels, charcoal.
[23] IPCC (1997), Volume 3 Reference Manual, Chapter 1.4.2 Energy, Tier 1, Non-CO_2 Emissions, Table 1-9 (page 1.38), Table 1-10 (page1.40) and Table 1-11 (page 1.42), Other sectors, charcoal.

9.6.3 Emission trend

The emission trend for the greenhouse gases from other product use is presented in Figure 9.6.2 and the air pollution emissions in Table 9.6.3. In addition, all emissions are presented in Annex G3-2.

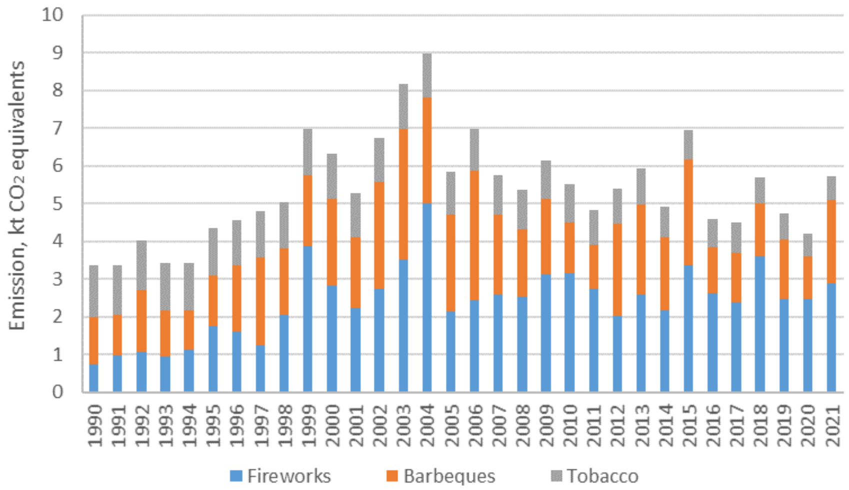


Figure 9.6.2 Greenhouse gas emissions from other product use.

Table 9.6.3 Excerpt of the emissions from other product use.

		Unit	1985	1990	1995	2000	2005	2010	2015	2020	2021
NO_x	Fireworks	t	0.3	0.3	0.8	1.3	1.0	1.4	1.5	1.1	1.3
	Tobacco	t	25.7	23.7	21.1	20.6	18.9	17.2	13.2	10.1	10.3
	BBQ	t	13.1	21.2	23.3	39.4	44.0	23.1	48.1	19.3	37.9
	Total	t	39.0	45.1	45.2	61.2	63.9	41.7	62.8	30.6	49.5
CO	Fireworks	t	6.9	8.8	20.7	33.5	25.4	37.4	40.0	29.3	34.4
	Tobacco	t	785	724	646	629	577	525	404	310	316
	BBQ	t	915	1481	1630	2758	3082	1618	3367	1354	2650
	Total	t	1707	2214	2297	3421	3685	2180	3811	1693	3000
$PM_{2.5}$	Fireworks	t	-	25.4	59.4	96.3	73.1	107.5	114.8	84.2	99.0
	Tobacco	t	-	179.6	160.4	156.1	143.3	130.3	100.2	76.9	78.3
	BBQ	t	-	22.2	24.5	41.4	46.3	24.3	50.6	20.3	39.8
	Total	t	-	227.2	244.3	293.8	262.6	262.1	265.6	181.4	217.1
Cu	Fireworks	kg	-	568.4	1332.3	2157.5	1637.1	2409.8	2573.8	1886.5	2217.9
	Tobacco	kg	-	4.6	4.2	4.0	3.7	3.4	2.6	2.0	2.0
	BBQ	kg	-	1.1	1.2	2.0	2.3	1.2	2.5	1.0	2.0
	Total	kg	-	574.2	1337.6	2163.6	1643.1	2414.3	2578.9	1889.5	2221.9
Hg	Fireworks	kg	-	0.1	0.2	0.3	-	-	-	-	-
	Tobacco	kg	-	0.08	0.07	0.07	0.06	0.06	0.04	0.03	0.03
	BBQ	kg	-	0.5	0.5	0.9	1.0	0.5	1.1	0.4	0.8
	Total	kg	-	0.6	0.8	1.2	1.0	0.6	1.1	0.5	0.9
Pb	Fireworks	kg	-	2813.9	6595.4	3236.7	2456.0	-	-	-	-
	Tobacco	kg	-	8.5	7.6	7.4	6.7	6.1	4.7	3.6	3.7
	BBQ	kg	-	31.9	35.1	59.4	66.4	34.9	72.6	29.2	57.1
	Total	kg	-	2854.3	6638.1	3303.5	2529.2	41.0	77.3	32.8	60.8
Zn	Fireworks	kg	-	332.6	779.5	1262.3	957.8	1409.8	1505.8	1103.7	1297.6
	Tobacco	kg	-	21.1	18.9	18.4	16.9	15.3	11.8	9.0	9.2
	BBQ	kg	-	13.6	15.0	25.4	28.4	14.9	31.0	12.5	24.4
	Total	kg	-	367.3	813.3	1306.0	1003.0	1440.1	1548.6	1125.2	1331.2
POPs	Tobacco	kg	-	3.2	2.9	2.8	2.6	2.3	1.8	1.4	1.4
	BBQ	kg	-	50.3	55.3	93.6	104.6	54.9	114.3	46.0	90.0
	Total	kg	-	53.5	58.2	96.4	107.2	57.3	116.1	47.4	91.4

9.6.4 Time series consistency and completeness

The time series is considered complete for the included sources, the time series is also consistent all though some data (e.g. cross-border shopping of tobacco) are estimated for some historical years.

9.6.5 Input to CollectER

The input data/data sources for calculating emissions are presented in Table 9.6.4.

Table 9.6.4 Input data for calculation of emissions from *Other product use*.

	Year	Parameter	Comment/Source
Activity	1988-2021	Import/Export for charcoal and fireworks	Statistics Denmark (2022)
	1980-1987		Estimated
	All	Sale of tobacco, population	Statistics Denmark (2022)
	2000-2020	Cross-border shopping of tobacco	Skatteministeriet (2016, 2021)
	1980-1999; 2021		Estimated
Emission	All	Emission factor	Literature, see Table 9.6.2

10 Other production

The sector *Other production* (NFR 2H) covers the following process relevant for the Danish inventory:

- Food and beverages industry (NFR 2H2); see section 10.2

10.1 Emissions

10.1.1 Air pollution emissions

The relevant pollutants from *Food and beverages industry* are NMVOC and particles. NMVOC emissions are presented in Figure 10.1.1 on subsector level. For more detailed data, please refer to Chapter 10.2.3 Emission trend and Annex H1-2.

