DANISH EMISSION INVENTORY FOR INDUSTRIAL PROCESSES AND PRODUCT USE

Results of inventories up to 2016

Scientific Report from DCE – Danish Centre for Environment and Energy No. 292 2018

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Data sheet

Series title and no.: Scientific Report from DCE – Danish Centre for Environment and Energy No. 292

Title: Danish emission inventory for industrial processes and product use
Subtitle: Results of inventories up to 2016

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Publisher: Aarhus University, DCE – Danish Centre for Environment and Energy ©
URL: http://dce.au.dk/en

Year of publication: November 2018
Editing completed: October 2018

Referees: Jytte Boll Illerrup, Danish Environmental Agency; Pia Frederiksen, Aarhus University, Department of Environmental Science;
Quality assurance, DCE: Vibeke Vestergaard Nielsen

Financial support: No external financial support

Please cite as: Hjelgaard, K.H. & Nielsen, O.-K. 2018. Danish emission inventory for industrial processes. Results of inventories up to 2016. Aarhus University, DCE – Danish Centre for Environment and Energy, 192 pp. Scientific Report No. 292
http://dce2.au.dk/pub/SR292.pdf

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 2016 are included.

Keywords: Industrial processes and product use, emissions, UNFCCC, UNECE, emission inventory

Layout: Ann-Katrine Holme Christoffersen
Front page photo: North Zealand Port A/S (Hundested Havn I/S). Photo by Katja Hjelgaard

ISBN: 978-87-7156-359-7
ISSN (electronic): 2245-0203

Number of pages: 192

Internet version: The report is available in electronic format (pdf) at
http://dce2.au.dk/pub/SR292.pdf

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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 Univesity
EPA	Environmental Protection Agency
EU-ETS	European Union Emission Trading Scheme
Gg	Gigagram, 10^9 g
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
Mg	Megagram, 10^6 g (equals metric ton or tonne)
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	Terajoul, 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 the Environment and the Ministry of Climate, Energy and Building to complete emission inventories for Denmark. Department of Environmental Science, Aarhus University is responsible for 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 2016 are included.

This report is the fourth version of a sectoral report for industrial processes and product use and has been reviewed externally by Jytte Illerup from the Danish Environmental Protection Agency. As a result of this review several changes were made to the report; mostly clarifications of the text and tables and elaboration of certain documentation. In addition, suggestions to future improvements are acknowledged and added to the list of planned improvements, e.g. better description of the emissions from cement production. The third version of the report was reviewed by Karsten Fuglsang from FORCE Technology and the report has been improved based on the comments received.

The next version of the report is tentatively scheduled for 2021.

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 in which the products of combustion are used for the direct heating, drying, or any other treatment of objects or materials – in other words to say 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*: carbon dioxide (CO_2), nitrous oxide (N_2O), hydroflourocarbons (HFCs), perflourocarbons (PFCs), sulphur hexafluoride (SF_6), methane (CH_4), sulphur dioxide (SO_2), nitrogen oxides (NO_x), non-volatile organic compounds (NMVOC), carbon monoxide (CO), particulate matter (PM), ammonia (NH_3), heavy metals (HMs), polyclorinated dibenzodioxins and –furans (PCDD / F), polycyclic aromatic hydrocarbons (PAHs), hexachlorobenzene (HCB) and polychlorinated biphenyls (PCBs). In addition to annual national emissions, the report includes emission data for a number of source categories. Every four years the reporting includes data on the geographical distribution of the emissions, a projection of emissions, data and data for large point sources. The next due date is 1 May 2021.

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 or on international guidance documents, e.g. EMEP / EEA Guidebook and IPCC Guideline (EMEP / EEA, 2016 and IPCC, 2006). The majority of the country-specific emission factors are determined from data given in Danish research reports or calculated from plant-specific emission data reported by individual plants. 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 2016. 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* (2016).

Process	IPCC Code	Substance	Emission, Gg CO_2e	%
Cement production	2A1	CO_2	1,095.5	52
Refrigeration and air conditioning	2F1	HFCs, PFCs	583.7	27
SF_6 from other product use	2G2	SF_6	78.4	4
Other uses of carbonates	2A4	CO_2	70.8	3
Other non-energy products from fuels and solvent use	2D3	CO_2, CH_4	66.9	3
Paraffin wax use	2D2	CO_2, CH_4, N_2O	66.1	3
Lime production	2A2	CO_2	55.4	3
Lubricant use	2D1	CO_2	31.7	1.5
Aerosols/Metered dose inhalers	2F4	HFCs	17.0	0.8
N_2O from product uses	2G3	N_2O	16.1	0.8
Foam blowing agents	2F2	HFCs	13.9	0.7
Electrical equipment	2G1	SF_6	13.4	0.6
Glass production	2A3	CO_2	9.0	0.4
Other product use	2G4	CO_2, CH_4, N_2O	4.8	0.2
Catalysts/fertilisers	2B10	CO_2	1.4	0.1
Lead production	2C5	CO_2	0.1	0.0
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			2,124.2	100

NO: Not occurring.

In 2016, the subsector *Mineral industry* (2A) constitutes 58 % and *Product uses as substitutes for ozone depleting substances* (ODS) (2F) constitutes 29 % 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 8 % and 5 % 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 2016. 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 (excl. emissions / removals from *Land-use, land-use change and forestry* (LULUCF)) in Denmark in 2016 is estimated to 55,546 Gg CO_2 equivalents (CO_2e), of which IPPU contributes with 2,124 Gg

CO_2e (3.8 %). The emission of greenhouse gases from IPPU from 1990-2016 is presented in Figure 0.1.

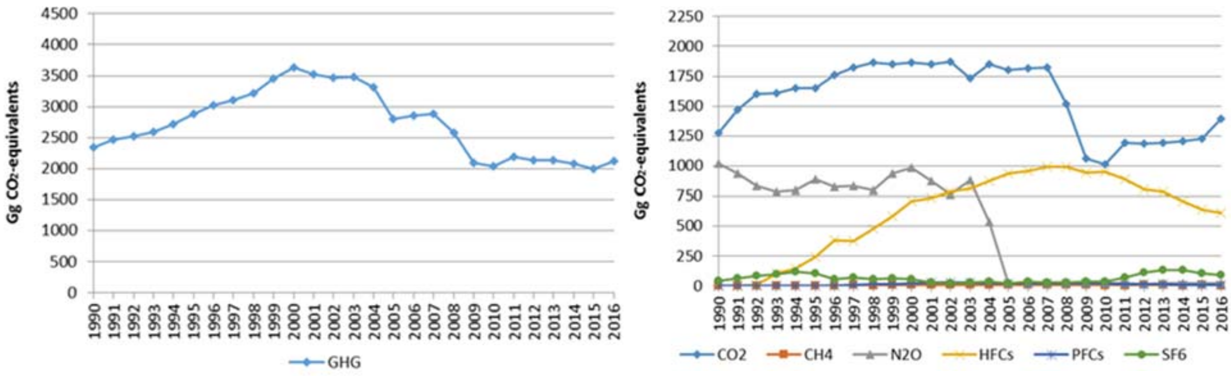


Figure 0.1 Emission of greenhouse gases from *Industrial processes and product use* (CRF Sector 2) from 1990-2016.

The key categories for level of emissions in the IPPU sector in 2016 are *Cement production* and *Refrigeration and air conditioning* - constituting 2.0 % and 1.1 % respectively of the total national emission of greenhouse gases (Nielsen et al., 2018a). For 1990, the key categories for level of emissions are *Cement production* and *Nitric acid production* – 1.2 % and 1.4 % respectively. 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 1990-2016.

Year	1990	1995	2000	2005	2010	2015	2016
CO_2 (Gg CO_2)							
A. Mineral Industry	1,081.8	1,422.3	1,632.7	1,567.0	806.4	1,052.2	1,230.7
B. Chemical Industry	0.6	0.7	0.9	1.1	1.1	1.5	1.4
C. Metal Industry	30.5	38.7	40.9	16.4	0.2	0.2	0.1
D. Non-energy products from fuels and solvent use	165.5	184.7	190.0	214.5	201.0	172.9	164.0
G. Other Product Manufacture and Use	0.1	0.1	0.2	0.2	0.2	0.2	0.2
Total	1,278.4	1,646.6	1,864.7	1,799.1	1,009.0	1,227.1	1,396.5
CH_4 (Gg CO_2e)							
D. Non-energy products from fuels and solvent use	0.3	0.4	0.4	0.5	0.4	0.5	0.5
G. Other Product Manufacture and Use	2.1	2.2	3.0	3.1	2.0	3.3	1.8
Total	2.4	2.5	3.4	3.6	2.5	3.7	2.2
N_2O (Gg CO_2e)							
B. Chemical Industry	1,002.5	868.9	964.7	NO	NO	NO	NO
D. Non-energy products from fuels and solvent use	0.1	0.1	0.1	0.2	0.3	0.2	0.2
G. Other Product Manufacture and Use	17.9	20.2	20.3	19.0	18.7	19.7	18.9
Total	1,020.5	889.2	985.1	19.3	18.9	19.9	19.1
HFCs (Gg CO_2e)							
E. Electronics Industry	NO	NO	NO	NO	5.3	NO	NO
F. Product Uses as Substitutes for Ozone Depleting Substances	NO	241.7	704.4	933.2	946.1	639.2	610.6
Total	NO	241.7	704.4	933.2	951.4	639.2	610.6
PFCs (Gg CO_2e)							
E. Electronics Industry	NO	NO	NO	NO	7.3	NO	NO
F. Product Uses as Substitutes for Ozone Depleting Substances	NO	0.6	22.6	18.8	11.4	4.9	4.0
Total	NO	0.6	22.6	18.8	18.7	4.9	4.0
SF_6 (Gg CO_2e)							
C. Metal Industry	29.6	34.2	20.3	NO	NO	NO	NO
G. Other Product Manufacture and Use	12.8	68.2	35.8	19.9	35.8	103.1	91.8
Total	42.4	102.4	56.1	19.9	35.8	103.1	91.8

NO: Not occurring.

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.

The emission of F-gases is documented in the annual report “Danish consumption and emission of F-gases” (Poulsen, 2018) 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* (IPCC / CRF 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	2016
SO_2	Gg	2A6 Other mineral products	2.90	3.09	3.01	2.96	1.43	0.93	1.17
		2B10a Other chemical industry	1.07	1.01	0.62	0.62	0.12	0.16	0.04
		2C1 Iron and steel production	0.04	0.04	0.04	0.02	NE	NE	NE
		2G4 Other product use	0.03	0.04	0.06	0.06	0.04	0.07	0.03
		Total	4.04	4.18	3.73	3.65	1.59	1.15	1.24
NO_x	Gg	2B Chemical industry	0.84	0.65	0.45	0.04	0.02	0.02	0.02
		2C1 Iron and steel production	0.08	0.09	0.08	0.03	NE	NE	NE
		2G4 Other product use	0.05	0.05	0.06	0.06	0.04	0.07	0.04
		Total	0.96	0.79	0.59	0.13	0.06	0.09	0.06
NMVOC	Gg	2A Mineral industry	0.08	0.08	0.09	0.08	0.06	0.06	0.07
		2B10a Other chemical industry	0.47	0.15	0.09	0.04	0.03	0.05	0.04
		2C1 Iron and steel production	0.03	0.03	0.03	0.01	0.004	0.004	0.004
		2D3b,c Use of asphalt products	0.05	0.06	0.06	0.07	0.05	0.06	0.06
		2D3d,e Coating applications and degreasing	4.96	5.75	6.25	4.17	2.60	2.61	2.56
		2D3g Chemical products	8.14	9.32	6.96	6.25	5.04	4.74	4.35
		2D3i Other solvent use	25.31	30.57	28.37	21.39	20.03	19.41	18.36
		2G4 Other product use	0.08	0.08	0.09	0.09	0.07	0.09	0.06
		2H2 Food and beverages industry	3.31	3.36	3.08	3.07	2.78	2.50	2.44
		Total	42.43	49.39	45.02	35.19	30.66	29.52	27.94
CO	Gg	2A Mineral industry	11.38	11.32	11.43	12.52	0.01	0.02	0.02
		2C1 Iron and steel production	0.001	0.001	0.001	0.0004	NE	NE	NE
		2D Non-energy products and solvent use	0.38	0.47	0.52	0.81	0.71	0.66	0.66
		2G4 Other product use	2.21	2.30	3.42	3.68	2.18	4.01	1.97
		Total	13.98	14.09	15.38	17.02	2.91	4.69	2.66
NH_3	Gg	2A3 Glass production	0.27	0.27	0.23	0.12	0.11	0.15	0.08
		2A6 Other mineral products	0.28	0.28	0.28	0.35	0.20	0.24	0.17
		2B Chemical industry	0.03	0.08	0.03	0.08	0.12	0.02	0.02
		2G4 Other product use	0.06	0.05	0.05	0.04	0.04	0.03	0.03
		2L Other production	0.04	0.05	0.05	0.05	0.04	0.03	0.03
		Total	0.68	0.74	0.63	0.64	0.51	0.47	0.33
$PM_{2.5}$	Mg	2A Mineral industry	0.44	0.46	0.52	0.54	0.37	0.39	0.41
		2B Chemical industry	0.39	0.34	0.38	0.017	0.020	0.004	0.008
		2C Metal industry	0.06	0.07	0.03	0.02	0.01	0.01	0.01
		2D Non-energy products and solvent use	0.03	0.03	0.04	0.07	0.07	0.06	0.05
		2G4 Other product use	0.23	0.24	0.29	0.26	0.26	0.27	0.21
		2H2 Food and beverages industry	0.02	0.02	0.02	0.02	0.01	0.02	0.02
		2I Wood processing	0.07	0.09	0.10	0.07	0.09	0.09	0.09
		Total	1.25	1.26	1.39	1.01	0.83	0.84	0.81

NE: Not estimated.

The emissions of heavy metals (arsenic (As), chromium (Cr), mercury (Hg), lead (Pb) and zinc (Zn)) and persistent organic pollutants (dioxins/furans (PCDD/F)) are shown in Table 0.4 and Annex 0-3 (also includes Cd, Cu, Ni, Se, 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	2016
As	Mg	2A3 Glass production	0.048	0.041	0.053	0.049	0.005	0.005	0.005
		2C Metal industry	0.043	0.044	0.045	0.039	0.029	0.032	0.032
		2G4 Other product use	0.004	0.007	0.010	0.008	0.009	0.011	0.008
		Total	0.10	0.09	0.11	0.10	0.04	0.05	0.04
Cr	Mg	2A3 Glass production	0.06	0.05	0.07	0.06	0.01	0.01	0.01
		2C1 Iron and steel production	0.17	0.17	0.17	0.13	0.09	0.10	0.10
		2G4 Other product use	0.02	0.05	0.08	0.06	0.09	0.09	0.07
		Total	0.25	0.27	0.32	0.25	0.18	0.19	0.18
Hg	Mg	2B10a Other chemical industry	0.012	0.016	0.013	0.011	0.001	0.001	0.013
		2C Metal industry	0.251	0.147	0.068	0.018	0.004	0.004	0.004
		2G4 Other product use	0.001	0.001	0.001	0.001	0.001	0.001	0.001
		Total	0.26	0.16	0.08	0.03	0.01	0.01	0.02
Pb	Mg	2A3 Glass production	0.48	0.41	0.33	0.15	0.02	0.05	0.05
		2C1 Iron and steel production	3.28	2.02	0.99	0.59	0.26	0.29	0.30
		2C3 Aluminium production	0.005	0.005	0.005	0.004	NE	NE	NE
		2C5 Lead production	0.34	0.43	0.34	0.40	0.38	0.42	0.31
		2C7c Other metal production	0.058	0.067	0.065	0.082	0.069	0.058	0.060
		2G4 Other product use	2.85	6.64	3.30	2.53	0.04	0.08	0.04
		Total	7.01	9.56	5.03	3.75	0.77	0.90	0.75
Zn	Mg	2A3 Glass production	0.038	0.032	0.057	0.039	0.004	0.004	0.004
		2C1 Iron and steel production	12.02	7.05	3.62	1.44	0.43	0.48	0.50
		2C5 Lead production	0.002	0.003	0.002	0.002	0.002	0.003	0.002
		2C7c Other Metal production	0.55	0.63	0.60	0.77	0.65	0.54	0.56
		2G4 Other product use	0.37	0.81	1.31	1.00	1.44	1.55	1.20
		Total	12.97	8.53	5.59	3.25	2.53	2.57	2.26
PCDD/F	g	2A2 Lime production	0.002	0.002	0.002	0.001	0.001	0.001	0.001
		2A6 Other mineral products	0.086	0.089	0.089	0.082	0.062	0.054	0.072
		2C1 Iron and steel production	12.00	7.50	0.52	0.75	NE	NE	NE
		2C3 Aluminium production	1.06	1.06	1.15	0.82	NO	NO	NO
		2C5 Lead production	0.006	0.008	0.006	0.008	0.007	0.008	0.006
		2D3h Paraffin wax use	0.0002	0.0002	0.0005	0.0009	0.0009	0.0007	0.0006
		2G4 Other product use	0.077	0.084	0.141	0.158	0.083	0.182	0.079
		Total	13.23	8.74	1.91	1.82	0.15	0.25	0.16

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 metal (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 difust 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 forbrændingsprodukterne anvendes til direkte opvarmning, tørring eller enhver anden behandling af genstande eller materialer - med andre ord i tilfælde 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*: kuldioxid (CO_2), lattergas (N_2O), hydroflourkarboner (HFC), perflourkarboner (PFC'er), svovlhexafluorid (SF_6), metan (CH_4), svovldioxid (SO_2), kvælstofoxider (NO_x), andre flygtige organiske forbindelser end metan (NMVOC), kulmonooxid (CO), partikler (PM), ammoniak (NH_3), tungmetaller (HM'er), dioxiner og furaner (PCDD/F), polycykliske aromatiske kulbrinter (PAH'er), hexachlorbenzen (HCB) and polychlorerede biphenyler (PCB'er). Ud over de årlige nationale emissioner indeholder opgørelsen også emissions data for en række kilde kategorier. Hvert fjerde år inkluderer opgørelsen desuden data for den geografiske fordeling af emissioner, en fremskrivning af emissioner, og punktkildedata. Den næste afrapporteringsdato for dette er d. 1. maj 2021.