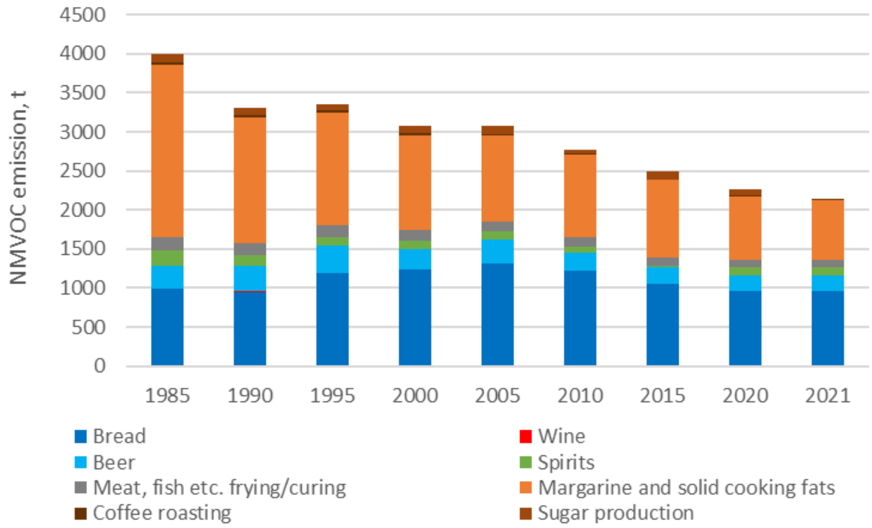


Figure 10.1.1 NMVOC emissions from the production of foods and beverages.

For the years (1985-1998), production of margarine and solid cooking fats was the largest NMVOC emitting category in *Foods and beverages industry* (42-59 %). However, for the more recent years (1999-2021) production of bread has become the largest source (39-46 %).

10.2 Food and beverages industry

The following SNAP-codes are covered:

- 04 06 05 Bread
- 04 06 06 Wine
- 04 06 07 Beer
- 04 06 08 Spirits
- 04 06 25 Sugar production
- 04 06 26 Flour production
- 04 06 27 Meat, fish etc. frying/curing
- 04 06 98 Margarine and solid cooking fats
- 04 06 99 Coffee roasting

The pollutants relevant for the *Food and beverages industry* are NMVOC and particles. The CO_2 emissions related to the use of lime in the sugar production are reported in Chapter 3.3 Lime production. Emissions associated with the fuel use are estimated and reported in the *Energy* sector and are hence not included in this sector report.

10.2.1 Process description

Beverages industry

The production of alcoholic beverages is spread out over a large number of different companies of different sizes.

When making any alcoholic beverage, sugar is fermented into ethanol by yeast. The sugar can come from a variety of sources but most often comes from grapes (wine), cereals (beer and some spirits) or other fruits and vegetables. Some pre-processing of the raw materials is often necessary before the fermentation process, e.g. in the production of beer where the barley grain is malted followed by mashing, lautering and boiling before yeast is added to the wort and the fermentation starts.

In the production of spirits, the fermented liquid is then distilled. Alcoholic beverages, particularly spirits and wine, may be casked for a number of years before consumption. However, in Denmark the main production of alcoholic beverages has been beer and spirits with no or very short maturation, which reduces the evaporative emissions.

Emissions may occur during several stages in the production of alcoholic beverages. During the preparation of the starch/sugar source, emissions can occur during the drying of the green malt. Malts are roasted to different degrees depending on the desired colour and specification.

During fermentation, ethanol and other NMVOCs are emitted together with the CO_2 generated by the fermentation as it escapes to the atmosphere. In some cases, the CO_2 can be recovered, thereby also reducing the emission of NMVOC as a result.

During the distillation of fermentation products as well as during maturation, NMVOCs evaporate from the distillation column or the stored beverage. During maturation, the emission will be proportional to the length of the maturation period.

Food industry

The production of food products is like beverages production, spread out over a large number of different companies of different sizes.

Food processing may occur in open vessels without forced ventilation, closed vessels with periodic purge ventilation or vessels with continuous controlled discharge to atmosphere. In the larger plants, the discharges may be extremely odorous and consequently emission may be controlled using end-of-pipe abatement (EMEP/EEA, 2019).

Emissions occur primarily from the following sources:

- Cooking of meat, fish and poultry, releasing mainly fats and oils and their degradation products

- Processing of fats and oils to produce margarine and solid cooking fat
- Baking of bread, cakes, biscuits and breakfast cereals
- Processing of meat and vegetable by-products to produce animal feeds
- Roasting of coffee beans

Where cooking or putrefaction is not involved, such as the production of fresh and frozen foods, emissions are considered negligible. Emissions from the pasteurisation of milk and the production of cheeses are also considered negligible (EMEP/EEA, 2019).

Sugar industry

Sugar production is concentrated at one company: Nordic Sugar (previously Danisco Sugar A/S) located in Assens, Nakskov and Nykøbing Falster (Danisco Sugar Assens, 2007; Danisco Sugar Nakskov, 2008; Danisco Sugar Nykøbing, 2008; Nordic Sugar Nakskov, 2012; Nordic Sugar Nykøbing, 2010).

The following description of production processes as well as data are based on environmental reports (Danisco Sugar Assens, 2007; Danisco Sugar Nakskov, 2008; Danisco Sugar Nykøbing, 2008; Nordic Sugar Nakskov, 2012; Nordic Sugar Nykøbing, 2010) combined with a general flow-sheet for production of sugar.

The primary raw material is sugar beets, the secondary raw materials are limestone gypsum, and different chemicals (e.g. sulphur). The primary product is sugar and the by-products are molasses and animal feed.

The sugar beets are delivered to the production site or collected by the company. The first step is to wash and cut up the beets followed by pressing/extraction of sugar juice. The sugar juice is purified by addition of burnt lime (see Chapter 3.3 Lime production). Protein compounds are removed by addition of sulphur dioxide. The sugar containing juice is concentrated and finally, the sugar is crystallised. Heat and power is produced on location.

Flour production

Production of potato flour and potato protein leads to particle emissions during the drying process. Potato flour is produced from a special potato variety that contains 18-19 % starch. In comparison, regular eating potatoes only contain 10 % starch.

Before the actual production begins, the potatoes are cleaned mechanically and then washed. Potato flour is produced by washing starch from the pulp and drying it, the ready product consists of 80 % potato starch and 20 % water.