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 product anvendelser* 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 / målinger eller henviser til internationale retningslinjer, f.eks. EMEP / EEA Guidebook og IPCC Guidelines (EMEP / EEA, 2016 og IPCC, 2006). 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 produkt anvendelse* i 2016. Emissionerne er ekstraheret fra CRF tabellerne (Common Reporting Format).

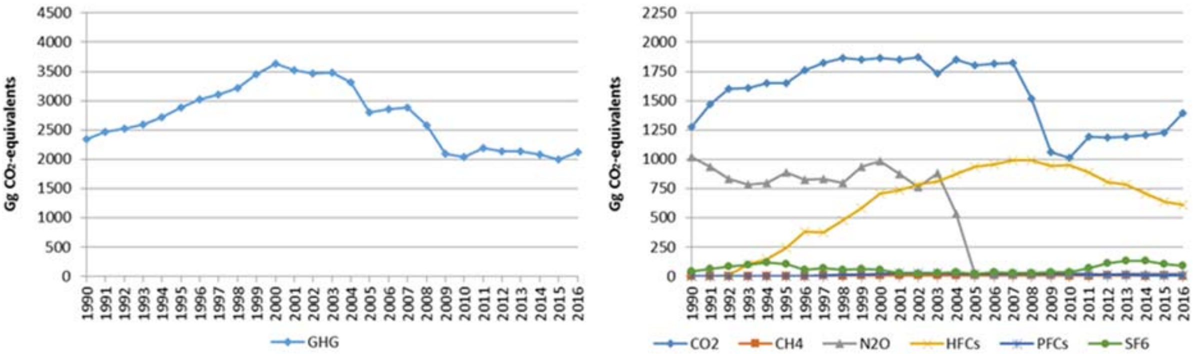
Tabel 0.1 Oversigt over drivhusgas emissionskilder for *Industrielle processer og produkt anvendelse* (2016).

Proces	IPCC kode	Stof	Emission, Gg CO_2e	%
Cement produktion	2A1	CO_2	1.095,5	52
Køling og aircondition	2F1	HFCs, PFCs	583,7	27
SF_6 fra andre produkt anvendelser	2G2	SF_6	78,4	4
Andre anvendelser for karbonater	2A4	CO_2	70,8	3
Andre ikke-energi produkter fra brændsler og opløsningsmidler	2D3	CO_2, CH_4	66,9	3
Paraffinvoks anvendelse	2D2	CO_2, CH_4, N_2O	66,1	3
Produktion af brændt kalk	2A2	CO_2	55,4	3
Brug af smøreolier	2D1	CO_2	31,7	1,5
Aerosoler/Dosisinhalatorer	2F4	HFCs	17,0	0,8
N_2O fra andre produkt anvendelser	2G3	N_2O	16,1	0,8
Opskumning	2F2	HFCs	13,9	0,7
Elektrisk udstyr	2G1	SF_6	13,4	0,6
Glasproduktion	2A3	CO_2	9,0	0,4
Øvrige produktanvendelser	2G4	CO_2, CH_4, N_2O	4,8	0,2
Produktion af katalysatorer/gødning	2B10	CO_2	1,4	0,1
Blyproduktion	2C5	CO_2	0,1	0,0
Salpetersyreproduktion	2B2	N_2O	NO	NO
Jern- og stålproduktion	2C1	CO_2	NO	NO
Øvrige (fiberoptik)	2E5	PFCs	NO	NO
Total			2.124,2	100

NO: Forekommer ikke.

Samlet udgør undersektoren *Mineralsk industri* (2A) (cement, tegl, kalk, glas, mv.) 58 % af drivhusgasemissionen i 2016 fra *Industrielle processer og produktanvendelse. Produktanvendelser som erstatning for ozonlagsnedbrydende stoffer* (2F) udgør 29 %, *Ikke-energi produkter fra brændsler og opløsningsmidler* (2D) udgør 8 % og *Andre produkters produktion og anvendelse* (2G) udgør 5 %. 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 2016. 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 totale drivhusgasemission eksklusive emissioner / optag fra arealanvendelse (LULUCF) i 2016 er beregnet til 55.546 Gg CO_2 ækvivalenter, hvoraf *Industrielle processer og produktanvendelse* bidrager med 2.124 Gg CO_2e svarende til 3,8 %. Drivhusgasemissionen fra IPPU for 1990-2016 er præsenteret i Figur 0.1.



Figur 0.1 Emission af drivhusgasser fra *Industrielle processer of produkt anvendelser* (CRF Sektor 2) for 1990-2016.

De vigtigste kategorier inden for *Industrielle processer og produktanvendelse* i 2016 er cementproduktion samt F-gasser anvendt til køling og aircondition. Disse to kilder udgør henholdsvis 2,0 % og 1,1 % af den samlede danske drivhusgasemission. 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 *Industrieller processer og produkt anvendelse* for 1990-2016.

Year	1990	1995	2000	2005	2010	2015	2016
CO_2 (Gg CO_2)							
A. Mineralsk industri	1.081,8	1.422,3	1.632,7	1.567,0	806,4	1.052,2	1.230,7
B. Kemisk industri	0,6	0,7	0,9	1,1	1,1	1,5	1,4
C. Metal industri	30,5	38,7	40,9	16,4	0,2	0,2	0,1
D. Ikke-energi produkter fra brændsler og opløsningsmidler	165,5	184,7	190,0	214,5	201,0	172,9	164,0
G. Øvrige produkters produktion og anvendelse	0,1	0,1	0,2	0,2	0,2	0,2	0,2
Total	1.278,4	1.646,6	1.864,7	1.799,1	1.009,0	1.227,1	1.396,5
CH_4 (Gg CO_2e)							
D. Ikke-energi produkter fra brændsler og opløsningsmidler	0,3	0,4	0,4	0,5	0,4	0,5	0,5
G. Øvrige produkters produktion og anvendelse	2,1	2,2	3,0	3,1	2,0	3,3	1,8
Total	2,4	2,5	3,4	3,6	2,5	3,7	2,2
N_2O (Gg CO_2e)							
B. Kemisk industri	1.002,5	868,9	964,7	NO	NO	NO	NO
D. Ikke-energi produkter fra brændsler og opløsningsmidler	0,1	0,1	0,1	0,2	0,3	0,2	0,2
G. Øvrige produkters produktion og anvendelse	17,9	20,2	20,3	19,0	18,7	19,7	18,9
Total	1.020,5	889,2	985,1	19,3	18,9	19,9	19,1
HFCs (Gg CO_2e)							
E. Elektronik industri	NO	NO	NO	NO	5,3	NO	NO
F. Produktanvendelse som erstatning for ozonnedbrydende stoffer	NO	241,7	704,4	933,2	946,1	639,2	610,6
Total	NO	241,7	704,4	933,2	951,4	639,2	610,6
PFCs (Gg CO_2e)							
E. Elektronik industri	NO	NO	NO	NO	7,3	NO	NO
F. Produktanvendelse som erstatning for ozonnedbrydende stoffer	NO	0,6	22,6	18,8	11,4	4,9	4,0
Total	NO	0,6	22,6	18,8	18,7	4,9	4,0
SF_6 (Gg CO_2e)							
C. Metal industri	29,6	34,2	20,3	NO	NO	NO	NO
G. Øvrige produkters produktion og anvendelse	12,8	68,2	35,8	19,9	35,8	103,1	91,8
Total	42,4	102,4	56,1	19,9	35,8	103,1	91,8

NO: Forekommer ikke.

Emissionerne af F-gasser er dokumenteret i den årligt udgivne rapport "Danish consumption and emission of F-gases" (Poulsen, 2018) 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, CO og NH_3) og $PM_{2.5}$ (partikler med en diameter under 2.5 µm) er præsenteret i Tabel 0.3 og Bilag 0-2 (inkluderer også black carbon (BC)).

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

Stof	Enhed	Sektor	1990	1995	2000	2005	2010	2015	2016
SO_2	Gg	2A6 Øvrige mineralske produkter	2,90	3,09	3,01	2,96	1,43	0,93	1,17
		2B10a Anden kemisk industri	1,07	1,01	0,62	0,62	0,12	0,16	0,04
		2C1 Jern- og stålproduktion	0,04	0,04	0,04	0,02	NE	NE	NE
		2G4 Øvrige produkt anvendelser	0,03	0,04	0,06	0,06	0,04	0,07	0,03
		Total	4,04	4,18	3,73	3,65	1,59	1,15	1,24
NO_x	Gg	2B Kemisk industri	0,84	0,65	0,45	0,04	0,02	0,02	0,02
		2C1 Jern- og stål produktion	0,08	0,09	0,08	0,03	NE	NE	NE
		2G4 Øvrige produktanvendelser	0,05	0,05	0,06	0,06	0,04	0,07	0,04
		Total	0,96	0,79	0,59	0,13	0,06	0,09	0,06
NMVOC	Gg	2A Mineralsk industri	0,08	0,08	0,09	0,08	0,06	0,06	0,07
		2B10a Anden kemisk industri	0,47	0,15	0,09	0,04	0,03	0,05	0,04
		2C1 Jern- og stålproduktion	0,03	0,03	0,03	0,01	0,004	0,004	0,004
		2D3b,c Anvendelse af asfalt produkter	0,05	0,06	0,06	0,07	0,05	0,06	0,06
		2D3d,e Overfladebehandling og affedtning	4,96	5,75	6,25	4,17	2,60	2,61	2,56
		2D3g Kemiske produkter	8,14	9,32	6,96	6,25	5,04	4,74	4,35
		2D3i Øvrig anvendelse af opløsningsmidler	25,31	30,57	28,37	21,39	20,03	19,41	18,36
		2G4 Øvrige produktanvendelser	0,08	0,08	0,09	0,09	0,07	0,09	0,06
		2H2 Fødevareproduktion	3,31	3,36	3,08	3,07	2,78	2,50	2,44
		Total	42,43	49,39	45,02	35,19	30,66	29,52	27,94
CO	Gg	2A Mineralsk industry	11,38	11,32	11,43	12,52	0,01	0,02	0,02
		2C1 Jern- og stålproduktion	0,001	0,001	0,001	0,0004	NE	NE	NE
		2D Ikke-energi produkter og anvendelse af opløsningsmidler	0,38	0,47	0,52	0,81	0,71	0,66	0,66
		2G4 Øvrige produktanvendelser	2,21	2,30	3,42	3,68	2,18	4,01	1,97
		Total	13,98	14,09	15,38	17,02	2,91	4,69	2,66
NH_3	Gg	2A3 Glasproduktion	0,27	0,27	0,23	0,12	0,11	0,15	0,08
		2A6 Øvrige mineralske produkter	0,28	0,28	0,28	0,35	0,20	0,24	0,17
		2B Kemisk industri	0,03	0,08	0,03	0,08	0,12	0,02	0,02
		2G4 Øvrige produktanvendelser	0,06	0,05	0,05	0,04	0,04	0,03	0,03
		2L Øvrig produktion	0,04	0,05	0,05	0,05	0,04	0,03	0,03
		Total	0,68	0,74	0,63	0,64	0,51	0,47	0,33
$PM_{2.5}$	Mg	2A Mineralsk industri	0,44	0,46	0,52	0,54	0,37	0,39	0,41
		2B Kemisk industri	0,39	0,34	0,38	0,017	0,020	0,004	0,008
		2C Metal industri	0,06	0,07	0,03	0,02	0,01	0,01	0,01
		2D Ikke-energi produkter og solvent anvendelse	0,03	0,03	0,04	0,07	0,07	0,06	0,05
		2G4 Øvrige produktanvendelser	0,23	0,24	0,29	0,26	0,26	0,27	0,21
		2H2 Fødevareproduktion	0,02	0,02	0,02	0,02	0,01	0,02	0,02
		2I Forarbejdning af træ	0,07	0,09	0,10	0,07	0,09	0,09	0,09
		Total	1,25	1,26	1,39	1,01	0,83	0,84	0,81

NE: Ikke estimeret.

Produktion af salpetersyre stoppede i Danmark i 2005, hvilket betød en betydelig reduktion af emissioner af NO_x og partikler fra *Industrielle processer og produktanvendelse*. CO-emissionen er reduceret betydeligt fra kategorien *Øvrige mineralske produkter*. Reduktionen stammer fra et fald i emissionen fra *Produktion af stenuld*, som skyldes installationen af røggasrensnings udstyr i 2009-2010. Emissionen af SO_2 er i de senere år faldet på grund af en lavere produktion af mursten, tegl og ekspanderede lerprodukter (inkluderet i *Øvrige mineralske produkter* (IPCC / CRF kode 2A6).

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

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

Stof		Sektor	1990	1995	2000	2005	2010	2015	2016
As	Mg	2A3 Glasproduktion	0,048	0,041	0,053	0,049	0,005	0,005	0,005
		2C Metalsk industri	0,043	0,044	0,045	0,039	0,029	0,032	0,032
		2G4 Øvrige produkt anvendelser	0,004	0,007	0,010	0,008	0,009	0,011	0,008
		Total	0,10	0,09	0,11	0,10	0,04	0,05	0,04
Cr	Mg	2A3 Glas produktion	0,06	0,05	0,07	0,06	0,01	0,01	0,01
		2C1 Jern- og stålproduktion	0,17	0,17	0,17	0,13	0,09	0,10	0,10
		2G4 Øvrige produktanvendelser	0,02	0,05	0,08	0,06	0,09	0,09	0,07
		Total	0,25	0,27	0,32	0,25	0,18	0,19	0,18
Hg	Mg	2B10a Anden kemisk industri	0,012	0,016	0,013	0,011	0,001	0,001	0,013
		2C Metal industri	0,251	0,147	0,068	0,018	0,004	0,004	0,004
		2G4 Øvrige produktanvendelser	0,001	0,001	0,001	0,001	0,001	0,001	0,001
		Total	0,26	0,16	0,08	0,03	0,01	0,01	0,02
Pb	Mg	2A3 Glasproduktion	0,48	0,41	0,33	0,15	0,02	0,05	0,05
		2C1 Jern- og stålproduktion	3,28	2,02	0,99	0,59	0,26	0,29	0,30
		2C3 Aluminiumproduktion	0,005	0,005	0,005	0,004	NE	NE	NE
		2C5 Blyproduktion	0,34	0,43	0,34	0,40	0,38	0,42	0,31
		2C7c Anden metalproduktion	0,058	0,067	0,065	0,082	0,069	0,058	0,060
		2G4 Øvrige produktanvendelser	2,85	6,64	3,30	2,53	0,04	0,08	0,04
		Total	7,01	9,56	5,03	3,75	0,77	0,90	0,75
Zn	Mg	2A3 Glasproduktion	0,038	0,032	0,057	0,039	0,004	0,004	0,004
		2C1 Jern- og stålproduktion	12,02	7,05	3,62	1,44	0,43	0,48	0,50
		2C5 Blyproduktion	0,002	0,003	0,002	0,002	0,002	0,003	0,002
		2C7c Anden metalproduktion	0,55	0,63	0,60	0,77	0,65	0,54	0,56
		2G4 Øvrige produktanvendelser	0,37	0,81	1,31	1,00	1,44	1,55	1,20
		Total	12,97	8,53	5,59	3,25	2,53	2,57	2,26
PCDD/F	g	2A2 Produktion af brændt kalk	0,002	0,002	0,002	0,001	0,001	0,001	0,001
		2A6 Øvrige mineralske produkter	0,086	0,089	0,089	0,082	0,062	0,054	0,072
		2C1 Jern- og stålproduktion	12,00	7,50	0,52	0,75	NE	NE	NE
		2C3 Aluminiumproduktion	1,06	1,06	1,15	0,82	NO	NO	NO
		2C5 Blyproduktion	0,006	0,008	0,006	0,008	0,007	0,008	0,006
		2D3h Paraffinvoksforbrug	0,0002	0,0002	0,0005	0,0009	0,0009	0,0007	0,0006
		2G4 Øvrige produktanvendelser	0,077	0,084	0,141	0,158	0,083	0,182	0,079
		Total	13,23	8,74	1,91	1,82	0,15	0,25	0,16

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 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, herunder anlæg hvor forbrændingsprodukterne anvendes til direkte opvarmning, tørring eller enhver anden behandling af genstande eller materialer - med andre ord i tilfælde hvor der er kontakt mellem brændsel og råmateriale under processen.

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*: carbon dioxide (CO_2), nitrous oxide (N_2O), methane (CH_4), hydrofluorocarbons (HFCs), perfluorocarbons (PFCs), sulphur hexafluoride (SF_6), sulphur dioxide (SO_2), nitrogen oxides (NO_x), non-volatile organic compounds (NMVOC), carbon monoxide (CO), particulate matter (PM), ammonia (NH_3), heavy metals (HMs), polyclorinated dibenzodioxins and –furans (PCDD / F), polycyclic aromatic hydrocarbons (PAHs), 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 will fall outside the scope of the emission inventories and therefore not be 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
- Serve as the basis for QA of the sector through independent review

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 actual 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 introducing relevant emission estimates for the years in question.

Table 1.0.1 Base year for different pollutants.

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

[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. 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

The consumption of halocarbons and SF_6 (F-gases) is documented in a separate report (Poulsen, 2018) and is therefore only presented and briefly discussed in this report.

All annexes referenced in this report are available only online, please see http://envs.au.dk/videnudveksling/luft/emissioner/reportingsectors/industrialprocesses/

2. Methodology and data sources

The methodologies applied for the inventory of process and product use related emissions are:

- EMEP/EEA guidebooks (EMEP/EEA, 2013 and 2016)
- IPCC guidelines (IPCC, 2006 and 2013)

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 Co-ordinated 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, 2010). 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 the emission of NO_x, SO_2 and TSP. For other pollutants, the information is scarcer.

2.2 EMEP/EEA guidebook

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

- 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

[1] https://miljoeoplysninger.mst.dk/

- 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 2013 (EMEP/EEA, 2013)
- EMEP/EEA air pollutant emission inventory guidebook 2016 (EMEP/EEA, 2016)

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, 2013)

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 yearly. 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 and reporting company specific CO_2 emissions under the EU-ETS have been decided by the EU (EU, 2012). 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 per Mg ratio 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 glyoxilic 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 2009/29/EC).