10.2.2 Methodology

The emission of NMVOC from production of foods and alcoholic beverages is generally estimated from production statistics (Statistics Denmark, 2022) and standard emission factors from the EMEP/EEA (2019).

Activity data for beer production from Statistics Denmark are supplemented with data from Danish Brewers' Association (2021). Activity data for whisky production are estimated based on contact to the Danish distilleries.

Activity data and particle emissions from flour production are available for 2007-2014 (and partly for 2004-2006). Data for 2015-2021 are estimated using surrogate data (Statistical data on potatoes for flour production) and the average yield for 2010-2014. Data for 1990-2004 are estimated from surrogate data and the 2007-2011 average yield.

A country specific emission factor is applied for sugar refining. Total sales statistics for produced sugar are available from Statistics Denmark (2022). Production statistics from the environmental reports are registered each 12 month period going from 1 May – 30 April until 2007/08 and from 1 March – 28 February from 2009/10 (Nordic Sugar Nakskov, 2012; Nordic Sugar Nykøbing, 2010). Therefore, the yearly production does not correspond with the yearly sale registered by Statistics Denmark (2022). The information from Statistics Denmark covers the whole time series and therefore the amount of sugar sold is used as activity data.

The sugar production site in Assens closed down in 2006.

Activity data

The production/sales statistics for the relevant processes have been aggregated based on data from Statistics Denmark and presented in Table 10.2.1 and Annex H1-1. The activity data for white wine includes the production of apple and pear cider and red wine includes other fruit wines.

Table 10.2.1 Production of foods and beverages.

		1985	1990	1995	2000	2005	2010	2015	2020	2021
Biscuits, cakes & other bakery prod.	kt	119	99	148	139	157	118	111	117	116
Bread (rye and wheat)	kt	193	190	231	244	257	245	208	186	186
Red wine	m l	12	10	5	5	1	4	1	2	2
White wine	m l	NO	3.2	0.5	0.9	3.1	18	10	10	12
Beer	m l	836	930	990	746	868	651	604	587	587
Malt whisky	m l	0.24	0.02	NO	NO	0.001	0.011	0.032	0.329	0.350
Grain whisky	m l	NO	NO	NO	NO	NO	0.003	0.008	0.330	0.350
Other spirits	m l	39	33	27	24	26	17	4	6	6
Sugar production	kt	533	506	444	443	503	262	468	421	430
Flour production	kt	-	180	182	210	175	140	239	438	386
Poultry curing	kt	4	11	14	24	35	54	64	75	82
Fish and shellfish curing	kt	35	52	31	44	41	73	69	60	64
Other meat curing	kt	531	448	464	393	361	303	211	173	183
Margarine and solid cooking fats	kt	222	161	144	123	109	105	100	82	76
Coffee roasting	kt	53	52	49	56	37	37	17	15	14

NO: not occurring

Emission factors

The emission factors used to calculate the NMVOC emissions from food and beverage production are shown in Table 10.2.2. Regarding refining of sugar, the default emission factor has been revised based on company specific measurements obtained from Nielsen (2011). TOC has been measured in order to solve odour issues. The emission of TOC has been used as indicator for NMVOC assuming a conversion factor at: 0.6 kg C/kg NMVOC.

It is assumed that Danish whisky is stored for six years.

The emission factor for particles from flour production is the calculated average implied emission factor for 2004-2014 of 0.10-0.13 tonnes PM_{10} per kt flour produced.

Table 10.2.2 Emission factors for NMVOC emission from food and beverages production.

Production	Unit	Value	Reference
Bread (rye and wheat)	kg/t bread	4.5	EMEP/EEA (2019)
Biscuits, cakes and other bakery products	kg/t product	1	EMEP/EEA (2019)
Red wine	kg/m^3 wine	0.8	EMEP/EEA (2019)
White wine	kg/m^3 wine	0.35	EMEP/EEA (2019)
Beer	kg/m^3 beer	0.35	EMEP/EEA (2019)
Malt whisky	kg/m^3 alcohol	150	EMEP/EEA (2019)
Grain whisky	kg/m^3 alcohol	75	EMEP/EEA (2019)
Other spirits	kg/m^3 alcohol	4	EMEP/EEA (2019)
Sugar production	kg/t sugar	0.2	Nielsen (2011)
Meat, fish and poultry	kg/t product	0.3	EMEP/EEA (2019)
Margarine and solid cooking fats	kg/t product	10	EMEP/EEA (2019)
Coffee roasting	kg/t beans	0.55	EMEP/EEA (2019)

10.2.3 Emission trend

The emission trends for emission of NMVOC and particles from production of foods and beverage are presented in Figure 10.2.1, Figure 10.2.2 and Annex H1-2.

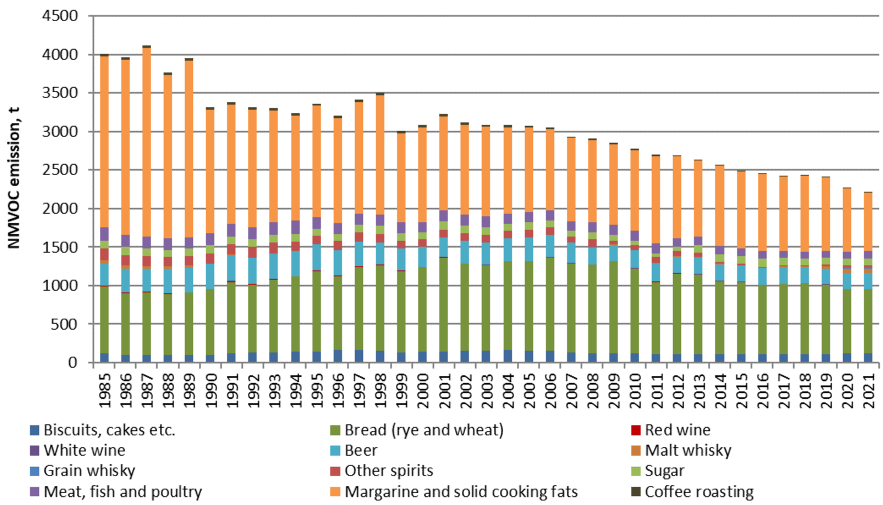


Figure 10.2.1 NMVOC emissions from the *Food and beverages industry*.

The emission of NMVOC from production of food and beverages follows the activity as the same emission factors have been used for the entire period.

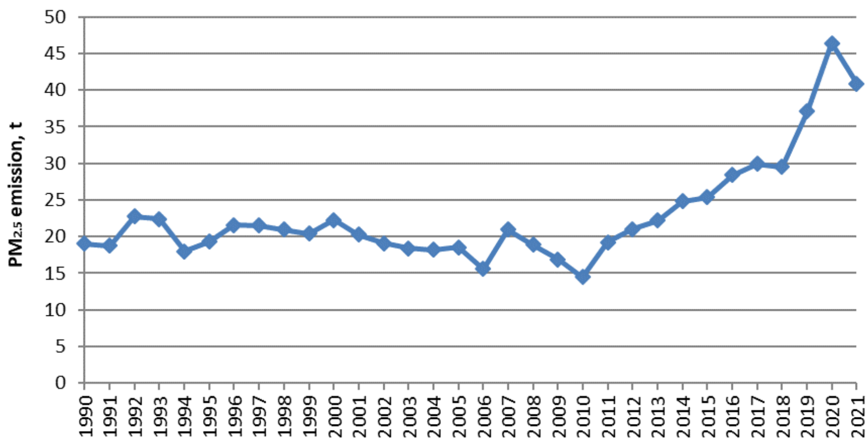


Figure 10.2.2 $PM_{2.5}$ emissions from the production of flour.

10.2.4 Verification

Figure 10.2.3 presents a comparison of activity data for sugar production for 1996-2009 from Statistics Denmark (applied) and the environmental reports from the three production sites that were active in this period. In addition, the consumption of sugar beets (dirty) is displayed in the same figure.

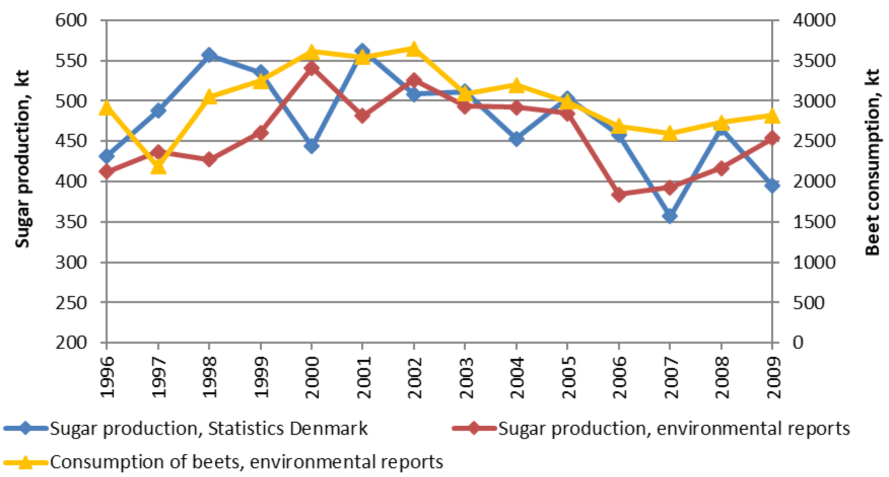


Figure 10.2.3 Comparison of production data and beet consumption data.

The comparison shows a fair agreement between the two sugar production datasets.

The general trend of the beet consumption displays a good agreement with the sugar production data from the environmental reports and a reasonable agreement with those from Statistics Denmark.

Data from the environmental reports are valid for 1 March to 28 February (1996-2006) and 1 May to 30 April (2007-2009), respectively, while data from Statistics Denmark are valid for 1 January to 31 December. However, this should not have a significant influence on the production data, since the production "campaign" runs from ultimo September to primo January where the fresh beets are delivered to the factories.

10.2.5 Time series consistency and completeness

The time series is consistent and complete for the included sources.

10.2.6 Input to CollectER

The input data/data sources for calculating emissions are presented in Table 10.2.3.

Table 10.2.3 Input data for calculation of emissions from the *Food and beverages industry*.

	Year	Parameter	Comment/Source
Activity	All	Sales data	Statistics Denmark (2022)
	2006-2020	Whisky production	Contact with producers, DCE judgement
	1985-2005; 2021		Estimated
	2005-2014	Production of flour	Producers' environmental reports
	1990-2004; 2015-2021		Estimated
Emission	All	Emission factors	EMEP/EEA (2019)
	All	Emission factor for sugar production	Nielsen (2011)
	2004-2014	Particle emissions from flour production	Producers' environmental reports

11 Wood processing

The sector *Wood processing* (NFR 2I) covers the production of wood products.

11.1 Emissions

11.1.1 Air pollution emissions

The relevant pollutants from *Wood processing* are particles. $PM_{2.5}$ emissions are presented in Figure 11.1.1 and Annex I1-2.

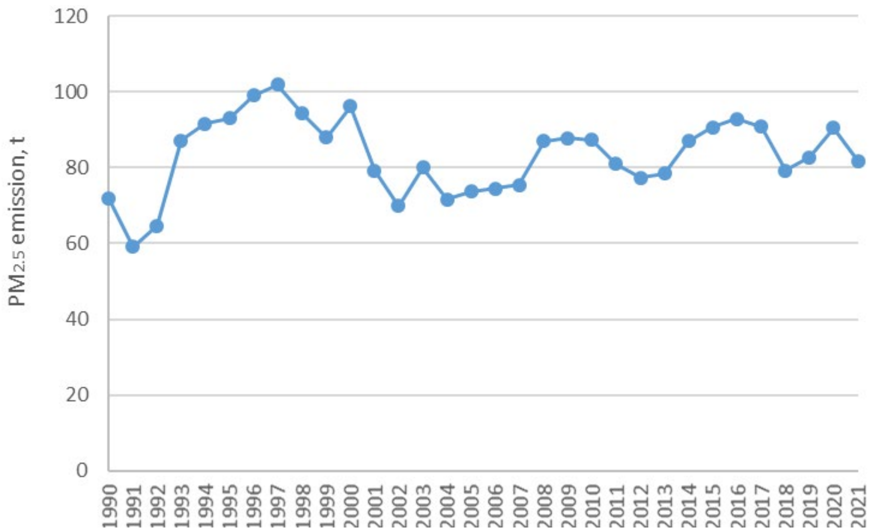


Figure 11.1.1 $PM_{2.5}$ emissions from *Wood processing*.

11.2 Wood processing

The following SNAP-code is covered:

- 04 06 20 Wood processing

The following pollutants are relevant for the wood processing industry:

- Particulate matter: TSP, PM_{10}, $PM_{2.5}$

11.2.1 Process description

Particle emissions are emitted during wood processing.