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 Mg 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 Mg per day or in other furnaces with a production capacity exceeding 50 Mg 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 Mg per day	CO_2	X
Manufacture of glass including glass fibre with a melting capacity exceeding 20 Mg 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 Mg per day	CO_2	X
Manufacture of mineral wool insulation material using glass, rock or slag with a melting capacity exceeding 20 Mg 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 Mg 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 Mg per day	CO_2	
Production of hydrogen (H_2) and synthesis gas by reforming or partial oxidation with a production capacity exceeding 25 Mg 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 2009/31/EC	CO_2	
Transport of greenhouse gases by pipelines for geological storage in a storage site permitted under Directive 2009/31/EC	CO_2	
Geological storage of greenhouse gases in a storage site permitted under Directive 2009/31/EC	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 included in the inventory. 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 considered 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 2016.

Plant	Plant type
Shell Raffinaderiet Fredericia	Refining of mineral oil
Aalborg Portland A/S	Production of cement clinker
Grenå Kraftvarmeværk	Combustion installation
Avedøreværket	Combustion installation
Asnæsværket	Combustion installation
Sønderborg Kraftvarme I/S	Combustion installation
Vattenfall A/S Amagerværket	Combustion installation
Fynsværket	Combustion installation
Studstrupværket	Combustion installation
Vattenfall A/S Nordjyllandsværket	Combustion installation
Nordic Sugar, Nakskov Sukkerfabrik	Combustion installation
I/S Vestforbrænding	Combustion installation
I/S Norfors	Combustion installation
I/S Reno Syd	Combustion installation
Esbjergværket	Combustion installation
Carl Matzens Teglværk A/S	Manufacture of ceramic products
Damolin Fur A/S	Manufacture of ceramic products
Damolin Mors A/S	Manufacture of ceramic products
Saint-Gobain Weber, Leca, Hinge	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, Egernsund Broager	Manufacture of ceramic products
Wienerberger A/S - Petersminde Teglværk	Manufacture of ceramic products

Plant	Plant type
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
Vedstaarup Teglværk 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 2013-2020. 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* and *Stone wool production*, the time series consistency remains a challenge and emission data have been estimated and validated as best possible.

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

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

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.

2.6 Methodological tiers

In the international agreed guidelines for compiling emission inventories, the methodological guidance is provided for different methodological tiers. Tier 1 will be 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 requires more detailed data. Under the EU ETS, the methodological requirements are also divided into tiers based on the plants 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.

3. Mineral industry

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

- Cement production; see section 3.2
- Lime production; see section 3.3
- Glass production; see section 3.4
- Ceramics; see section 3.5
- Other uses of soda ash; see section 3.6
- Flue gas desulphurisation; see section 3.7
- Stone wool production; see section 3.8
- Quarrying and mining of minerals other than coal; see section 3.9
- Construction and demolition; see section 3.10
- Storage, handling and transport of mineral products; see section 3.11

3.1 Greenhouse gas emissions

The emission time series for the greenhouse gas emissions (only CO_2 is relevant) from the individual source categories in *Mineral industry* are presented in Figure 3.1.1, for background data see Annex 1-1. The figure shows that cement production is by far the largest contributor to CO_2 emissions within the mineral industries and that emissions were strongly influenced by the financial crisis in 2007-2009.

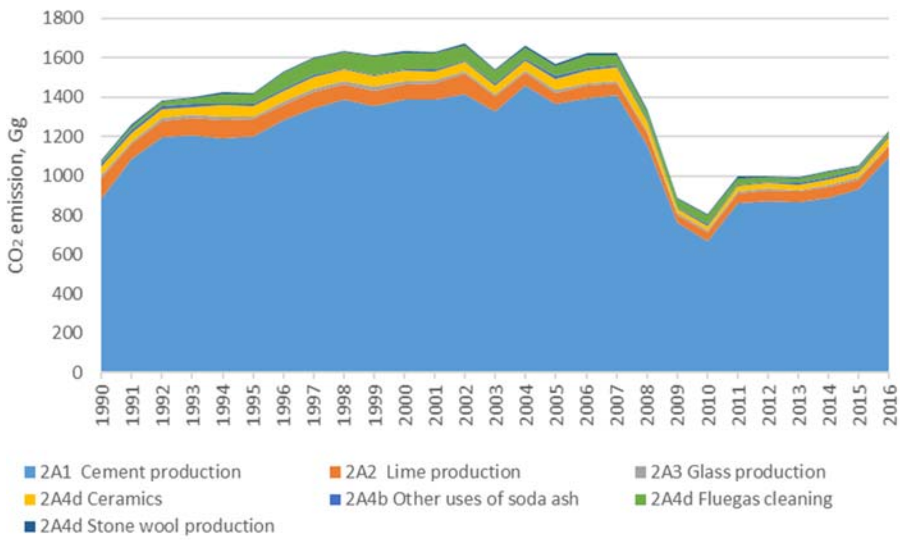


Figure 3.1.1 Emission of CO_2 from the individual source categories compiling *2A Mineral Industry*, Gg.

Greenhouse gas emissions from *Mineral industry* consist mainly of CO_2 emissions from the production of cement; min. 82 % (1990) to max. 89 % (2016).

Emissions from *Mineral industry* increased with 54 % from 1990 to the time series peak in 2002 (1670 Gg). The overall development in the CO_2 emission for 1990 to 2016 shows an increase from 1082 Gg to 1231 Gg CO_2, i.e. by 14 %.

The increase from 1990 to 2002 can be explained by the increase in the annual cement production. The emission factor has only changed slightly as the distribution between types of cement especially grey/white cement has been almost constant throughout the 1990s. The decrease in 2007-2010 may be explained by the decrease in the construction activity due to the global financial crisis. Since 2010, the emissions have slowly increased as the cement plant has increased production.

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:

- 03 03 11 Cement
- 04 06 12 Cement (decarbonising)

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

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 belt 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 grounded to cement in the cement mill. During the process, cement kiln dust is recirculated.

Production of cement is a very 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, asphalt, residue from production of vitamins, sewage sludge, and “CemMiljø fuel”[3]). The company focuses on alternative fuels in order to reduce cost as well as environmental effects (i.e. CO_2 originating from fossil sources). The emissions that are related to combustion are not included in this report.

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.

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

At the same time, the company has stated that data until 1997 cannot be improved as there is no further information available (Aalborg Portland, 2005).

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

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.

1998-2004

From 1998-2004, 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 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).

2005-2016

From the year 2005, the CO_2 emission determined by Aalborg Portland independently verified and reported under the EU-ETS is used in the inventory (Aalborg Portland, 2017a). 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 2017a).

Fuel type	Biomass fraction, %
Cemmiljø fuel	30-56
Paper residues	79
Dry wastewater sludge	100
Meat and bone meal	100
Tyre residues	15
Plastic pellet	64

The information on fuels is used in the compilation of the emission inventory for the fuel combustion part (Nielsen et al., 2018c)

Activity data

Production statistics for cement (measured in Total Cement Equivalents (TCE)) and clinker production are presented in Table 3.2.2 and Annex 2-1. 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. 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 production (Aalborg Portland 2017a, b and Aalborg Portland, 2008).

	1990	1995	2000	2005	2010	2015	2016
Gg TCE	1620.0	2273.8	2612.7	2706.4	1454.0	1902.1	2202.5
Gg clinker[1]	1406.2	2353.1	2452.4	2520.8	1313.7	1714.8	1972.7

[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 the TCE and clinker production are presented in Table 3.2.3 and Annex 2-2.

Table 3.2.3 Implied emission factors for CO_2 for cement production.

	1990	1995	2000	2005	2010	2015	2016
IEF Mg CO_2 per Mg TCE[1,2,3]	0.545	0.529	0.530	0.504	0.462	0.490	0.497
IEF Mg CO_2 per Mg clinker[3,4]	0.628	0.512	0.565	0.541	0.512	0.543	0.555

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

[2] 1998-2004: IEF based on information provided by Aalborg Portland (2008).

[3] 2005-2016: IEF based on emissions reported to EU-ETS (Aalborg Portland, 2017a).

[4] 1998-2016: IEF based on clinker production statistics provided by Aalborg Portland (2017b).

The IEF for CO_2 from the calcination process is expressed per Mg 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. When the implied CO_2 emission factor in 1990 is markedly higher than for the remaining time series it is because the production of white cement was higher in 1990 than for the following years, leading the ratio white / grey cement to be higher for 1990. The share of white cement decreases significantly through the early part of the 1990s causing the IEF to decrease as well. In 1990, 25 % of cement produced was white cement; in 1991-1997 that same share fluctuates around 21 % (20 % in 1992 to 22 % in 1995). As presented in Table 3.2.4, emission factors are higher for white than for grey cement products resulting in a higher IEF for 1990.

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

Product	Value	Unit
White cement	0.669	Mg CO_2/Mg white cement
GLK clinker	0.477	Mg CO_2/Mg GLK grey clinker
FKH clinker	0.459	Mg CO_2/Mg FKH grey clinker
SKL/RKL clinker	0.610	Mg CO_2/Mg 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 (1998-2016). 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 2016, similar data are available back to 2006 (Aalborg Portland 2017a) and to a less detailed degree back to 1998 (Aalborg Portland, 2017b).

Table 3.2.5 Emission factors for some of the raw materials used in 2016 (Aalborg Portland, 2017a).

Raw material	Mg CO_2 per Mg raw material
Limestone	0.44
Magnesium carbonate	0.522
Sand	0.006-0.030
Fly ash	0.147
CKD	0.21-0.40

The emission factors for limestone and magnesium carbonate are in accordance with the stoichiometric factors and the emission factors for the remaining raw materials and CKD are determined by individual yearly 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 presented in this report.

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

Pollutant	Unit	Emission factor
As	mg/Mg	20
Cd	mg/Mg	7
Cr	mg/Mg	10
Cu	mg/Mg	10
Hg	mg/Mg	0.06
Ni	mg/Mg	20
Pb	mg/Mg	10
Se	mg/Mg	7
Zn	mg/Mg	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 in 1996.

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 trends

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

Table 3.2.7 CO_2 emission for cement production, Gg.

	1990	1995	2000	2005	2010	2015	2016
CO_2	882.4	1203.8	1385.3	1363.4	672.2	931.5	1095.5

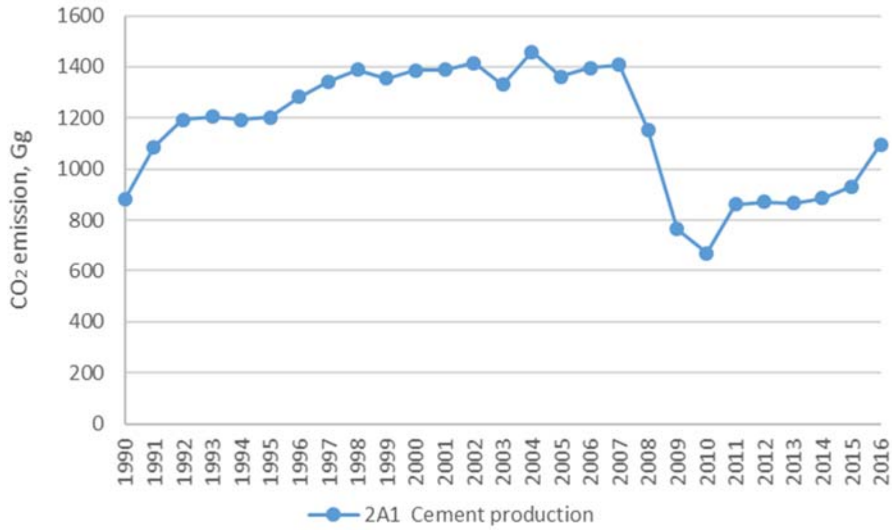


Figure 3.2.1 Emission of CO_2 from cement production.

The increase in CO_2 emission from the production of cement from 1990 to 1998 can be explained by the increase in the 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 in 2010-2016, but the emissions are still below the pre-recession levels due to lower production. The overall development in the CO_2 emission from 1990 to 2016 is an increase from 882 to 1095 Gg CO_2, i.e. by 24 %. The maximum emission occurred in 2004 and constituted 1,459 Gg CO_2; see Figure 3.2.1.

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 Danish authorities (DEA) prior to the reporting of the emissions. Cement production applies the Tier 3 methodology for calculating the CO_2 emission. See EU (2012) 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 2006-2016.

The process CO_2 emission for cement production is based on measurements of the consumption of calcium carbonate to the calcination process. These measurements fulfil a Tier 3 methodology (± 1.6 %) as defined in the EU decision (EU Commission, 2007). The emission factor is based on continuous measurements with flow meters, density meters, X-ray and CaO analysis. (Aalborg Portland, 2013b).

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 102-115 % (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 (presented in Annex 2-3) these two years are where the data from Statistics Denmark are notably higher than those from Aalborg Portland (310 and 210 Gg 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 2-3) 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 2-4; 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, Gg (Statistics Denmark, 2017).

	1990	1995	2000	2005	2010	2015	2016
Cement clinker							
Produced	NAV	NAV	103	43	4	NO	NO
Import	0.4	0.01	0.002	31	22	90	120
Export	17	281	90	56	12	0.1	0.01
Supply	-	-	12	18	14	90	120
Portland cement, white							
Produced	412	531	551	715	482	614	705
Import	NO	0.02	11	15	23	8	30
Export	367	473	546	508	501	551	714
Supply	44	58	17	222	3	71	21
Portland cement, grey							
Produced	1244	2053	1985	2166	1085	1414	1555
Import	190	272	238	215	160	198	270
Export	19	790	634	732	201	264	271
Supply	1414	1535	1589	1650	1044	1348	1554

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

The data presented in Table 3.2.8 and Annex 2-4 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 1.1 % (-24.1 Gg) through the time series (1990-2016). 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 is presented in Table 3.2.9 and Annex 2-3.

Table 3.2.9 Production data for Portland cement as given by Aalborg Portland and Statistics Denmark respectively.

	Unit	1990	1995	2000	2005	2010	2015	2016
Aalborg Portland	Gg	1620	2274	2613	2706	1454	1902	2202
Statistics Denmark	Gg	1656	2584	2536	2881	1567	2028	2260
Difference	Gg	-36	-310	77	-174	-113	-126	-57

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 1992-2016. The average IEF for these years is 0.54 Mg per Mg 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	Mg/Mg clinker	IPCC (2006)[4]
Tier 3[1]	0.51-0.57	Mg/Mg clinker	Aalborg Portland (2008, 2017a, b)

[1]1992-2016.

1990 and 1991 are both outliers because the production of white cement (EF: 0.669 Mg / Mg) and SKL / RKL clinker (EF: 0.610 Mg / Mg) peeked in these years, resulting in overall IEFs of 0.63 and 0.60 Mg per Mg clinker respectively.

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 Gg. For 1991-1997, this number is only 20-22 % of 2019-2629 Gg.

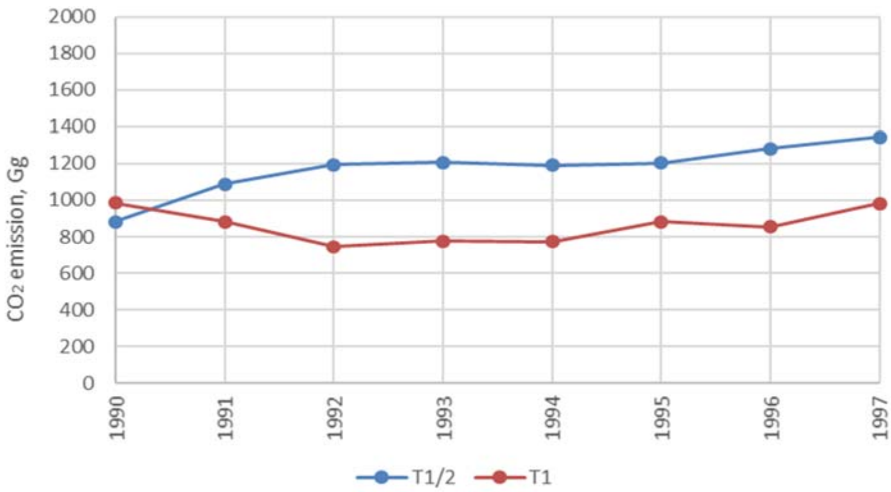


Figure 3.2.2 Comparison of calculation methods for CO_2 emissions from cement production in 1990-1997.

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

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 considered 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 %) only 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 for the entire time series been determined by the loss on ignition methodology, 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.

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)
	1998-2016	Cement equivalents	Aalborg Portland (2017b)
	1998-2016	Clinker produced	Aalborg Portland (2008; 2017a)
Emissions	1997	Heavy metals	Illerup et al. (1999)
	1985-1996, 1998-2016	Heavy metals	Assumed to be the same per produced amount as in 1997
	1985-1997	CO_2	Aalborg Portland (2005)
	1998-2005	CO_2	Aalborg Portland (2008)
	2006-2016	CO_2	Aalborg Portland (2017a)

3.3 Lime production

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

In addition to the marketed lime production, lime production is also related to production of sugar. Sugar production is concentrated at one company: Nordic Sugar (previously Danisco Sugar A / S) located in Assens (closed in 2006), Nakskov and Nykøbing Falster (Danisco Sugar Assens, 2007; Danisco Sugar Nakskov, 2008; Danisco Sugar Nykøbing, 2008; Nordic Sugar Nakskov, 2013; Nordic Sugar Nykøbing, 2013). 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, PCB

In addition to emissions from marketed lime, only 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:

$$M_x(CO_3) + heat \rightarrow M_xO + CO_2$$

and for limestone:

$$CaCO_3 + heat \rightarrow CaO + CO_2$$

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 (see Table 3.3.1) and emission factors.

Since 2006, point source data for Faxe Kalk (i.e. the largest Danish producer) have been applied, but the total national production is always taken as the national statistics. Plant specific activity data for marketed lime from Faxe Kalk are available from PRTR and EU-ETS for the years 2006-2016. Faxe Kalk constitutes 36-83% (59 % in average) of the Danish activity in 2006-2016, 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. A number of smaller companies account for the remaining part of the Danish production.

The process CO_2 emissions calculated by Faxe Kalk and reported to EU-ETS have since 2008 included the content of $MgCO_3$. 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 2007-2013.

Total sales statistics for produced sugar are available from Statistics Denmark (2017). Production statistics from the environmental reports are registered each 12 month period going from May 1 - April 30 until 2007/08 and from March 1 – February 28 from 2009/10 (Nordic Sugar Nakskov, 2009; Nordic Sugar Nykøbing, 2009). Therefore, the yearly production does not correspond with the yearly sale registered by Statistics Denmark (2017). The information from Statistics Denmark covers the whole time series and therefore the amount of sugar sold is used as activity data. The company information is only used for calculating the allocation of production/sale between the three point source locations/factories and for verification. The consumption of lime is estimated from the production statistics and a number of assumptions: consumption of 0.02 Mg $CaCO_3$ per Mg sugar and precipitation of 90 % CaO resulting in an emission factor at 0.0088 Mg CO_2 per Mg sugar (2 weight% $CaCO_3$ consumption per sugar beets, 10 weight% sugar in sugar beets). The assumptions are based on environmental reports covering the year 2002.