11.2.2 Methodology

The emission of particles from processing of wood is estimated from the mass of harvested wood products, standard emission factors from the EMEP/EEA (2019) and an assumption for the particle distribution TSP/PM_{10}/$PM_{2.5}$. The applied methodology corresponds to a Tier 1 method.

The amount of harvested wood products is based on the national statistics on production of wood products (Statistics Denmark, 2022), and validated based on a questionnaire that supplements with data from smaller producers not included in the national statistics (Schou, 2015). All the following semi-finished wood product categories are included: sawn wood, wood-based panels and paper/paper products with default half-lives of 35, 25 and two years, respectively, stipulated by IPCC (2014).

In addition to this, activity data from Statistics Denmark (m^3) are multiplied by a country specific density to gain the unit of kt wood product.

Activity data

The production data from Statistics Denmark (2022) are multiplied with the density 0.522 tonnes per m^3 for sawn wood and 0.595 tonnes per m^3 for wood-based panels (IPCC, 2014, Table 2.8.1). The density for sawn wood is calculated from the carbon content of 0.261 tonnes C per m^3 (Schou, 2015) and the carbon fraction of 0.5 (IPCC, 2014, Table 2.8.1). The resulting activity data are presented in Table 11.2.1 and Annex I1-1.

Table 11.2.1 Activity data wood processing, kt.

	1990	1995	2000	2005	2010	2015	2020	2021
Wood processing	359.3	464.8	481.3	368.3	436.6	453.4	452.1	409.2

Emission factors

The emission factors used to calculate the particle emissions from wood processing are shown in Table 11.2.2.

Table 11.2.2 Emissions factors for wood processing.

Pollutant	Unit	Value	Reference
TSP	t/kt	1	EMEP/EEA (2019)
PM_{10}	% of TSP	40	DCE judgement
$PM_{2.5}$	% of TSP	20	DCE judgement

11.2.3 Emission trend

The emission trends for particles are available in Table 11.2.3 and Annex I1-2.

Table 11.2.3 Particle emissions from wood processing, t.

	1990	1995	2000	2005	2010	2015	2020	2021
TSP	359.3	464.8	481.3	368.3	436.6	453.4	452.1	409.2
PM_{10}	143.7	185.9	192.5	147.3	174.6	181.4	180.8	163.7
$PM_{2.5}$	71.9	93.0	96.3	73.7	87.3	90.7	90.4	81.8

11.2.4 Time series consistency and completeness

The time series is considered consistent and complete.

11.2.5 Input to CollectER

The input data/data sources for calculating emissions are presented in Table 11.2.4.

Table 11.2.4 Input data for calculation of emissions from wood processing.

	Year	Parameter	Comment/Source
Activity	All	Harvested wood products	Statistics Denmark (2022)
	All	Densities	IPCC (2014), Schou (2015)
Emission	All	Emission factor	EMEP/EEA (2019)

12 Other production, consumption, storage, transportation or handling of bulk products

The sub-sector *Other production, consumption, storage, transportation or handling of bulk products* (NFR 2L) covers the treatment of slaughterhouse waste (NFR 2L3).

12.1 Emissions

12.1.1 Air pollution emissions

Treatment of slaughterhouse waste is the only source included in the *Other production, consumption, storage, transportation or handling of bulk products* sector. The NH_3 emissions from slaughterhouse waste are presented in Figure 12.1.1.

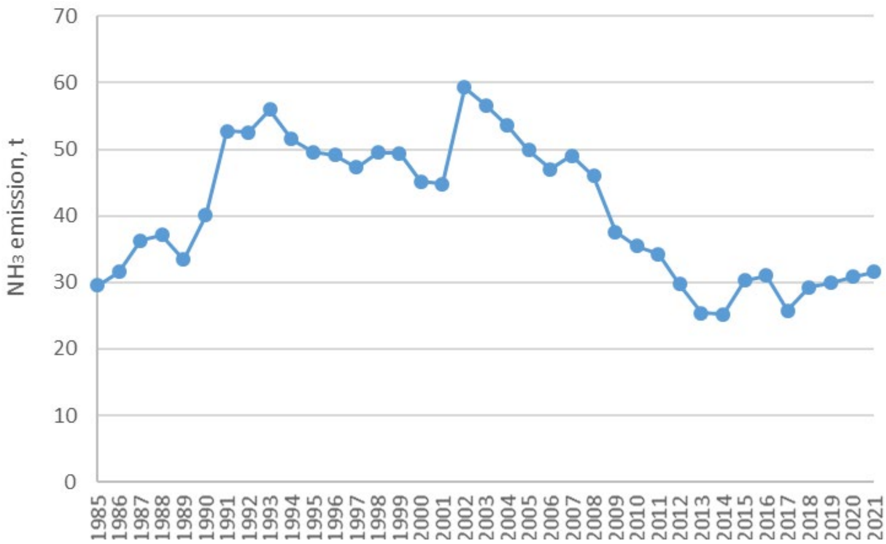


Figure 12.1.1 NH_3 emissions from treatment of slaughterhouse waste.

12.2 Treatment of slaughterhouse waste

One company treats slaughterhouse waste in Denmark: Daka with five plants located in Løsning, Randers, Lunderskov, Ortved, and Nyker. Daka is the result of the merger of Daka and Kambas. The plants in Ortved and Nyker are closed. The following SNAP-code is covered:

- 04 06 17 Slaughterhouse waste

The only pollutant relevant for this source category is NH_3. Emissions related to the consumption of energy are reported under the Energy sector and hence is not included in this report.

12.2.1 Process description

The raw materials for the processes are by-products from the slaughterhouses, animals dead from accidents or diseases, and animal blood. The outputs from the processes are protein and fat products as well as animal fat, meat and bone meal.

The processes involved are e.g. separation, drying and grinding.

The NH_3 emissions and odour from the processing of slaughterhouse waste relates to storage of the raw materials as well as to the drying process.

The information on treatment of slaughterhouse waste is based on Daka (2002; 2004).

12.2.2 Methodology

The emission of NH_3 from treatment of slaughterhouse waste is calculated from national statistical data supplemented and verified with production data from the company. The emission factor is the average implied emission factor measured by the company (Daka, 2002; 2004).

Activity data

The activity data for treatment of slaughterhouse waste are compiled from different sources. Due to changes in the company structure, environmental reports are only available for the years 1997-2009 (Daka, 2009). These environmental reports in combination with environmental reports for one of the merging companies are used to identify the corresponding data in the statistical information from Statistics Denmark (2022).

Data from Statistics Denmark are used in combination with blood meal data (partly estimated based on data from the environmental reports). The activity data are presented in Table 12.2.1 and Annex L1-1.

Table 12.2.1 Activity data for treatment of slaughterhouse waste, kt.

	1985	1990	1995	2000	2005	2010	2015	2020	2021
Meat/bone meal	134.4	128.8	197.0	156.0	164.1	104.6	98.5	115.1	113.0
Animal fat	11.1	72.1	54.2	71.3	89.5	75.3	54.0	40.8	46.7
Blood meal	11.0	11.0	11.0	11.4	10.2	7.5	7.5	7.5	7.5
Total	156.5	211.9	262.2	238.7	263.9	187.4	160.0	163.3	167.1

Emission factors

The emission of NH_3 from treatment of slaughterhouse waste has been calculated from an average emission factor based on measurements from the Danish plants (Daka, 2004). Measurements of NH_3 during the years 2002/2003 from three locations (Lunderskov, Løsning and Randers) with different product mix have been included in the determination of an emission factor.

The weighted emission factors for NH_3 covering all the products within the sector have been estimated for 2000-2003 as 64-475 g per tonne product. The applied emission factor for NH_3 is the average 189 g per tonne product.

12.2.3 Emission trend

Emissions from the treatment of slaughterhouse waste are available in Table 12.2.2 and Annex L1-2.

Table 12.2.2 Emissions from the treatment of slaughterhouse waste, t.

	1985	1990	1995	2000	2005	2010	2015	2020	2021
NH_3	29.6	40.0	49.6	45.1	49.9	35.4	30.2	30.9	31.6

13 Assessment of completeness

A number of emission sources are not covered by the current emission inventory. At the moment, resources are not available to implement all improvements that could be desired for the *Industrial processes and product use* sector. A number of improvements related to the sources that are currently covered by the inventory will be considered together with the possibility of adding new sources to ensure the highest possible overall quality of the inventory.

13.1 Activities not included

A number of activities are possible sources of emissions that are not currently included in the emission inventory. The activities described below do not necessarily form a complete list of potential emission sources within *Industrial processes and product use*.

13.1.1 Grain drying and feedstuff production

This activity is part of the food production/processing category. During the drying of grain NMVOC and particular matter is emitted. Production of feed is a source of particulate matter emission.

13.1.2 Secondary magnesium smelting

In addition, to emissions of cover gas (SF_6), the secondary magnesium smelting can also be a source of particulate matter emission.

13.1.3 Concrete batching

Concrete batching is a potential emission source of particulate matter and also some heavy metals.

13.1.4 Meat/fish smokehouses

In addition to NMVOC emissions, smoking of fish and meat is a potential source of emissions of particulate matter and PAH.

13.1.5 Yeast manufacturing

Emissions of NMVOC will occur during the fermentation to produce yeast.

14 Uncertainties

Uncertainty estimates include uncertainty with regard to the total emission inventory as well as uncertainty with regard to trends. Uncertainties are reported annually for both greenhouse gases and for other pollutants.

14.1 Methodology

The uncertainty for greenhouse gas emissions have been estimated according to the 2006 IPCC Guidelines (IPCC, 2006). The uncertainty has been estimated by the "Approach 1" methodology, this is further described in Nielsen et al. (2023a, Chapter 1.7).

The Approach 1 calculation is based on a normal distribution and a confidence interval of 95 %.

The input data for the Approach 1 estimate are:

- Emission data for the base year and the latest year
- Uncertainties for emission factors
- Uncertainties for the activity data

14.2 Uncertainty input for greenhouse gases

The source specific uncertainties for *Industrial processes and product use* are presented in Table 14.3.1. The uncertainties are based on IPCC (2006) combined with assessment of the individual processes.

14.2.1 Mineral industry

The single Danish producer of cement has delivered the activity data for production as well as calculated the emission factor based on quality measurements. For activity data, there is a shift in methodology from 1997 to 1998. Prior to 1998 activity data are derived by the Tier 2 (1-2 % uncertainty) methodology for grey cement production and the Tier 1 (<35 % uncertainty) for white cement production (20-25 % of total production). Activity data have fulfilled the Tier 3 methodology since 1998 and is assumed to have an uncertainty of 1 %. Since uncertainties cannot vary over time in Approach 1 uncertainty calculations, the activity data uncertainty is assumed to be 2 % for the entire time series. The estimation of emission factors fulfils the Tier 3 methodology for the entire time series and uncertainties are therefore assumed to be 2 %.

The activity data for production of lime, including non-marketed lime in the sugar production, are based on information compiled by Statistics Denmark. The uncertainty for the entire time series is assumed to be 1 % for activity data. The emission factor for marketed lime production cover many producers and a variety of high calcium products, assumptions that influence the uncertainty includes the assumptions of no impurities, 100 % calcination and for sugar production also the assumptions on the lime consumption and sugar content in beets. Since 2006 and the introduction of EU-ETS data, the uncertainty decreased as many of the mentioned assumptions were no longer needed, the combined uncertainty for emission factors are estimated to be 4 %.

The activity data uncertainty associated with glass production (including glass wool production) are low for recent years (EU-ETS data) but higher for historic years (carbonate data were not available for 1990-1996 and were therefore estimated for these years), since uncertainties cannot vary over time in Approach 1 calculations, activity data uncertainties are assumed to be 1 % for the entire time series. Uncertainties associated with the emission factors from glass production are low. Denmark uses the Tier 3 methodology and therefore stoichiometric CO_2 factors, some uncertainty is however connected to assuming a calcination factor of 1, and the overall emission factor uncertainty is therefore estimated to be 2 %.

The activity data for production of ceramics are based on information compiled by Statistics Denmark and EU-ETS and the uncertainty is assumed to be 5 % (Tier 2). The emission factor is based on stoichiometric relations and the assumption of full calcination; the uncertainty is assumed to be 2 %.

The CO_2 emission from other uses of soda ash is calculated based on national statistics and the stoichiometric emission factor for soda ash (Na_2CO_3) assuming the calcination factor of 1. Uncertainties are assumed to be 5 % and 2 % for activity data and emission factor, respectively.

The category "Other Process Uses of Carbonates" in the Danish inventory includes flue gas desulphurisation and stone wool production. The activity data uncertainty for flue gas desulphurisation is assumed to be 10 %. For stone wool the activity data uncertainty is low for recent years (EU-ETS data) but higher for historic years (calculated/estimated), the uncertainties are assumed to be 2 % and 15 %, respectively. The overall activity data uncertainties for other process uses of carbonates are assumed to be 4 %. The uncertainty of the stoichiometric emission factors for both source categories is assumed to be 2 %.