Activity data

Statistics from Statistics Denmark (2017) have been chosen as data source to ensure consistent data throughout the period from 1990. However, after EU-ETS data have become available 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 3-1.

Table 3.3.1 Production of burnt lime, Gg.

	1990	1995	2000	2005	2010	2015	2016
From Faxe Kalk[1]	NAV	NAV	NAV	NAV	25.6	30.1	37.7
From other producers[2]	128.0	100.8	92.0	71.2	24.8	33.4	31.1
From sugar production	5.8	5.1	5.8	4.7	2.0	0.7	1.5
Total burnt lime production	133.8	105.9	97.8	75.9	52.4	64.2	70.4

NAV: Not available, [1] Faxe Kalk (2014, 2017), [2] Non-ETS producers of marketed lime, calculated as national statistics data minus Faxe Kalk.

The production of hydrated lime (slaked lime) from burnt lime does not emit any greenhouse gases, see Chapter 3.3.1. All burnt lime that is later slaked, is included in the statistics shown in the table above. Adding the production of slaked lime to the activity data, would therefore result in double counting. Dolomitic lime/dolomite ($CaMg(CO_3)_2$) is not produced in Denmark.

Emission factors

The CO_2 emission factor 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 2017). These measurements include 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 emission factors for TSP, PM_{10}, and $PM_{2.5}$ are dependent on process conditions including pollution abatement equipment. The emission factors provided by the EMEP/EEA (2016) and CEPMEIP are presented in Table 3.3.2.

Table 3.3.2 Emission factors for marketed lime production, g per Mg.

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, 2016	
Tier 2, uncontrolled	9000	3500	700	3.2	EMEP/EEA, 2016	
Tier 2, controlled	400	200	30	0.1	EMEP/EEA, 2016	Applied in Danish inventory

For the Danish inventory the Tier 2, controlled emission factors published by EMEP/EEA (2016) have been chosen as default as they are assumed to cover an average of small and large plants operating with Danish standards.

The emission factors used to calculate the HCB, PCDD/F and PCB emissions from lime production are shown in Table 3.3.3 along with their respective sources.

Table 3.3.3 Emission factors for other pollutants for production of marketed lime

Pollutant	Unit	Value	Source
HCB	mg/Mg	0.01	Nielsen et al. (2013a)
PCDD/F	µg/Mg	0.02	Henriksen et al. (2006)
PCB	mg/Mg	0.15	Nielsen et al. (2013a)

3.3.3 Emission trends

The trends for the emissions from lime production, including sugar production are presented in Table 3.3.4, Figure 3.3.1 and Annex 3-2.

Table 3.3.4 Emissions from lime production.

			1990	1995	2000	2005	2010	2015	2016
	Total	Gg	105.4	83.4	77.1	59.8	41.3	50.6	55.4
CO_2	Lime production	Gg	100.8	79.4	72.5	56.1	39.8	50.0	54.3
	Sugar production	Gg	4.6	4.0	4.6	3.7	1.6	0.6	1.2
TSP	Total	Mg	53.5	42.4	39.1	30.4	21.0	25.7	28.1
PM_{10}	Total	Mg	26.8	21.2	19.6	15.2	10.5	12.8	14.1
$PM_{2.5}$	Total	Mg	4.0	3.2	2.9	2.3	1.6	1.9	2.1
BC	Total	kg	18.5	14.6	13.5	10.5	7.2	8.9	9.7
HCB	Total	g	1.1	0.8	0.8	0.6	0.4	0.5	0.6
PCDD/F	Total	mg	2.4	1.9	1.8	1.4	0.9	1.2	1.3
PCB	Total	g	20.1	15.9	14.7	11.4	7.9	9.6	10.6

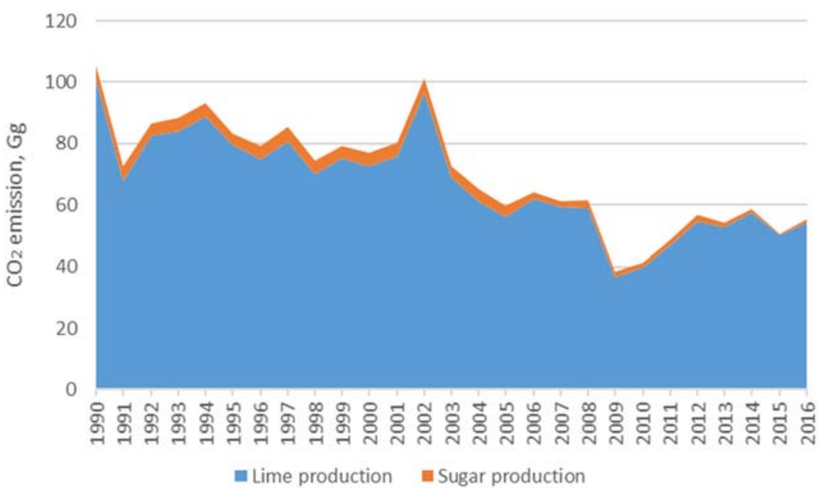


Figure 3.3.1 CO_2 emission trends for lime production.

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. As there are very few producers in Denmark, it will not be possible to obtain data that are more detailed 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 Danish authorities (DEA) prior to the reporting of the emissions. Faxe Kalk applies the Tier 2 methodology for the activity data 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 2006-2016.

The CO_2 emission for lime production is based on sales (± 1.0 %) and measurements of the MgO content in the product (assuming the product is pure CaO / MgO) (Faxe Kalk, 2013).

3.3.5 Verification

For verification, the implied emission factors are calculated; these are constant at 0.788 Mg CO_2 per Mg lime for all years and for both marketed lime production and production of lime in the sugar industry.

If the simple Tier 2 methodology had been used instead of using plant specific emission factors from EU-ETS data, i.e. if it is assumed that the MgO impurity is negligible by applying the default 0.7848 Mg CO_2 per Mg lime produced then the CO_2 emission from the marketed lime production would have been 0.4 % lower (0.1-0.4 Gg), proving that the impurity is in fact insignificant.

The 2006 IPCC guidelines provide Tier 1 emission factors for lime; see Table 3.3.5. According to the Tier 1 default, Danish measured MgO impurities are in the lower end of the expected range.

Table 3.3.5 Basic parameters for calculation of emission factors for lime products.

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

TSP emissions from the largest lime producer (Faxe Kalk A / S, Lhoist Group) are available for 2001-2008. Emissions and the calculated IEFs are presented in Table 3.3.6.

Table 3.3.6 TSP emission factor at Faxe Kalk A/S, Lhoist Group (Faxe Kalk, 2014).

	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	Mg	6.6	9.0	8.5	7.1	5.0	5.5	1.5	5.7
Lime production	Gg	70.5	69.8	63.3	64.1	57.3	62.8	57.0	57.8
IEF TSP	g/Mg	94	129	134	110	88	88	26	99

The average emission factor for the years 2001-2008 is 96 g TSP per Mg lime. This figure is very low compared to the chosen emission factor of 400 g TSP per Mg lime from EMEP / EEA (2016). 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.

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.

All though 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 constant and this source category is therefore also considered consistent.

With regards to completeness concerning production of other lime products than burnt lime, dolomitic lime is not produced in Denmark and the production of hydrated lime (slaked lime) from burnt lime does not emit any greenhouse gases. All domestically produced 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 chemical industries, metal industries, production for emissions abatement etc. these have been searched 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 low with the exception of the sources listed, and the sector must therefore be considered complete.

3.3.7 Input to CollectER

The input data / data sources for calculating emissions are presented in Table 3.3.7.

Table 3.3.7 Input data for calculating emissions from production of lime incl. slaked lime.

	Year	Parameter	Comment/Source
Activity	1990-2016	Production	Danisco Sugar, Nordic Sugar, Statistics Denmark
Emissions	1990-2016	CO_2	Stoichiometric relations combined with product information from one company
	2006-2016	CO_2	Faxe Kalk (2017), Nordic Sugar (2017)
	2006-2016	TSP, PM_{10}, $PM_{2.5}$, BC	EMEP/EEA (2016)
	1990-2016	HCB, PCB	Nielsen et al. (2013a)
	1990-2016	PCDD/F	Henriksen et al. (2006)

3.4 Glass production

Glass production covers production of:

- Flat glass
- Container 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 for art industrial glass products: 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 estimated and reported in the energy sector; they are therefore not included in this report.

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 10-18% Na_2O (Lenntech).

The products are bottles and glass jars (Rexam Glass Holmegaard) as well as drinking glasses and glass art products (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 glass production are presented in Table 3.4.1 and Annex 4-1. Information on consumption of carbon containing raw materials is available from the environmental reports of the plant for 1997-2013 (Ardagh, 2014) and from EU-ETS since 2006 (Ardagh, 2017) (confidential). For the years prior to 1997, the production of glass is based on information contained in Illerup et al. (1999).

Table 3.4.1 Production of glass, activity data, Gg.

	1990	1995	2000	2005	2010	2015	2016
Production of glass[1,2]	164	140	183	168	173	156	167
Consumption of soda ash[3]	18	15	16	13	c	c	c
Consumption of limestone[3]	14	12	8	6	c	c	c
Consumption of dolomite[3]	1	1	9	6	c	c	c

[1] 1990-1997: Illerup et al. (1999).

[2] 1998-2013: Estimated based on 1997 and total consumption of raw materials.

[3] 1990-1996: Estimated based on total production and the consumption of raw materials in 1997.

c: Confidential.

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

The activity data for glass wool production are presented in Table 3.4.2 and Annex 4-2. Information on consumption of carbon containing raw materials is available from the environmental reports of the plant for 1996-2013 (Saint-

Gobain Isover, 2014) and EU-ETS since 2006 (Saint-Gobain Isover, 2017a) (confidencial). For the years prior to 1996 the production of glass wool and consumption of carbonates are estimated.

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

	1985	1990	1995	2000	2005	2010	2015	2016
Production of glass wool[1]	36	36	36	40	37	25	33	36
Consumption of soda ash[2]	-	3.6	3.6	3.0	3.6	c	c	c
Consumption of limestone[2]	-	0.8	0.8	0.2	0.6	c	c	c
Consumption of dolomite[3]	-	1.0	1.0	1.0	1.0	c	c	c

[1] 1985-1996: 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.
c: Confidential.

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

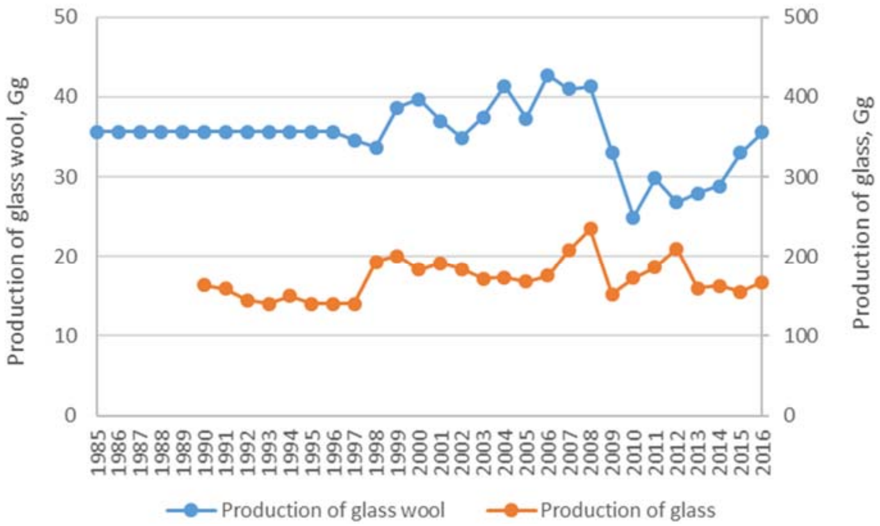


Figure 3.4.1 Activity data for container glass and glass wool production.

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

Emission factors

The emission factors for the glass industry are a combination of default Tier 2 emission factors from the EMEP/EEA guidebook (2016) and calculated implied emission factors based on measurements by the specific industries. The emission factors are supplemented with estimated CO_2 emissions from the calcination of carbonate compounds and some measured emissions.

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 Na_2CO_3 and other carbonate containing raw materials in production of glass and glass wool, based on stoichiometric relationships, are:

- 0.41492 Mg CO_2 / Mg Na_2CO_3
- 0.43971 Mg CO_2 / Mg $CaCO_3$
- 0.47732 Mg CO_2 / Mg $CaMg(CO_3)_2$
- 0.52197 Mg CO_2 / Mg $MgCO_3$

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 the EU-ETS (Ardagh, 2017; Saint-Gobain Isover, 2017a) but the applied emission factors (however rounded) 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 measurements of the emissions from production of container glass are available in the environmental reports / PRTR; 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 (2016), 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 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/Mg	280	EMEP/EEA (2016)
	2015-2016	g/Mg	13.7	EMEP/EEA (2016) with PS abatement[1]
PM_{10}	All	% of TSP	90	EMEP/EEA (2016)
$PM_{2.5}$	All	% of TSP	80	EMEP/EEA (2016)
BC	All	% of $PM_{2.5}$	0.06	EMEP/EEA (2016)
As	1990-2005	g/Mg	0.29	EMEP/EEA (2016)
	2006-2016	g/Mg	0.03	EMEP/EEA (2016) with PS abatement[1]
Cd	1990-2005	g/Mg	0.12	EMEP/EEA (2016)
	2006-2016	g/Mg	0.01	EMEP/EEA (2016) with PS abatement[1]
Cr	1990-2005	g/Mg	0.37	EMEP/EEA (2016)
	2006-2016	g/Mg	0.04	EMEP/EEA (2016) with PS abatement[1]
Ni	1990-2005	g/Mg	0.24	EMEP/EEA (2016)
	2006-2016	g/Mg	0.02	EMEP/EEA (2016) with PS abatement[1]
Pb	1990-1996	g/Mg	2.9	EMEP/EEA (2016)
	2015-2016	g/Mg	0.29	EMEP/EEA (2016) with PS abatement[1]
Se	1990-1996	g/Mg	1.5	EMEP/EEA (2016)
	2010-2011; 2014-2016	g/Mg	0.19	Average IEF (2008-09;2012-13)
Zn	1990-1996; 2002-2005	g/Mg	0.23	Average IEF (2007-2001)
	2006-2015	g/Mg	0.02	Average IEF (2007-2001) with CP abatement[1]

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

The emissions of NH_3 and TSP from the production of glass wool has been measured yearly for 1996-2014 (NH_3 also in 2016) and are available in the company's environmental reports (Saint-Gobain Isover, 2014 and 2017b). 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 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 (2016). Prior to 1996, where the total production is not available, the emissions have been assumed constant at the average emission level of 1996-1998. 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. All applied emission factors are shown in Table 3.4.4.

Table 3.4.4 Emission factors for production of glass wool.

Pollutant	Applied for the years	Unit	Value	Source
NMVOC	1985-2006	kg/Mg	1.35	Average IEF (2007-2009)
	2015-2016	kg/Mg	1.17	Average IEF (2012-2014)
CO	1985-1995; 1998-2016	kg/Mg	0.06	IEF (1997)
NH_3	1985-1995	kg/Mg	7.6	Average IEF (1996-1998)
	2015	kg/Mg	4.4	Average IEF (2012-2014)
TSP	1990-1995	kg/Mg	2.9	Average IEF (1996-2000)
	2015-2016	kg/Mg	1.4	Average IEF (2012-2014)
PM_{10}	All	% of TSP	90	EMEP/EEA (2016)
$PM_{2.5}$	All	% of TSP	80	EMEP/EEA (2016)
BC	All	% of $PM_{2.5}$	2.0	EMEP/EEA (2016)

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, 2017; Saint-Gobain Isover, 2017a). However, this information is confidential and data since 2006 can therefore only be presented as total emitted CO_2.

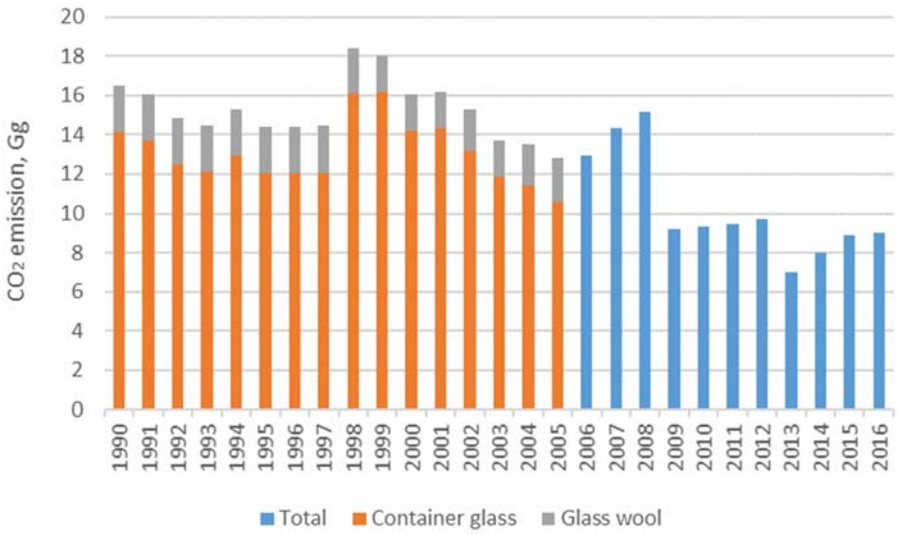


Figure 3.4.2 CO_2 emissions from glass production.

The emission trends from production of container glass and glass wool are presented in Table 3.4.5 and Annex 4-3. Annex 4-3 also presents emissions of TSP, PM_{10} and BC.

Table 3.4.5 Emissions from production of glass.