14.2.2 Chemical industry

The producers have registered the production of nitric acid during many years and, therefore, the activity data uncertainty is assumed to be 2 %. The measurement of N_2O is problematic and is only carried out for one year. Therefore, the emission factor uncertainty is assumed to be 25 %.

The uncertainty for the activity data as well as for the emission factor is assumed to be 5 % for production of catalysts/fertilisers.

14.2.3 Metal industry

The uncertainty for the activity data and emission factor is assumed to be 5 % and 10 %, respectively, for production of secondary steel.

The uncertainty for the activity data and emission factor is assumed to be 10 % and 30 %, respectively, for production of magnesium (SF_6) and 10 % and 50 %, respectively, for lead production.

14.2.4 Non-energy products from fuels and solvent use

Emissions from consumption of lubricant oil is derived from the energy statistics and standard emission factors. Uncertainties are assumed to be 5 % and 10 %, respectively, for activity data and emission factors.

For paraffin wax use, the activity data are known for the entire time series (Statistics Denmark) and emission factors from literature. The fraction of candles made from beeswax is unknown, beeswax candles emit biogenic CO_2. Candles produced and sold at e.g. souvenir shops (less than 10 employees) are not included in the activity data from Statistics Denmark. Uncertainties are assumed to be 10 % and 20 %, respectively, for the two data sets.

Important uncertainty issues related to the mass-balance approach used for solvent use are: (i) Identification of pollutants that qualify as NMVOCs (The definition in Directive (2010) is used) as it is possible that relevant pollutants are not included, e.g. pollutants that are not listed with their name in Statistics Denmark but as a product. (ii) Distribution of solvent consumption between appliances. Although the total consumption is set, a change in distribution of consumption between industrial sectors and households will affect the total emissions, as different emission factors are applied in industry and households, respectively. Uncertainties are assumed to be 10 % for activity data and 15 % for emission factors, except for "other use of solvents and related activities" where the emission factor uncertainty is set at 20 %.

While the activity data for the use of asphalt products are known for the entire time series from Statistics Denmark (uncertainty set at 5 %), the emission factors are calculated using a number of assumptions (uncertainty set at 75 %).

Activity data for urea based catalysts are calculated by the COPERT 5 model. The emission factor includes a number of assumptions. Uncertainties are assumed to be 5 % and 10 % for activity data and emission factors, respectively.

14.2.5 Electronics industry

Uncertainty estimates for HFCs and PFCs from other electronics industry are 10 % and 50 % for activity data and emission factors, respectively. No emissions occur in either 1995 or 2020, Electronic industry is therefore not included in the uncertainty calculations in Table 14.3.1.

14.2.6 Product uses as substitutes for ozone depleting substances

Uncertainty varies from substance to substance. Uncertainty is highest for HFC-134a due to its widespread application in products imported and exported. The largest uncertainty in the analysis of substances by application areas is assessed to concern the breakdown of consumption of HFC-404A and HFC-134a between commercial stationary refrigerators and mobile A/C systems. This breakdown is significant for the short-term (about 5 years) emission calculations, but will balance in the long term. This is because the breakdown is only significant for the rate at which emissions are released (Poulsen, 2023).

The emission of F-gases is dominated by emissions from refrigeration equipment and therefore, the uncertainties assumed for this sector will be used for all the F-gases. The IPCC propose an uncertainty at 30-40 % for regional estimates. However, Danish statistics have been developed over many years and, therefore the uncertainty on activity data is assumed to be 10 %. The uncertainty on the emission factor is assumed to be 50 %. The base year for F-gases for Denmark is 1995.

14.2.7 Other product manufacture and use

The uncertainty of *Medical applications of N_2O* is assumed to be 5-50 % for activity data and 20 % for the emission factor. The activity data uncertainty is highest for historic years and lower for recent years; since uncertainty cannot vary over time in Approach 1 calculations the uncertainty input is here estimated to be 25 % for all years.

The uncertainty of N_2O used as propellant for pressure and aerosol products is estimated to be 100 % for activity data and 150 % for the emission factor.

The main issues leading to uncertainties for activity data for "Other Product Use" are collection of data for quantifying production, import and export of products. Some data, like private import (cross-border shopping) of fireworks, are not available. Other missing data like the composition of mineral containing charcoal for barbequing are unobtainable due to confidentiality. The uncertainty for activity data for all three product uses (fireworks, tobacco and BBQs) is estimated to be 5 %. Reliable emission factors are difficult to obtain for the other product use categories. Some chosen emission factors apply to countries that are not directly comparable to Denmark, and hereby is introduced an increased uncertainty. The uncertainties for emission factors are estimated to be 50 % for fireworks, 50 % for tobacco and 100 % for barbeques.

14.3 Uncertainty results for greenhouse gases

All uncertainty input values are discussed in Chapter 14.2 above. Table 14.3.1 presents the uncertainty inputs for activity data and emission factors and the calculated total emission and uncertainty for Approach 1 for the individual greenhouse gases. The total greenhouse gas emission from the IPPU sector in 2021 is 1851 kt CO_2 equivalents and the calculated Approach 1 uncertainty for the year is 7.6 %. The trend decreases with 23.7 % during the time series and the trend uncertainty is 9.3 %.

The dominant sources of uncertainty for greenhouse gas emissions in 2021 is by far emissions of HFCs from *Refrigeration and air conditioning*, the second and third largest contribution to uncertainty are CO_2 from *Cement production* and CO_2 from *Paraffin wax use*.

Table 14.3.1 Input uncertainties and calculated Approach 1 emission and uncertainties.

		Activity data uncertainty	Emission factor uncertainty					
			CO_2	CH_4	N_2O	HFCs[2]	PFCs[2]	SF_6[2]
CRF	Category	%	%	%	%	%	%	%
2A1	Cement production	2	2					
2A2	Lime production	1	4					
2A3	Glass production	1	2					
2A4a	Ceramics	5	2					
2A4b	Other uses of soda ash	5	2					
2A4d	Other process uses of carbonates	4	2					
2B2	Nitric acid production[1]	2			25			
2B10	Catalysts/fertiliser production	5	5					
2C1	Iron and steel production	5	10					
2C4	Magnesium production	10						30
2C5	Secondary lead production	10	50					
2D1	Lubricant use	5	10					
2D2	Paraffin wax use	10	20	20	20			
2D3	Paint application	10	15					
2D3	Degreasing, dry cleaning and electronics	10	15					
2D3	Chemical products manufacturing or processing	10	15					
2D3	Other use of solvents and related activities	10	20					
2D3	Printing industry	10	15					
2D3	Domestic solvent use (other than paint applicat.)	10	15					
2D3	Road paving with asphalt	5	75	75				
2D3	Asphalt roofing	5	75					
2D3	Urea from fuel consumption	5	10					
2E5	Other electronics industry[3]	-						
2F1	Refrigeration and air conditioning	10				50	50	
2F2	Foam blowing agents	10				50		
2F4	Aerosols	10				50		
2F5	Solvents[3]	-						
2G1	Electrical equipment	10						50
2G2	SF_6 from other product use	10						50
2G3a	Medical application	25			20			
2G3b	Propellant for pressure and aerosol products	100			150			
2G4	Fireworks	5	50	50	50			
2G4	Tobacco	5		50	50			
2G4	Barbeques	5		100	100			
Emission 2021, kt			1538	0.1	0.1	275[4]	0.01[4]	15.0[4]
Overall uncertainty in 2021, %			2.3	66.3	59.1	49.0	51.0	46.1
Trend 1990-2021 (1995-2021), %			31.5	19.9	-97.9	15.8	-99.0	-85.9
Trend uncertainty, %			2.8	31.0	1.5	66.2	0.1	7.5

[1] The production closed down in the middle of 2004.
[2] The base year for F-gases is for Denmark 1995.
[3] Uncertainties are not calculated for this source category because the activity occurs in neither 1995 nor 2021.
[4] CO_2 equivalents.

14.4 Uncertainty input and results for other pollutants

According to the Good Practice Guidance for LRTAP Emission Inventories (Pulles & Aardenne, 2004) uncertainty estimates should be estimated and reported each year.

With regard to other pollutants, IPCC methodologies for uncertainty estimates have been adopted for the LRTAP Convention reporting activities

(Pulles & Aardenne, 2004). The Danish uncertainty estimates are based on the simple Approach 1 estimate.

The uncertainty estimates are based on emission data for the base year (1990) and the latest year (2021) as well as on uncertainties for activity data and emission factors aggregated for each of the NFR source categories in the IPPU sector.

The results of the uncertainty analysis for other pollutants are shown in Table 14.4.1 below.

Table 14.4.1 Approach 1 uncertainties for Industrial processes and product use (NFR 2).

Pollutant	Uncertainty total emission %	Trend 1990-2021 %	Uncertainty trend %-age points
SO_2	134.27	-76.8	9.7
NO_x	73.31	-92.6	6.6
NMVOC	13.30	-22.1	7.3
CO	76.15	-73.3	46.0
NH_3	158.12	-38.8	116.3
TSP	635.86	-33.7	140.1
PM_{10}	264.08	-33.1	98.2
$PM_{2.5}$	131.36	-44.2	43.1
BC	112.35	-39.9	48.9
As	557.82	-40.9	103.5
Cd	515.36	-70.8	63.1
Cr	570.67	-23.2	139.3
Cu	286.60	223.0	423.6
Hg	675.34	-97.6	6.9
Ni	367.77	-78.1	170.9
Pb	772.14	-76.3	150.0
Se	383.71	-85.1	15.7
Zn	376.38	-82.2	130.8
HCB	702.66	-99.8	0.3
PCDD/F	169.80	-98.3	15.3
benzo(b)flouranthene	200.25	-69.1	257.4
benzo(k)flouranthene	200.25	-80.3	176.3
benzo(a)pyrene	199.02	-68.5	258.9
indeno(1,2,3-c,d)pyrene	200.25	-77.6	197.3
PCB	828.92	-96.2	4.7

15 QA/QC and verification

For greenhouse gases, the *Industrial processes and product use* sector is covered by the QA/QC manual guiding the quality work for the Danish greenhouse gas inventory, see Nielsen et al. (2020) for specific information on the QA/QC plan for the Danish greenhouse gas inventory. For specific information on the implementation of the QA/QC plan for the *Industrial processes and product use* sector, please refer to the National Inventory Report (Nielsen et al., 2023a).

Documentation concerning verification of the Danish emission inventories has been published in Fauser et al. (2007). An updated verification report for the Danish emission inventories for GHGs is published in 2013 (Fauser et al., 2013).

This report serves as a key part of the QA of the emission inventory for *Industrial processes and product use*. The previous version of this report was reviewed by Jytte B. Illerup from the Danish Environmental Protection Agency. The comments received have been incorporated in the report or have been listed as future improvements.

16 Source specific planned improvements

A number of areas have been identified for future improvements. However, the resources are limited and therefore it is necessary to prioritise the improvements. In Table 16.0.1, the identified improvements are listed together with an indication of the prioritisation. The improvements have been categorised on a scale from 1-3, where 1 indicates the most urgent need for improvement.

Table 16.0.1 List of identified areas for future improvement.

Main sector	Subsector	Improvement	Priority
Mineral industry	Lime production	Inclusion of measured particle emissions from Faxe Kalk	2
Mineral industry	Ceramics	It will be investigated whether emissions of particulate matter can be included for production of ceramics	3
Chemical industry	Catalyst/fertiliser production	Through contact with the plant, it will be attempted to verify the assumptions on the split between combustion and process emissions for CO_2 and NO_x	3
Metal industry	Iron and steel production	For iron foundries, a process description will be elaborated.	3
Other product manufacture and use	Other product use	Other activities not currently included, such as the burning of incense and use of ammunition will be investigated	3
Other industry	Food production/processing	Other activities not currently included, such as grain drying, production of animal feeds including animal rendering, yeast manufacturing and fish meal processing will be investigated further	2

An indication of priority 1 means that this is a top-priority and will be carried out within the next 1-2 years. Priority 2 means a time horizon of 1-5 years while the areas for improvement with priority 3 mean that they are depending on additional resources becoming available.

When carrying out improvements related to the sector special attention will be given to the reference documents on best available technology (BREF documents). BREF documents are periodically updated and when new BREF documents are published, the documents will be analysed for information that can be used to improve the Danish emission inventory.

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Annexes

All annexes referenced in this report are available only online, please see the bottom of page https://envs.au.dk/en/research-areas/air-pollution-emissions-and-effects/air-emissions/reporting-sectors/industrial-processes

DANISH EMISSION INVENTORY FOR INDUSTRIAL PROCESSES AND PRODUCT USE

Results of inventories up to 2021

This report forms part of the documentation for the emission inventories for industrial processes and product use. The report includes both methodological descriptions for estimating emissions of greenhouse gases and air pollutants and presents the resulting emission data as reported to the United Nations Framework Convention on Climate Change and the United Nations Economic Commission for Europe Convention on Long-Range Transboundary Air Pollution. The results of inventories up to 2021 are included.

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