Pollutant		Unit	1985	1990	1995	2000	2005	2010	2015	2016
CO_2	Total	Gg	-	16.5	14.4	16.0	12.8	9.3	8.9	9.0
	- of which container glass	*Gg*	-	14.1	12.1	14.2	10.6	c	c	c
	- of which glass wool	*Gg*	-	2.3	2.3	1.8	2.3	c	c	c
$PM_{2.5}$	Total	Mg	-	118.1	112.8	109.0	73.5	22.3	37.9	40.9
	- of which container glass	Mg	-	36.1	30.8	20.0	5.5	1.3	1.7	1.8
	- of which glass wool	Mg	-	82.0	82.0	89.0	68.0	21.0	36.3	39.1
NMVOC	From glass wool	Mg	48.1	48.1	48.1	53.5	50.3	32.0	38.6	41.5
CO	From glass wool	Mg	2.0	2.0	2.0	2.3	2.1	1.4	1.9	2.0
NH_3	From glass wool	Mg	270.8	270.8	270.8	225.0	116.0	108.0	145.0	78.9
As	From container glass	kg	-	47.6	40.6	53.2	48.8	5.0	4.5	4.8
Cd	From container glass	kg	-	19.7	16.8	22.0	20.2	1.7	1.6	1.7
Cr	From container glass	kg	-	60.7	51.8	67.8	62.2	6.4	5.8	6.2
Ni	From container glass	kg	-	39.4	33.6	44.0	40.4	4.2	3.7	4.0
Pb	From container glass	kg	-	475.6	406.0	330.0	148.0	24.0	45.1	48.5
Se	From container glass	kg	-	246.0	210.0	340.0	107.0	33.0	29.7	31.9
Zn	From container glass	kg	-	37.7	32.2	57.0	38.7	4.0	3.6	3.8

c: Confidential.

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 Danish authorities (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 measuring on the storage silos; Tier 2: 1.10-1.37% depending on the silo) and standard emission factors except for dolomite where Ca/Mg analysis are performed for each new batch (Ardagh, 2012).

The CO_2 emission from glass wool production is based on weight measurements of carbonate raw materials (Tier 1: ±2.5%) and standard emission factors (Saint-Gobain Isover, 2012).

3.4.5 Verification

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

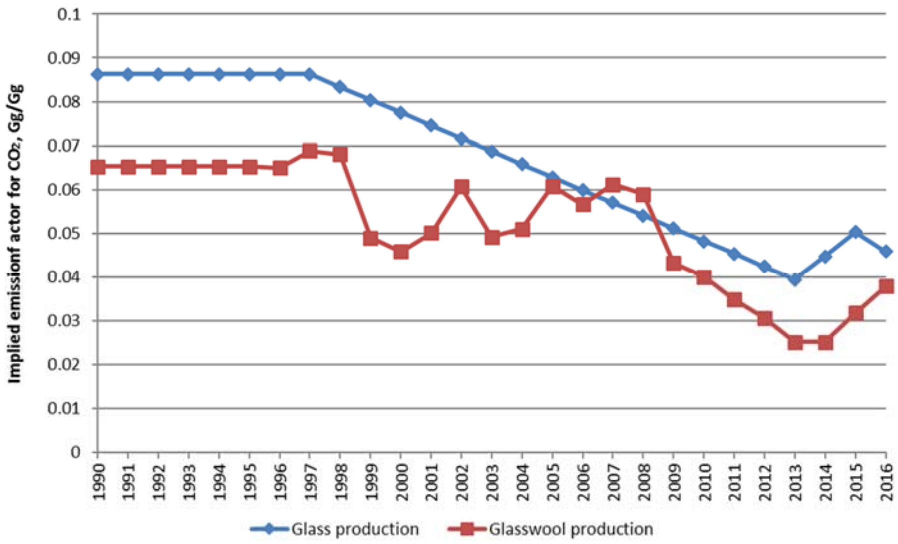


Figure 3.4.3 Implied emission factors for glass production.

Figure 3.4.3 shows that improvements in both glass production processes have lowered the IEFs significantly during the time series.

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 Mg CO_2 per Mg product and 0.5 cullet ratio (IPCC, 2006[5])
- Tier 2: 0.21 kg CO_2 per kg container glass (IPCC, 2006[6]) and the actual annual cullet ratios (0.34-0.76)

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

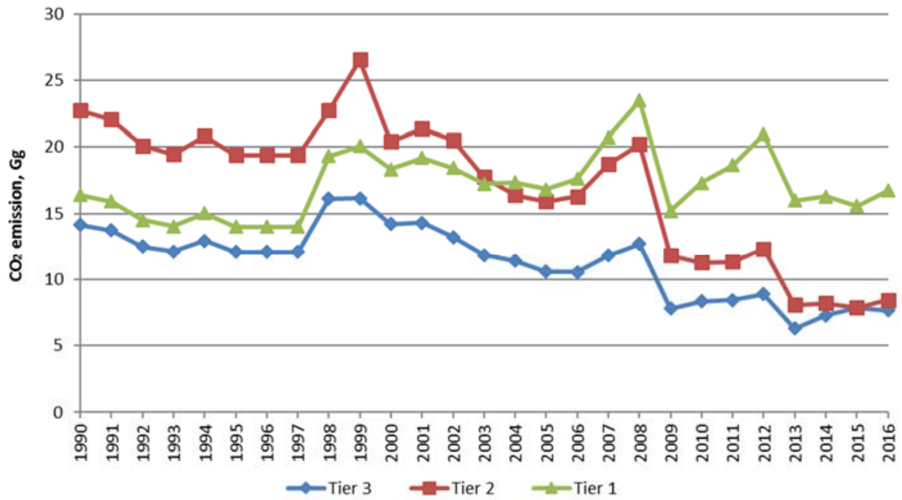


Figure 3.4.4 Comparison of CO_2 emission from container glass production calculated using different methods.

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 similar decrease in emissions. 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 estimation methods available in the 2006 IPCC guidelines.

3.4.6 Time series consistency and completeness

CO_2 emissions from glass production (including container glass, art glass and glass wool productions) 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 Flat glass) does not occur in Denmark. The processes in Denmark are limited to mounting of sealed glazing units. The mounting process does not contribute to emission of pollutants to air 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 produces their own virgin glass. The source category of glass production is therefore considered complete.

3.4.7 Input to CollectER

The environmental reports / PRTR (Saint-Gobain Isover, 2014 and 2017b) present energy as well as process related emissions. The process related emissions are used as input for calculating along with estimated the CO_2 emission 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 (2016) 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)
	1998-2016	Container glass production	Estimated from consumption of raw
	1990-1996	Consumption of raw materi-als for container glass	Estimated from production
	1997-2016	Consumption of raw mate-rials for container glass	Ardagh (2014 and 2017)
	1985-1996	Glass wool production	Assumed to be average 1997-
	1997-2016	Glass wool production	Saint-Gobain Isover (2014 and
	1990-1995 (1990-2005)	Consumption of raw materi-als for glass wool	Assumed to be average 1996-1998 (2006-2008 for dolomite)
	1996-2016	Consumption of raw materi-als for glass wool	Saint-Gobain Isover (2014 and 2017a)
Emissions	1990-1996, 2015-2016	Pb	Illerup et al. (1999), EMEP/EEA (2016)
	1997-2014	Pb	Ardagh (2014 and 2015)
	1990-1996, 2010-2011, 2014-2016	Se	Illerup et al. (1999), EMEP/EEA (2016)
	1997-2009, 2012-2013	Se	Ardagh (2014 and 2015)
	1990-1996, 2015-2016	TSP	Illerup et al. (1999), EMEP/EEA (2016)
	1997-2014	TSP	Ardagh (2014, 2015), Saint-Go-bain Isover (2014, 2017b)
	All	PM_{10}, $PM_{2.5}$, BC	Distribution between TSP, PM_{10}, $PM_{2.5}$ and BC from EMEP/EEA (2016)
	All	As, Cd, Cr, Ni	EMEP/EEA (2016)
	1997-2001	Zn	Ardagh (2014)
	1990-1996; 2002-2016	Zn	Calculated from activity data and implied emission factors (IEF) (1997-2001)
	1985-2006	NMVOC	Calculated from activity data and IEF (2007-2009)
	2015	NMVOC	Calculated from activity data and IEF (2012-2014)
	2007-2014, 2016	NMVOC	Saint-Gobain Isover (2014 and 2017b)
	1985-1995	NH_3	Average IEF for 1996-1998 and 2007-2009 respectively
	1996-2014	NH_3	Saint-Gobain Isover (2014 and
	1985-1995, 1998-2016	CO	Calculated from activity data and IEF (1997)
	1996-1997	CO	Saint-Gobain Isover (2014)
	1990-2005	CO_2	Estimated from consumption of raw materials
	2006-2016	CO_2	EU-ETS (Ardagh, 2017; Saint-Gobain Isover, 2017a)

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 (and 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. 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	Vedstårup Teglværk	5610 Assens
	Vesterled Teglværk	6400 Sønderborg
	Pipers Teglværk Vindø	9500 Hobro
	Pedershvile Teglværk	3200 Helsinge
	Prøvelyst Teglværk[1]	2980 Kokkedal
	Lundgård Teglværk[1]	7850 Stoholm, Jylland
	Bachmanns Teglværk[1]	6400 Sønderborg
	Petersens Tegl Egernsund	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
	P.M. Tegl Egernsund	6320 Egernsund
	Pipers Teglværk Gandrup	9362 Gandrup
	Pipers Teglværk Hammershøj	8830 Tjele
	Pipers Teglværk Højslev	7840 Højslev
	Monier Volstrup Teglværk	9300 Sæby
	Villemoes Teglværk[1]	6690 Gørding
Expanded clay products	Saint-Gobain Weber	8900 Randers
	Damolin Mors	7900 Nykøbing Mors
	Damolin Fur	7884 Fur

[1] Production has been closed down.

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
Damolin	Fur, Nykøbing Mors	Cat litter
		Felicia
		Amigo
		Absorbant
		Absodan
		Sorbix
		Oil Dri
		Moler
		Bentonite
		Perlite
		Vermiculite
Saint-Gobain Weber	Randers, Gadbjerg	Optiroc
		Leca

3.5.2 Methodology

Emission of CO_2 and SO_2 is related to limestone and sulphur content in the raw material respectively, whereas emission of NO_x and other pollutants is related to fuel consumption / process conditions. The NO_x and SO_2 emissions have previously been discussed by DTI (2000). 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

Since 2006, the producers of ceramics have measured and reported process CO_2 emissions to EU-ETS and production statistics are known from Statistics Denmark (2017) for the entire time series. From these two datasets, implied emission factors are calculated for 2006-2013 and used to calculate the CO_2 emission back to the years 1990.

EU-ETS data from Saint-Gobain Weber includes carbonates in the clay raw material for leca production from 2013 onwards. To increase time series consistency, the $CaCO_3$ equivalent contribution from clay is estimated and included for 1980-2012.

The SO_2 emission and fuel consumption are known for nine different producers of ceramics for 2007-2014. The SO_2 emission from the fuel consumption is calculated using Danish standard emission factors, and this is substracted from the total SO_2 emission. The remaining emission is used to calculate a SO_2 emission factor for 1980-2006 based on IEF (2007-2010) and one for 2015-2016 based on IEF (2012-2014). These factors are used for all producers.

The PCDD/F emission factor is known from national literature.

Activity data

National statistics on production of bricks, tiles and expanded clay products 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 for all pollutants, not just for CO_2; available for 2006-2016.

The national production statistics for ceramics (Statistics Denmark, 2017) is used as surrogate data to calculate the consumption of lime in the productions for 1980-2005. Activity data are presented in Table 3.5.4 and Annex 5-1.

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

	Unit	1980	1985	1990	1995	2000	2005	2010	2015	2016
Bricks and tiles										
Produced	million pieces	407.6	441.7	315.2	385.6	436.3	426.5	223.0	226.7	250.7
Consumed lime[1]	Gg $CaCO_3$	75.7	82.1	58.6	71.7	81.1	79.2	35.1	46.2	53.3
Expanded clay products										
Produced	Gg	370.0	363.2	331.8	340.9	316.2	310.9	157.4	155.0	145.7
Consumed lime[1]	Gg $CaCO_3$-eq	51.8	50.9	46.5	47.8	44.3	43.6	18.7	19.4	25.0

[1] 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.

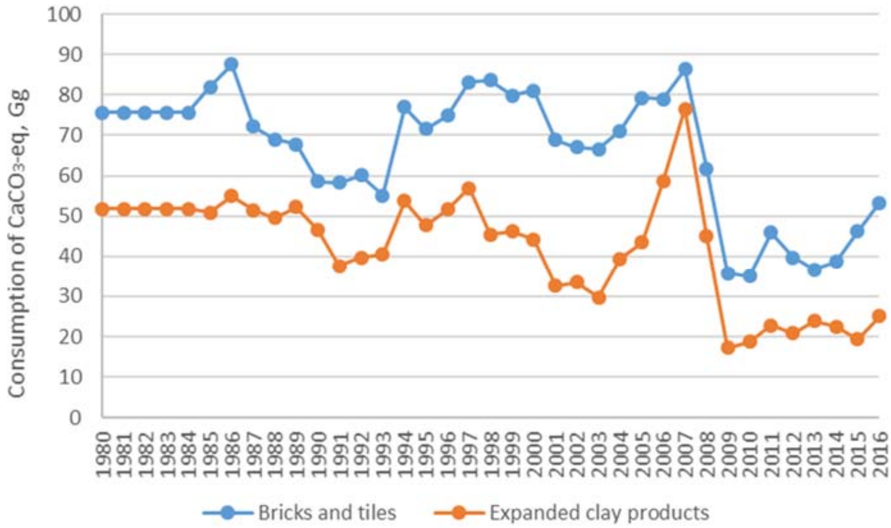


Figure 3.5.1 Consumption of $CaCO_3$ equivalents in the production of ceramics.

Both the brickworks and expanded clay production displays a significant decrease from 2007 to 2009 that can be explained by the financial crisis.

Emission factors

The CO_2 emission factor for lime is 0.43971 kg CO_2 per kg $CaCO_3$ based on stoichiometry. The calcination factor is assumed to be one for all years and all producers.

For 2006-2016 CO_2 emissions are reported by the brickworks under the EU-ETS, there are currently approximately 15 brickworks, which is a decrease from the 20-25 that operated in 2006. The reported emissions are calculated from measured lime contents of the raw materials and the stoichiometric emission factor 0.43971 kg CO_2 per kg $CaCO_3$. From the reported total emissions, an implied emission factor is calculated to match the activity data for brickworks using the stoichiometric factors.

Producers of expanded clay products also report CO_2 emissions to EU-ETS for the years 2006-2016 (Damolin, 2017; Saint-Gobain Weber, 2017). The reported emissions are calculated from the difference in C contents measured in the raw materials and products and the stoichiometric emission factor of 3.664 kg CO_2 per kg C.

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. 2007-2014 are the only years where this information is available, as it has been politically decided that the producers of ceramics are not obligated to report any further information in the future.

The SO_2 emissions attributed to the process have been adjusted for the fuel related emissions as far as possible to derive the process emissions. Five plants were using 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., 2018b). 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	574
Petroleum coke	605
Residual oil	344

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 factor is 0.018 µg per Mg product (Henriksen et al., 2006), using the total carbonate consumption (environmental reports), national production statistics (Statistics Denmark) and an assumption of 2.5 kg per brick or tile.

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.

	Brickworks		Expanded clay		
Pollutant	Value	Unit	Value	Unit	Source
CO_2	0.44	kg	0.44	kg	Stoichiometric
SO_2 – 1980-2006	9.9	kg	49.9	kg	Environmental reports*
SO_2 – 2015-2016	4.4	kg	37.5	kg	Environmental reports*
PCDD/F	0.25	µg	0.13	µg	Henriksen et al. (2006)*

* Derived EFs have been converted from different units

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 3.5.2, Figure 3.5.3 and Annex 5-2.

Table 3.5.7 Process emissions from production of ceramics.

Pollutant	Source	Unit	1980	1985	1990	1995	2000	2005	2010	2015	2016
CO_2	Total	Gg	-	-	46.2	52.5	55.1	54.0	23.6	28.8	34.4
	Brickworks	Gg	-	-	25.8	31.5	35.6	34.8	15.4	20.3	23.4
	Expanded clay	Gg	-	-	20.4	21.0	19.5	19.2	8.2	8.5	11.0
SO_2	Total	Gg	3.3	3.4	2.9	3.1	3.0	3.0	1.4	0.9	1.2
	Brickworks	Gg	0.7	0.8	0.6	0.7	0.8	0.8	0.4	0.2	0.2
	Expanded clay	Gg	2.6	2.5	2.3	2.4	2.2	2.2	1.1	0.7	0.9
PCDD/F	Total	mg	-	-	20.7	24.1	26.0	25.5	11.2	14.1	16.6
	Brickworks	mg	-	-	14.6	17.9	20.3	19.8	8.8	11.6	13.3
	Expanded clay	mg	-	-	6.0	6.2	5.8	5.7	2.4	2.5	3.2

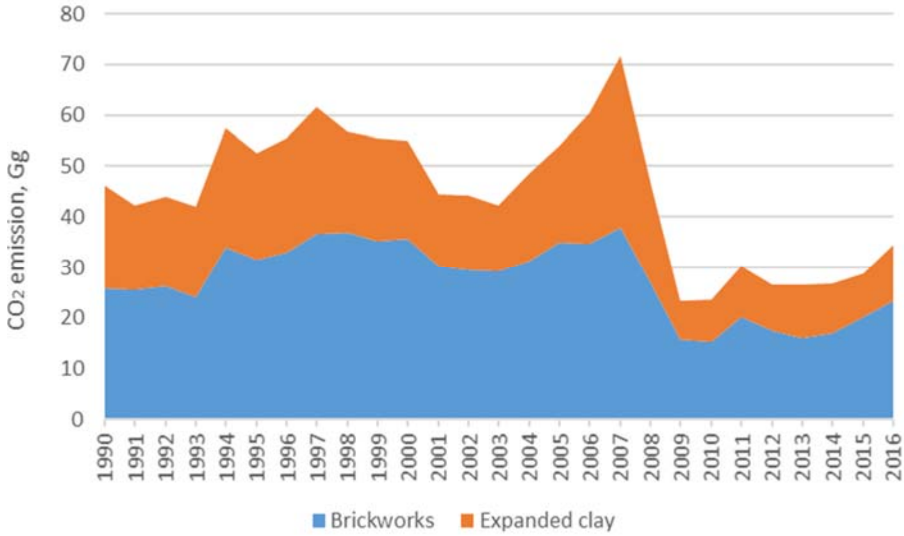


Figure 3.5.2 CO_2 emissions from the production of ceramics.

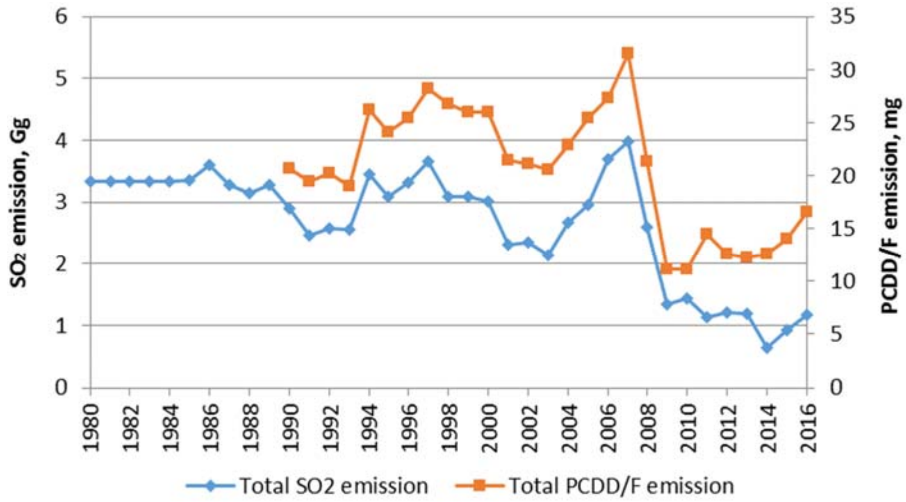


Figure 3.5.3 Total SO_2 and PCDD/F emissions from the production of ceramics.

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 Danish authorities (DEA) prior to the reporting of the emissions. The production of ceramics applies the Tier 2 methodology for calculating the CO_2 emission.

The CO_2 emission for ceramics production is based on measured carbonate content in all raw materials and consumption of the individual carbonate containing raw materials (Tier 2; ± 5.0 %). The CO_2 emission factors for the production facilities are based on stoichiometry.

3.5.5 Verification

For 2013-2016, the brickwork companies have reported production of brick / tile products (Mg) 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 3.6.8.

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

	Unit	2013	2014	2015	2016
Statistics Denmark[1]	Mg product	466790	498335	566685	626698
EU-ETS	Mg product	474512	493691	566640	620238
Difference	Mg product	-7722	4644	45	6459
Difference	-	-1.6%	0.9%	0.01%	1.0%

[1] Data are calculated into Mg (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 only 0.1 % for 2013-2016. All though it is difficult to conclude much with only four data years, this comparison indicates that all Danish brickworks report to EU-ETS and that this source is therefore complete.

For 2006-2016, the implied emission factors have been derived from CO_2 emissions reported by the producers of ceramics to EU-ETS (confidential reports) and production statistics (Statistics Denmark, 2017). Figure 3.5.4 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 Mg bricks / tiles (average: 33.5 kg CO_2 per Mg product) for 2006-2016 and the IEF for expanded clay products is 52.2-75.5 kg CO_2 per Mg product (average: 63.2 kg CO_2 per Mg product) for the same period. Figure 3.5.4 shows the development of these IEFs for the years 1990-2016. The emission factor for both types of ceramics is 0.43971 Mg CO_2 per Mg $CaCO_3$.

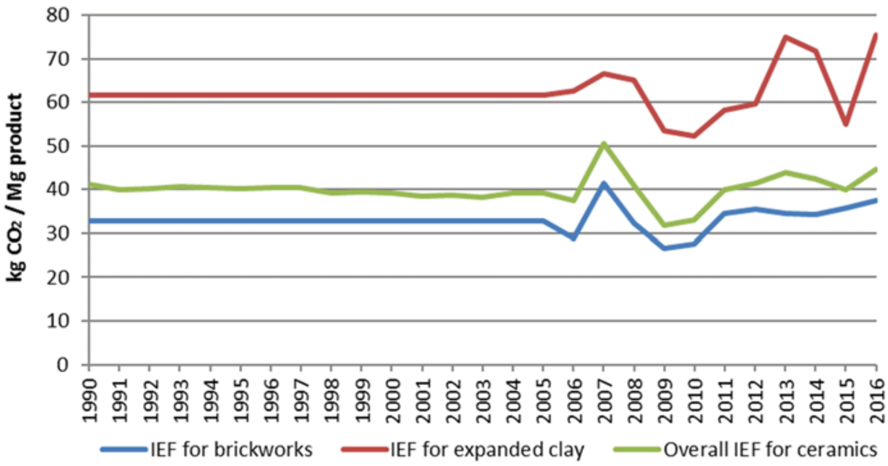


Figure 3.5.4 Implied emission factors for ceramics.

Figure 3.5.4 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 IPCC (2006)[7] default emission factor for ceramics is 49.0 kg CO_2 per Mg product, which is within reasonable compliance with the IEFs of Figure 3.5.4.

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 (2017) and default Tier 1 assumptions from IPCC (2006), see Figure 3.5.5.

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

- Consumption of clay: 1.1 Mg clay per Mg product
- Carbon content in clay: 10 %
- Distribution between carbonates: 85 % limestone / 15 % dolomite
- Order of calcination: 100 %
- Emission factors: 0.43971 Mg CO_2 per Mg limestone and 0.47732 Mg CO_2 per Mg dolomite

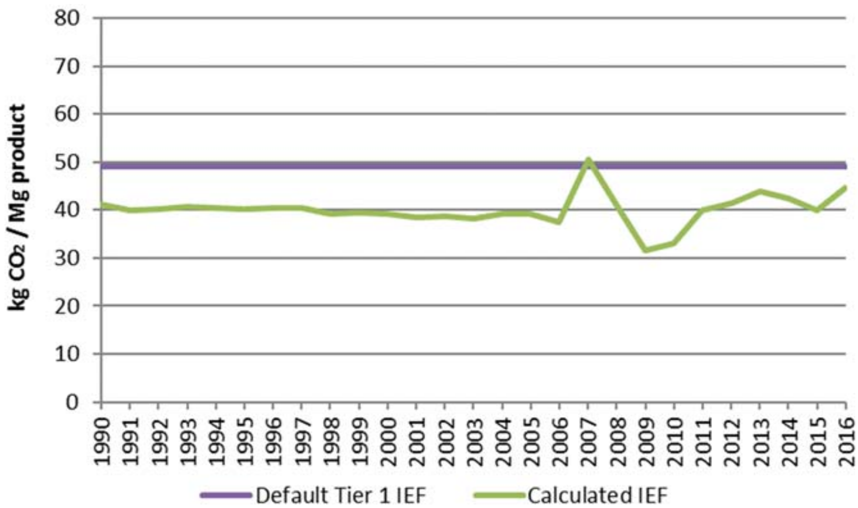


Figure 3.5.5 Development in implied emission factors for CO_2.

The comparison of IEFs shown in Figure 3.5.5 shows good agreement considering the rough assumptions listed above the figure.

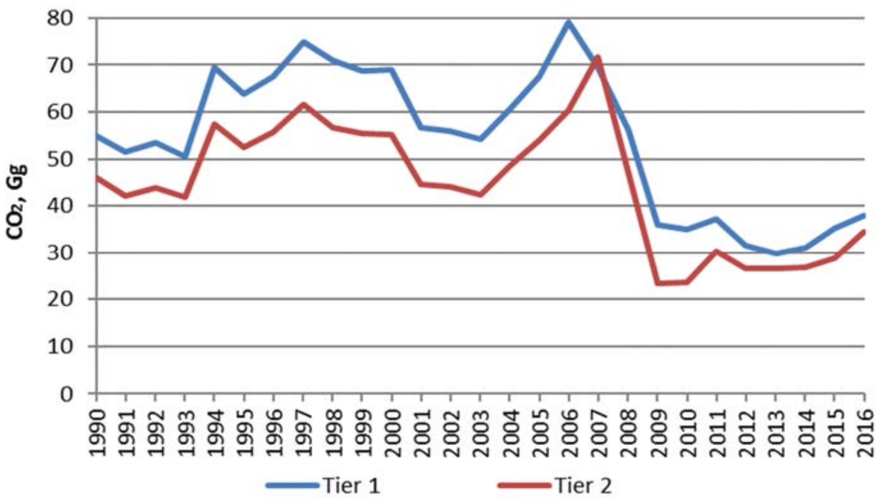


Figure 3.5.6 Comparison of emissions calculated by Tier 1 and Tier 2 method.

[7] 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).

Figure 3.5.6 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 2006-2016 are known from the EU-ETS reports and emissions for 1990-2005 are estimated. However, due to the various performed verifications, the source category *Ceramics* 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	1990-2016	Sale of products	Statistics Denmark; assumptions: 2.5 kg per brick
	1990-2005	Consumption of carbonates	Calculated from sale statistics and average carbonate consumption per product (2006-2013)
	2006-2016	Consumption of carbonates	Company reports to EU-ETS
Emissions	1990-2005	CO_2	Calculated from consumption of carbonates
	2006-2016	CO_2	Company reports under the EU-ETS
	1990-2016	SO_2	EF estimated from environmental reports 2007-2014
	1990-2016	PCDD/F	Calculated using emission factor from Henriksen et al. (2006)

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 a mass balance using national statistics on import/export and the stoichiometric emission factor. Since no detailed information on the specific uses of soda ash is available, it is assumed in the inventory that all of the apparent consumption leads to emissions. 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 6-1.

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

	1990	1995	2000	2005	2010	2015	2016
Import	55	48	42	60	36	34	35
Export	0.1	2.1	0.3	0.01	0.1	0.1	0.1
Glass production	21	19	19	17	11	9	9
Supply	33	27	22	43	26	25	26

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 0.41492 Mg CO_2 per Mg Na_2CO_3 based on the stoichiometry of the chemical conversion. The calculation assumes a calcination factor of 1.

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 1-1.

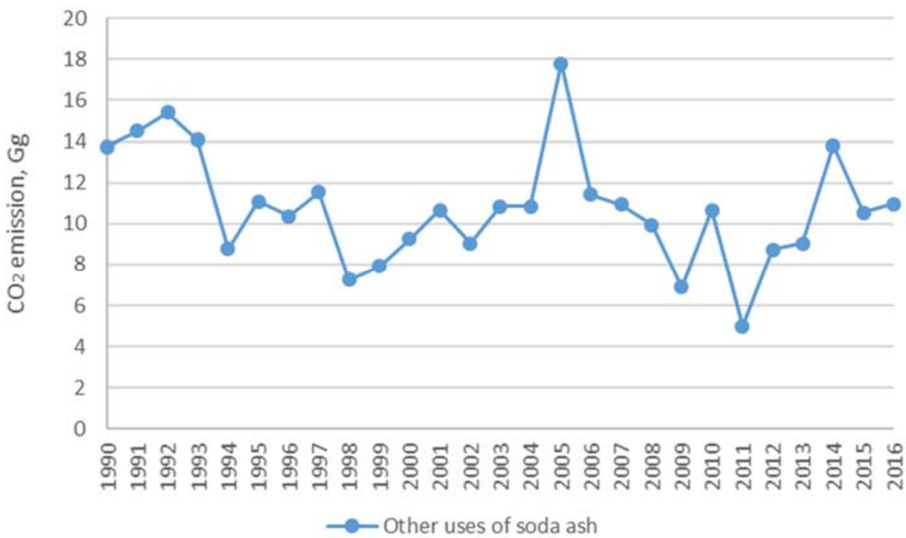


Figure 3.6.1 CO_2 emissions from other uses of soda ash.

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 (2017) has been checked against data from Eurostat (2014, 2018) for 2000-2016, see Table 3.6.2 and Annex 6-2.

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

	2000	2005	2010	2015	2016
Statistics Denmark	41.7	59.5	36.4	34.0	35.3
Eurostat	41.6	50.3	31.3	36.6	38.9
Difference	0.01	9.2	5.1	-2.5	-3.5

The comparison shows good agreement for most years.

3.6.5 Time series consistency and completeness

The same methodology is used for calculating emissions for the entire time series, the source category of *Other uses of soda ash* is therefore consistent. Calculations are based on a national mass balance using import / export statistics and are therefore 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	1990-2016	Import/export statistics	Statistics Denmark (2017)
Emissions	1990-2016	CO_2	Calculated using the stoichiometric emission factor

3.7 Flue gas desulphurisation

Flue gas cleaning systems utilising different technologies are primarily present at major combustion plants i.e. power plants and combined heat and power plants using coal as well as waste incineration plants. The following SNAP category is covered:

- 04 06 18 Limestone and dolomite use

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:

$$SO_2\,(g) + \tfrac{1}{2}O_2\,(g) + CaCO_3\,(s) + 2H_2O\,(l) \rightarrow CaSO_4{,}2H_2O\,(s) + CO_2\,(g)$$

The overall equation can be broken down to a number of individual equations. The emission factor is depending 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 Mg CO_2/Mg gypsum
- 0.4397 Mg CO_2/Mg $CaCO_3$

The emission factor for gypsum is used in the inventory when information on calcium carbonate consumption by power plants and waste incineration plants is not available.

Energinet.dk compiles 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 (2017). Statistics on the generation of gypsum are available from Energinet.dk (2017) for the entire time series. However, for 2006-2016 information on consumption of $CaCO_3$ at the relevant power plants and waste incineration plants has been compiled from EU-ETS and used in the calculation of CO_2 emission from flue gas cleaning.

The consumed amount of limestone is used as activity data for the years where these data are available from EU-ETS (2006-2016). Some information on limestone consumption is available for 1998-2005 from the (at that time) mandatory environmental reports, but this is not applied.

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

The power plants equipped with wet flue gas cleaning are:

- Amagerværket
- Asnæsværket
- Avedøreværket
- Enstedværket*
- Esbjergværket
- Grenå Kraftvarmeværk
- Nordjyllandsværket
- 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 fluegas cleaning are:

- Affaldscenter Aarhus
- KARA (Roskilde Forbrænding)*
- Kommunekemi
- L90 Affaldsforbrænding*

- Odense Kraftvarmeværk*
- Reno-Nord*
- Reno-Syd
- Sønderborg Kraftvarme
- Vestforbrænding

  *Since 2013 these operators have measured total CO_2 emissions, this means that process CO_2 emissions are included under the energy sector for these operators for 2013-2016.

Activity data

During the time series, this source has increased due to more plants being fitted with desulphurisation. 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, three 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.

For 1990-2005, the production of gypsum is used for calculating the CO_2 emission and for 2006-2016 the consumption of $CaCO_3$ is used. 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 7-1.

Table 3.7.1 Activity data for flue gas desulphurisation, Gg.

	1990	1995	2000	2005	2010	2015	2016
Gypsum production[1]	41.6	211.5	354.3	220.4	185.8	91.7	98.8
$CaCO_3$ consumption[2,3]	22.0	111.8	187.3	116.6	96.7	36.2	40.9

[1] Energinet.dk (2017).

[2] 1998-2005: Environmental reports of the individual plants.

[3] 2006-2016: EU-ETS of the individual plants.

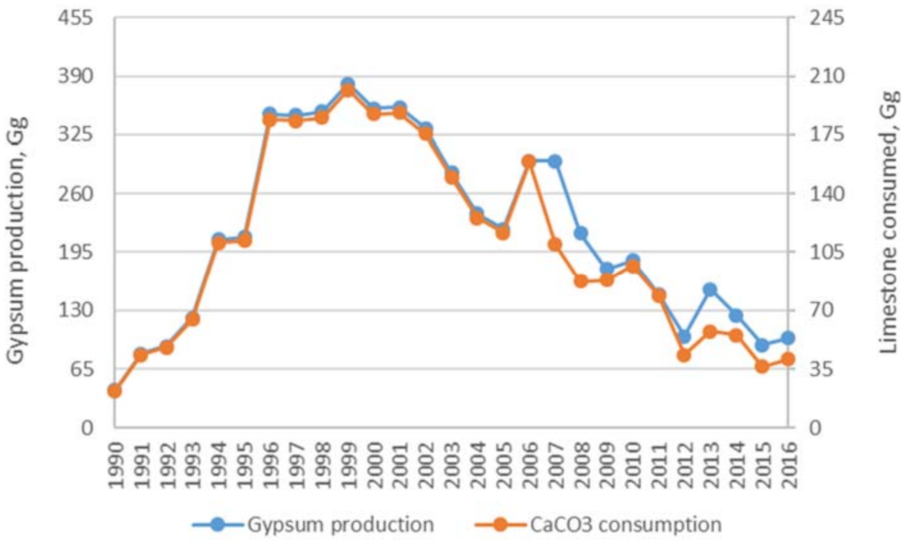


Figure 3.7.1 Activity data for flue gas desulphurisation.

The activity data level varies with the coal consumption that again varies greatly with electricity import/export.

Emission factors

From the chemical reaction equation presented in the "Methodology" section, the stoichiometric emission factor can be calculated to 0.2325 Mg CO_2 per Mg gypsum produced. This emission factor is used in the inventory when information on calcium carbonate consumption by power plants and waste incineration plants is not available from EU-ETS (1990-2005).

The emission factor applied when using limestone consumption as activity data is the stoichiometric emission factor 0.43971 Mg CO_2 per Mg $CaCO_3$ (2006-2016).

3.7.3 Emission trend

The emission trend for CO_2 emitted from flue gas cleaning at combined heat and power (CHP) plants and waste incineration plants is presented in Table 3.7.2 and Annex 7-2.

Table 3.7.2 Emission of CO_2 from wet fluegas cleaning, Gg.

	1990	1995	2000	2005	2010	2015	2016
Desulphurisation	9.7	49.2	82.4	51.2	42.5	15.9	18.0

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 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 Danish authorities (DEA) prior to the reporting of the emissions. The use of flue gas desulphurisation applies the Tier 1-2 methodology for calculating the CO_2 emission depending on the individual units.

The CO_2 emission for *Flue gas desulphurisation* is based on measured lime consumption (± 1.5 % to ± 7.5 %). The implied CO_2 emission factors for the production facilities are based on stoichiometry.

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.

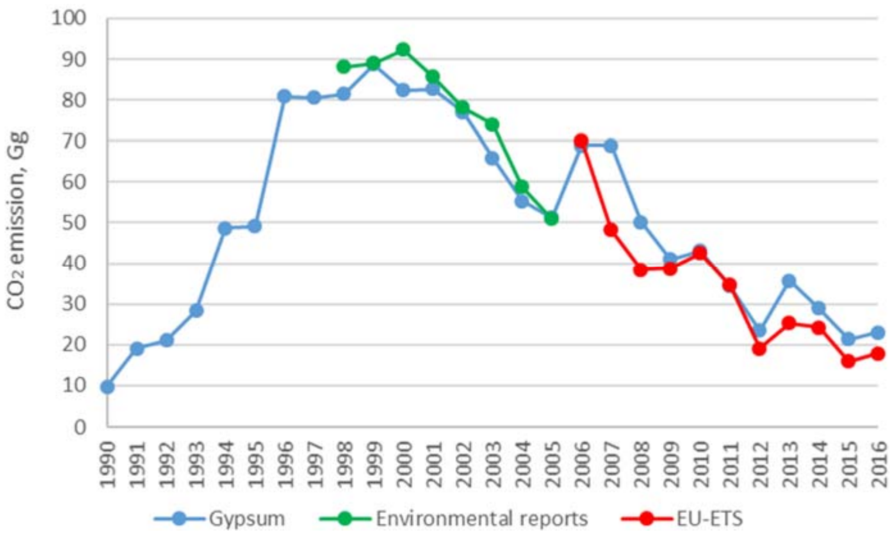


Figure 3.7.2 CO_2 emissions from *Flue gas desulphurisation* calculated with different methodologies; from gypsum production and limestone consumption compiled by environmental reports and EU-ETS respectively.

Emissions calculated from the limestone consumption data provided by the environments 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 -30 % (2007) to +2 % (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 inconsistent; 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	1990-2016	Gypsum generation	Energinet.dk (2017)
	1998-2005	Limestone consumption	Environmental reports
	2006-2016	Limestone consumption	EU-ETS
Emission	1990-2016	CO_2	Estimated by use of stoichiometric emission factor

3.8 Stone wool production

Only one company produces stone wool in Denmark, Rockwool situated at three localities: Hedehusene[8], Vamdrup and Øster Doense. The following SNAP categories are covered:

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

[8] The melting of minerals (cupola) has been closed down in 2002.

Emissions associated with the fuel use are included 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
- NMVOC
- CO
- NH_3
- Particulate matter: TSP, PM_{10}, $PM_{2.5}$, BC
- PCDD/F

The following description is based on information from the plant (Rockwool, 2003).

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. The consumption of raw material as well as amount of produced stone wool is confidential.

3.8.2 Methodology

Information on emissions from some years has been used, in combination with yearly data on raw material consumption, to extrapolate the emissions to other years. The data have been extracted from the environmental reports (Rockwool, 2014a), EU-ETS (Rockwool, 2017a) and reporting to PRTR (Rockwool, 2017b). Measured emissions of CO and NH_3 are available for the years 2001, 2004 and 2007-2014, for NH_3 also 2015-2016. Emissions of particulate matter are available for 1995-2014, and for NMVOC and PCDD/F, the inventory is based on measured emissions for 2012-2014 and 2004 respectively.

Implied CO_2 emission factors have been calculated for 2006-2010 (1998 for Hedehusene) and with these, emissions are extrapolated back to 1990.

The proxy activity data (i.e. limestone consumed) are calculated from the CO_2 emission. The proxy activity data are necessary because the Kyoto Protocol, the UNFCCC and the UNECE requires the categories of *Ceramics, Other uses of soda ash, Flue gas desulphurisation* and *Stone wool production* to be summarised. When activity data for the source categories *Ceramics, Other uses of soda ash* and *Flue gas desulphurisation* are given in $CaCO_3$ equivalents consumed, then activity data for *Stone wool production* should be given in the same unit.

All calculations are performed for the three factories individually.

Activity data

Data on the produced amount of stone wool is confidential for 1985-2013; however the consumption of raw materials and the consumption of carbonates ($CaCO_3$ equivalents calculated from the CO_2 emission) at the three

Danish Rockwool factories are available from the annual environmental reports (Rockwool, 2014a) and EU-ETS (Rockwool, 2017a). 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 (2006-2016) and are therefore also all included in the proxy activity data of limestone equivalents consumed presented in Table 3.8.1 and Figure 3.8.1.

The consumption of raw materials is available for 1995-2013 and the consumption of carbonates (i.e. the CO_2 emission) for 2006-2016. Raw material consumption for 1990-1994 is assumed constant as the average of the years 1995-1999.

Both activity data and proxy activity data are presented in Table 3.8.1, Figure 3.8.1 and Annex 8-1.

Table 3.8.1 Activity data for stone wool production, Gg.

	1985	1990	1995	2000	2005	2010	2015	2016
Consumption of raw materials	195.6	195.6	196.5	190.0	172.0	155.0	119.8	167.4
Consumption of $CaCO_3$ equivalents	-	17.9	18.0	17.3	18.0	17.1	13.5	17.0

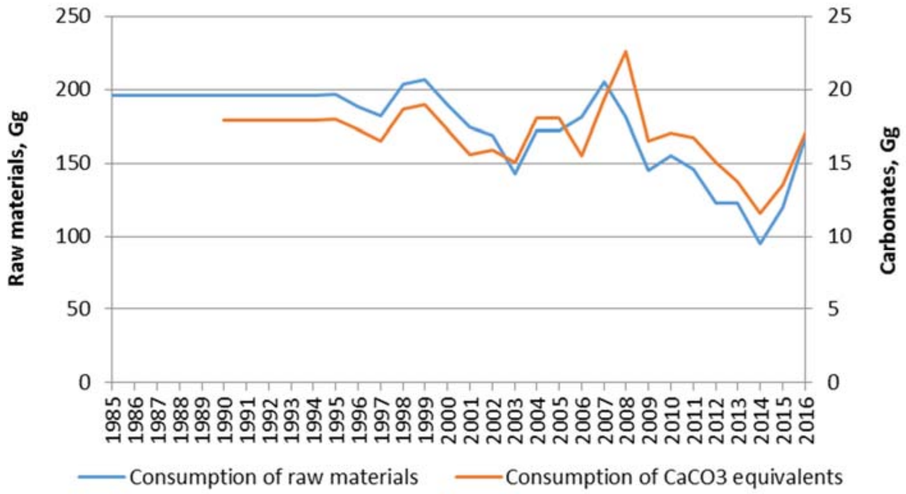


Figure 3.8.1 Activity data for stone wool production.

Emission factors

From 2006, the CO_2 process emission data have been obtained from the company's reportings under the EU-ETS (Rockwool, 2017a). For 1990-2005, the CO_2 emission is estimated from the calculated factor of "CO_2 emission per raw material consumption" (average for 2006-2010) and the raw material consumption time series. CO_2 emissions for 1990-1994 are estimated as the constant average of 1995-1999.

Emission factors for CO and NH_3 are calculated from the measured emission values reported in the annual environmental reports for each Rockwool factory for the years 2001, 2004 and 2007-2014; NH_3 is known for 2015-2016 from PRTR (Rockwool, 2017b). TSP is available in the environmental reports for 1995-2014. PM_{10}, $PM_{2.5}$ and BC are estimated from the distribution between TSP, PM_{10} and $PM_{2.5}$ (1 / 0.9 / 0.7) and BC = 2 % of $PM_{2.5}$. The applied emission factor for BC is actually that of glass wool from EMEP / EEA (2016). NMVOC is known for the Doense factory for 2012-2014. For PCDD / F, the inventory is based on measured emissions from 2004 (Henriksen et al., 2006).

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 back to 1985. The implied emission factors are presented in Table 3.8.2.

Table 3.8.2 Emission factors for stone wool production.

Pollutant	Unit	Hedehusene	Vamdrup	Doense	Source/Comment
CO_2	Mg/Mg $CaCO_3$	0.44	0.44	0.44	Stochiometry
NMVOC	kg/Mg raw material	0.25	0.25	0.25	IEF average Doense 2012-2014
CO	kg/Mg raw material	88.8	38.4	61.4	Before abatement. IEF average 2001, 2004, 2007-2008(2009)
CO	kg/Mg raw material	-	0.19	0.02	After abatement. IEF average 2009(2010)-2014
NH_3	kg/Mg raw material	1.8	1.5	1.6	IEF average 2001, 2004, 2007-2016
TSP	kg/Mg raw material	0.29	0.46	0.7	IEF average 1995-2014
PCDD/F	mg/Mg raw material	-	0.0003	0.0003	Henriksen et al. (2006)

3.8.3 Emission trend

The emission trends for emission of CO_2, NMVOC, CO, NH_3, TSP, PM_{10}, $PM_{2.5}$, BC and PCDD/F from production of stone wool at three (from 2006 two) locations are presented in Table 3.8.3 and Annex 8-2.

Table 3.8.3 Emissions from production of stone wool.

	Unit	1985	1990	1995	2000	2005	2010	2015	2016
CO_2	Gg	-	7.9	7.9	7.6	7.9	7.5	5.9	7.5
NMVOC	Mg	35	35	35	34	31	28	22	30
CO	Mg	11381	11381	11317	11430	12517	11	14	20
NH_3	Mg	284	284	284	281	353	203	242	175
TSP	Mg	-	94	94	71	114	87	71	99
PM_{10}	Mg	-	85	84	64	102	78	63	89
$PM_{2.5}$	Mg	-	65	66	50	79	61	49	69
BC	Mg	-	1.3	1.3	1.0	1.5	1.2	1.0	1.3
PCDD/F	mg	-	65	65	63	57	51	40	55

The measurements from Rockwool (2014a) 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 Tier 3 methodology for calculating the CO_2 process emission for 2006-2016.

The implied CO_2 emission factor for Rockwool 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 – 2016.

The CO_2 emission for stone wool production is based on measurements of the consumption of carbonates. These measurements fulfil a Tier 1 methodology (± 1.6 - 5.0 % depending on the carbonate). The emission factors are based on carbon content measurements for each carbonate (Tier 2). (Rockwool, 2014b).

3.8.5 Time series consistency and completeness

The source category of *Stone wool production* is complete but inconsistent, the inconsistency occurs because emissions for 2006 onward are known (EU-ETS) but emissions for 1990-2005 are estimated via surrogate data.

3.8.6 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	1995-2013	Raw material consumption	Rockwool (2014a)
	2006-2013	Carbonate consumption estimated from CO_2 emission	Rockwool (2017a)
Emissions	2001, 2004, 2007-2013	CO	Rockwool (2017b)
	2001, 2004, 2007-2016	NH_3	Rockwool (2017b)
	2012-2014	NMVOC	Rockwool (2017b)
	1995-2014	TSP	Rockwool (2014, 2017b)
	2004	PCDD/F	Henriksen et al. (2006)

3.9 Quarrying and mining of minerals other than coal

Quarrying and mining of minerals other than coal covers several different types of minerals and occurs all over Denmark. The following SNAP-category 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

The annual amount of extracted minerals is available from national statistics. These resource extraction data cover “sand and gravel”, “chalk and dolomite”, “clay and kaolin”, “salt”, “marble, granite, sandstone, porphyry, basalt and building stone, etc.” and “other”.

Emission factors are available from EMEP / EEA (2016).

Activity data

Activity data for *Quarrying and mining of minerals other than coal* are presented in Table 3.9.1; the full time series is available in Annex 9-1.

Table 3.9.1 Extracted minerals other than coal, Gg.

	1990	1995	2000	2005	2010	2015	2016
Quarrying and mining	47493	56126	67122	77523	47113	58392	61605

Emission factors

The applied emission factors are shown in Table 3.9.2. Emission factors are chosen for Tier 2 low emission level for plants having well maintained abatement / BAT.

Table 3.9.2 Emission factors for quarrying and mining of minerals other than coal

Pollutant	Value	Unit	Source
TSP	51	g/Mg mineral	EMEP/EEA (2016)
PM_{10}	25	g/Mg mineral	EMEP/EEA (2016)
$PM_{2.5}$	3.8	g/Mg mineral	EMEP/EEA (2016)

Emission trends

Emissions of TSP are presented in Figure 3.9.1. Emissions of TSP, PM_{10} and $PM_{2.5}$ are available in Annex 9-2.

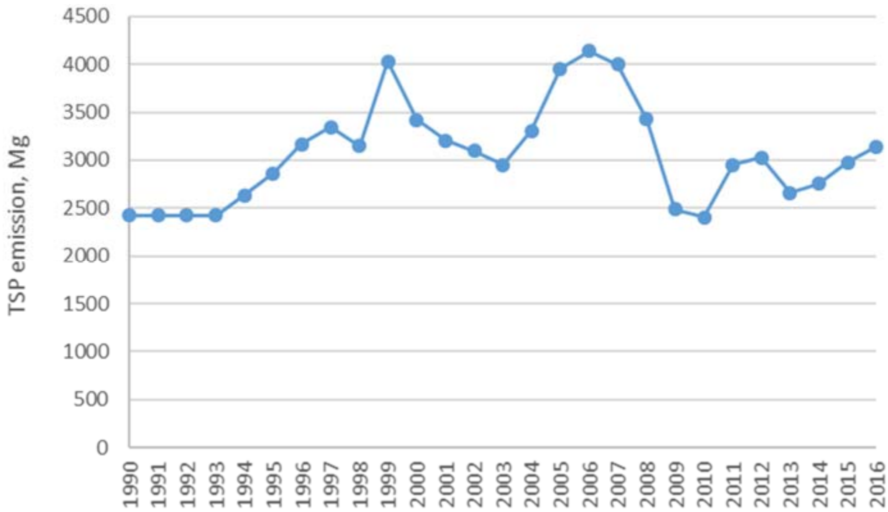


Figure 3.9.1 Emission of particulate matter (TSP) from *Quarrying and mining of other minerals than coal*.

3.9.2 Time series consistency and completeness

The time series is both consistent and complete.

3.9.3 Input to CollectER

The input data / data sources for calculating emissions are presented in Table 3.9.3.

Table 3.9.3 Input data for calculating emissions from quarrying and mining.

	Year	Parameter	Comment/Source
Activity data	1994-2016	Extracted minerals	Statistics Denmark (2017)
Emission factors	All	TSP, PM_{10}, $PM_{2.5}$	EMEP/EEA (2016)

3.10 Construction and demolition

Construction and demolition covers the following SNAP category:

- 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

The activity data for *Construction and demolition* are calculated based on national statistics on completed constructions (m^2) and demolished floor area

(m^2). Prior to 2007, demolition data are not available and these are therefore estimated based on statistics on total floor area in the building stock (m^2).

Emission factors are available from EMEP / EEA (2016).

Activity data

Activity data for *Construction and demolition* are presented in Table 3.10.1. The full time series is available in Annex 10-1.

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

	1990	1995	2000	2005	2010	2015	2016
Construction and demolition	8.6	6.6	12.1	10.8	12.1	8.4	6.9

Emission factors

The applied emission factors are shown in Table 3.10.2.

Table 3.10.2 Emission factors for construction and demolition

Pollutant	Value	Unit	Source
TSP	0.29	kg/m^2/year	EMEP/EEA (2016)
PM_{10}	0.086	kg/m^2/year	EMEP/EEA (2016)
$PM_{2.5}$	0.0086	kg/m^2/year	EMEP/EEA (2016)

3.10.2 Emission trends

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

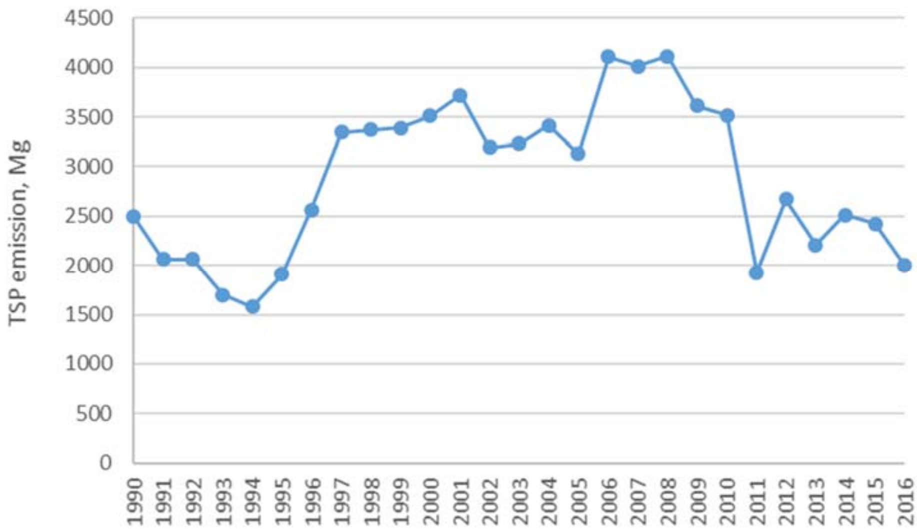


Figure 3.10.1 Emission of particulate matter (TSP) from *Construction and demolition.*

3.10.3 Time series consistency and completeness

The time series is consistent but incomplete as construction of roads is not currently included.

3.10.4 Input to CollectER

The input data / data sources are presented in Table 3.10.3.

Table 3.10.3 Input data for calculating emissions from construction and demolition.

	Year	Parameter	Comment/Source
Activity data	All	Constructed and demolished buildings m^2	Statistics Denmark (2017)
Emission factors	All	TSP, PM_{10}, $PM_{2.5}$	EMEP/EEA (2016)

3.11 Storage, handling and transport of mineral products

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

- 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* cover minerals used in *Cement production*, *Ceramics*, *Other uses of soda ash*, *Flue gas desulphurisation* and *Stone wool production*. The particle emissions from *Storage, handling and transport of mineral products* in *Lime production*, *Glass production*, *Quarrying and mining* and *Construction and 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).

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 11-1.

Table 3.11.1 Activity of Storage, handling and transport of mineral products, Gg mineral.

	1990	1995	2000	2005	2010	2015	2016
Storage, handling and transport of mineral product	462.8	580.3	524.8	545.1	558.7	488.1	546.7

Emission factors

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).

The applied emission factors for calculating emissions 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	Mg/Gg	Expert judgement
PM_{10}	0.05	Mg/Gg	Particle distribution from EMEP/EEA (2016)
$PM_{2.5}$	0.005	Mg/Gg	Particle distribution from EMEP/EEA (2016)

3.11.2 Emission trends

Emissions are presented in Figure 3.11.1 and Annex 11-2.

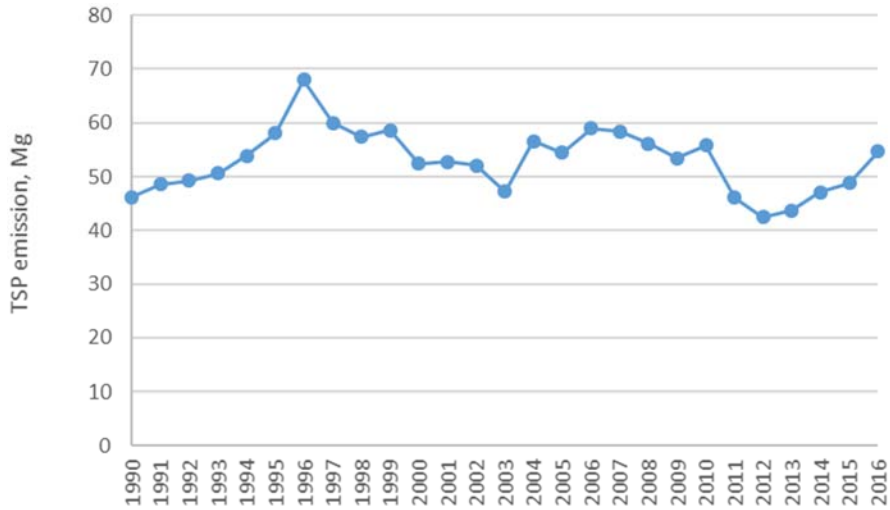


Figure 3.11.1 Emission of particulate matter from *Storage, handling and transport of mineral products*.

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 amounds	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 (2016)

4. Chemical industry

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

- Nitric- and sulphuric acid production; see section 4.2
- Catalyst and fertiliser production; see section 4.3
- Production of chemical ingredients; see section 4.4
- Pesticide production; see section 4.5
- Production of tar products; see section 4.6

4.1 Greenhouse gas emissions

The greenhouse gas emission time series for the source categories within *Chemical Industry* (2B) are presented in Figure 4.1.1 and individually in the subsections below (Sections 4.2 – 4.6). The following figure gives an overview of which source categories contribute the most to greenhouse gas emissions throughout the time series.

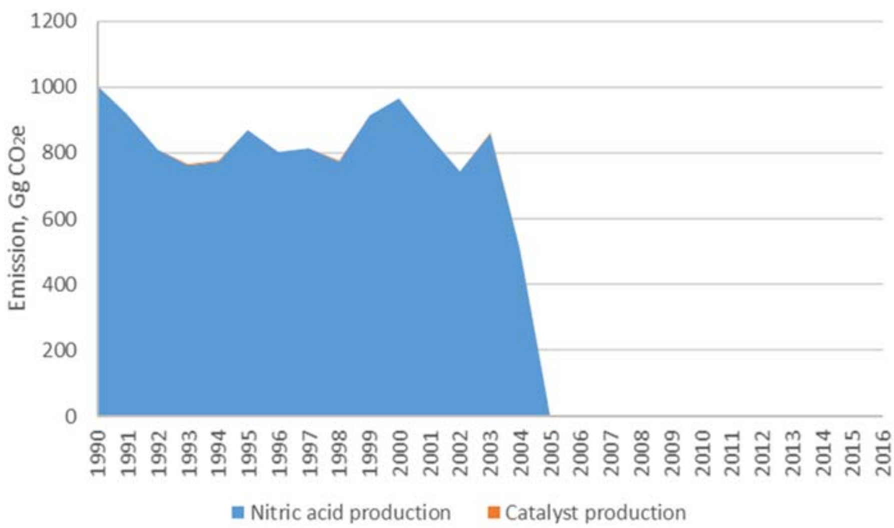


Figure 4.1.1 Emission of CO_2 equivalents from the individual source categories compiling *2B Chemical Industry*, Gg.

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.

4.2 Nitric and sulphuric acid production

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

- 04 04 01 Sulphuric acid

- 04 04 02 Nitric acid

Emissions of the following pollutants are included 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 prodution 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, 2004) 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 (Kemira GrowHow, 2004), contact to the company (Jacobsen, 2005) as well as information from the county. 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 for which years measured emissions are available for the different pollutants (Kemira Growhow, 2005).

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 in accordance 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 personal communication (Kemira Growhow, 2005) and Kemira GrowHow (2004). The data are presented in Table 4.2.2 and Annex 12-1.

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

	1980	1985	1990	1995	2000	2005	2010	2015	2016
Nitric acid	-	350	450	390	433	NO	NO	NO	NO
Sulphuric acid	188	188	148	102	NO	NO	NO	NO	NO

NO: Not occurring.

Production of sulphuric acid decreased from approximately 150 to 55 Gg from 1990 to 1996, and production of nitric acid decreased from approximately 450 to 380 Gg from 1990 to 2004. Overall, production of fertiliser decreased from approximately 800 to approximately 400 Gg from 1990 to 2004.

Emission factors

The calculated implied emission factors are presented in Table 4.2.3 together with the standard emission factors given by IPCC (2006) and EMEP/EEA (2016).

Table 4.2.3 Plant specific emission factors for production of nitric acid and sulphuric acid in Denmark compared with standard emission factors, kg per Mg 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 plant with abatement technology (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, 2016), [6]Medium pressure (EMEP/EEA, 2016), [7]High pressure (EMEP/EEA, 2016), [8]Direct strong acid process (EMEP/EEA, 2016), [9]Modern plant with abatement technology (EMEP/EEA, 2016), [10]Contact process with intermediate absorption; different gas conditions (EMEP/EEA, 2016), [11]Wet/dry process with intermediate condensation/absorption (EMEP/EEA, 2016), [12]Wet contact process (EMEP/EEA, 2016).

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 factors for NH_3 and N_2O are 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 (2016) (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 and Annex 12-2.

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

	Unit	1980	1985	1990	1995	2000	2005	2010	2015	2016
NH_3	Mg	-	12	12	62	13	NO	NO	NO	NO
N_2O	Gg	-	2.6	3.4	2.9	3.2	NO	NO	NO	NO
NO_x	Mg	-	627	806	612	413	NO	NO	NO	NO
SO_2	Mg	415	415	327	217	NO	NO	NO	NO	NO
TSP	Mg	-	-	388	336	362	NO	NO	NO	NO
PM_{10}	Mg	-	-	388	336	362	NO	NO	NO	NO
$PM_{2.5}$	Mg	-	-	388	336	362	NO	NO	NO	NO
BC	Mg	-	-	7.0	6.1	6.5	NO	NO	NO	NO

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 to 2.9 Gg, 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.

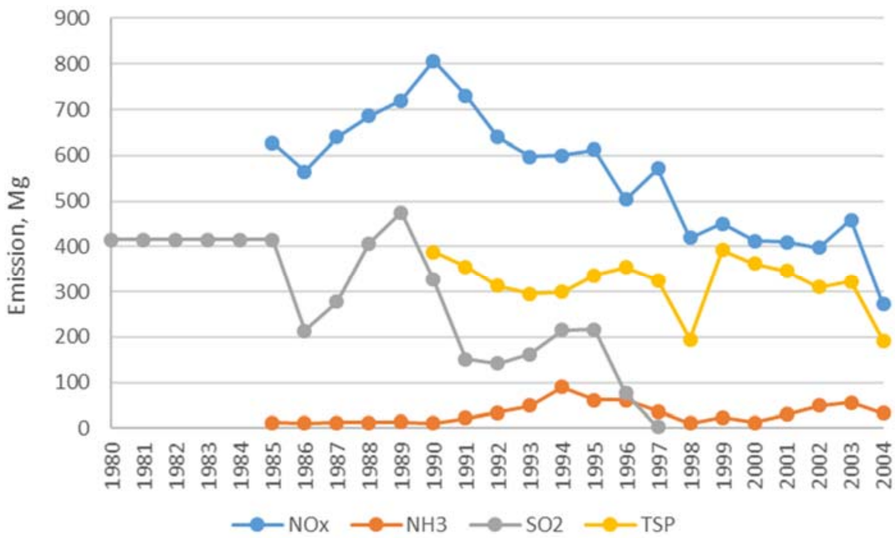


Figure 4.2.1 Emissions from *Nitric- and sulphuric acid production.*

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.

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 (2004, 2005)
	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 (2005)
	1980-1988	NH_3	IEF 1989
	1989-2004	NH_3	Kemira GrowHow (2004)
	1996-2003	TSP	Kemira GrowHow (2004)
	1980-2001; 2003-2004	N_2O	IEF 2002
	2002	N_2O	Kemira GrowHow (2005)
	All	PM_{10}, $PM_{2.5}$	Assumed to equal TSP
	All	BC	EMEP/EEA (2016)

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 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. The company has estimated the emission of CO_2 from known emission factors for incineration of natural gas and liquefied petroleum gases (LPG) and from information on the raw materials containing carbonate. The contribution from carbonate compounds is estimated to be the difference between the total CO_2 emission reported in the environmental reports (Haldor Topsøe, 2013) and PRTR (Haldor Topsøe, 2017b) and the CO_2 emission from energy consumption reported to EU-ETS (Haldor Topsøe, 2017a). Implied emission factors were calculated for 2003-2009 using this method. For the years 1985-1995, the production is estimated using linear regression. Potential retention of CO_2 in the flue gas cleaning system has not been taken into account.

The emissions of NO_x, NH_3 and PM_{10} from *Catalysts and fertiliser production* are measured yearly from 1996 to 2016 (Haldor Topsøe, 2013 and 2017b). The emissions from 1985-1995 were calculated using an implied emission factor (average of 1997-2001).

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 of 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 (Haldor Topsøe, 2013) where these are available. 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 13-1, the annex includes the applied surrogate data.

Table 4.3.1 Source of activity data

Years	Determined by
1985-1995	Extrapolation by linear regression
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
2015-2016	Estimated using the fuel consumption as surrogate data and the average produced fraction of each product in relation to total production for 2003-2012

Table 4.3.2 Production of catalysts and potassium nitrate, Gg.

	1985	1990	1995	2000	2005	2010	2015	2016
Catalysts produced	16.8	23.7	30.5	36.4	46.5	46.4	62.4	57.7
Potassium nitrate produced	18.4	18.4	18.4	19.2	23.3	25.9	35.2	34.4
Total produced	35.2	42.1	48.9	55.6	69.7	72.3	97.5	92.2

Emission factors

The average calculated implied CO_2 emission factor for 2003-2009 is 0.0241 Mg CO_2 per Mg 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		Mg/Gg	Mg/Gg	Mg/Gg	Mg/Gg	Mg/Gg	kg/Gg
Range	0.02-0.03	0.32-1.76[3]	0.26-3.70[3]	0.11-0.70[3]	0.09-0.56[3]	0.06-0.42[3]	1.12-7.56[3]
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, [3]Average for 1997-2016.

PM_{10} 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 (2016) (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 Mg in 2000 to 123 Mg in 2010; in the same period the IEF fluctuates around the average 2.0 Mg per Gg product (2001-2010) but shows no trend. For the remaining time series, the NH_3 emission only varies between 9-21 Mg and the IEF has an average below 0.5 Mg per Gg product.

From 1990 to 2016, the emission of CO_2 from the production of catalysts / fertilisers has increased from 0.6 to 1.5 Gg with maximum in 2015 due to an increase in the activity 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 13-2, Figure 4.3.1 and Figure 4.3.2.

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

	1985	1990	1995	2000	2005	2010	2015	2016
CO_2	-	570	735	877	1120	1118	1503	1391
NO_x	20	29	37	39	36	17	23	23
NH_3	11	15	20	14	79	123	19	16
TSP	-	11	15	24	29	33	7	13
PM_{10}	-	9	12	19	23	26	6	10
$PM_{2.5}$	-	6.8	8.7	14.3	17.3	19.5	4.0	8.0
BC	-	0.12	0.16	0.26	0.31	0.35	0.07	0.14

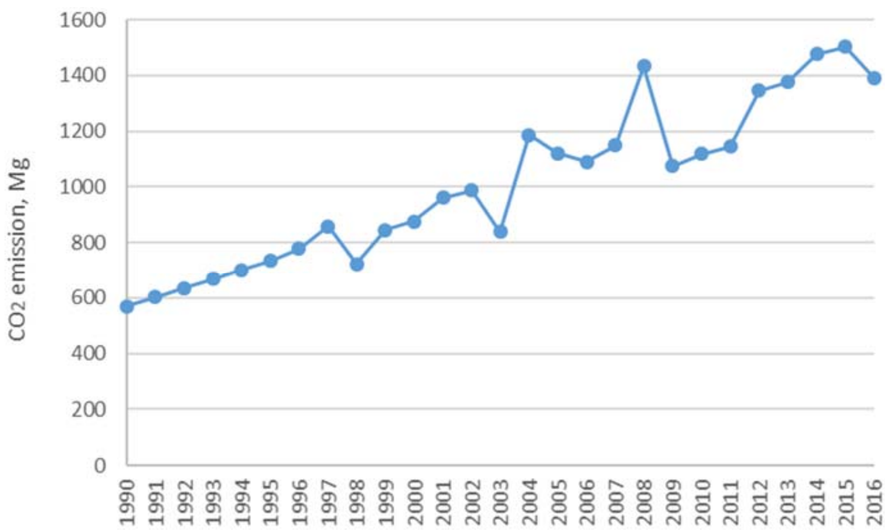


Figure 4.3.1 Emission of CO_2 *Catalyst and fertiliser production*, Mg.

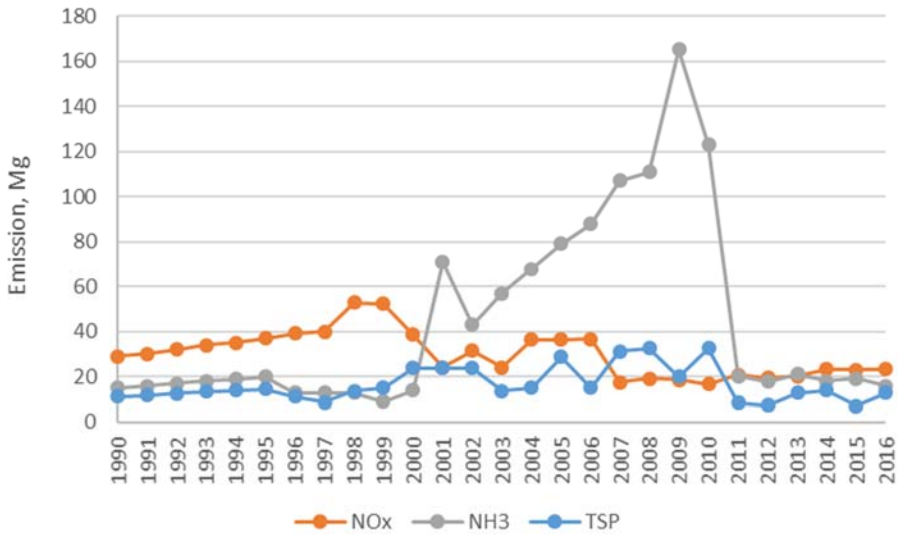


Figure 4.3.2 Emissions of NO_x, NH_3 and TSP from *Catalyst and fertiliser production*.

4.3.4 Time series consistency and completeness

There is an inconsistency between the methodology applied for 1997-2016 and the one applied for 1985-1995. The latter uses an average implied emission factor and projected activity data while emissions have been provided from the company since 1996. The source category of catalyst production is complete.

4.3.5 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	KNO_3, catalysts	Estimated
	1996-2012	KNO_3, catalysts	Haldor Topsøe (2013)
Surrogate data	2013-2014	Raw material consumption	Haldor Topsøe (2017b)
	2014-2016	Fuel consumption	Haldor Topsøe (2017a)
Emissions	1985-1995	CO_2, NO_x, NH_3	Estimated
	1996-2013	CO_2, NO_x, NH_3, PM_{10}	Haldor Topsøe (2013 and 2017b)
	All	PM_{10}, $PM_{2.5}$	Particle distribution from CEPMEIP
	All	BC	EMEP/EEA (2016)

4.4 Production of chemical ingredients

The production of chemical ingredients takes place at DuPont Nutrition Biosciences ApS (previously Danisco Grindsted) located in Grindsted (Danisco Grindsted, 2014). The following SNAP code is covered:

- 04 05 00 Production in organic chemical industry

The following pollutant is included 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 environmental report 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

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 Eriksen, 2017). Emissions for 1985- 1996 have been estimated. The production of farmaceutical products has ceased in 2017 and 2016 will therefore be the last year in the NMVOC timeseries.

The emission has decreased from the peak in 1999 of 103 Mg to 9 Mg NMVOC in 2016. However, no explanation can be given on this emission trend, as information on activity is not available. The NMVOC emissions are presented in Table 4.4.1 and Annex 14-1.

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

	1985	1990	1995	2000	2005	2010	2015	2016
NMVOC	44	75	87	62	16	12	10	9

4.4.4 Time series consistency and completeness

There is an inconsistency between the methodology applied for 1997-2016 and the one applied for 1985-1995. For 1985-1995, emissions are estimated using surrogate data from Statistics Denmark (2017) while emissions have been provided from the company since 1996. 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	1985-2016	Sale of own product, enzymes, emulgator etc.	Statistics Denmark (2017)
Emissions	1985-1996	NMVOC	Estimated
	1997-2013	NMVOC	Danisco Grindsted (2014)
	2014-2016	NMVOC	Eriksen (2017)

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
- NMVO

Because it is not possible to separate process and fuel emissions reported in the companys 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 known for 1990-2016 and 1990-2000+2013-2016 respectively (Cheminova, 2015 and Lundhus, 2017). For the years where data are not available, activity data are extrapolated and emissions are calculated using implied emission factors.

Activity data

Activity data for 1980-1995 are calculated using the national statistics on value of pesticides produced (million DKK) as surrogate data. For 2010-2016, no information on the production is available and activity data are estimated using expert 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 15-1.

Table 4.5.1 Production of pesticides, Gg.

	1980	1985	1990	1995	2000	2005	2010	2015	2016
Pesticides	20.8	42.0	37.7	45.3	60.3	53.5	40.0	60.0	60.0

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/Mg	Average[2], kg/Mg
Pesticides	SO_2	0.1 – 26.1	6.9
	NMVOC	0.4 - 10.4	1.8

[1]Interval for 1980/1985-2016.

[2]Average only for years where actual emissions and activity data are available; i.e. 1990-2016 for SO_2 and 1990-2000+2013-2016 for NMVOC.

4.5.3 Emission trend

The emission of NMVOC from production of pesticides was reduced significantly from 1985 to 1993. 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, 2008).

Emissions of NMVOC and SO_2 are presented in Figure 4.5.1, Table 4.5.3 and Annex 15-2.

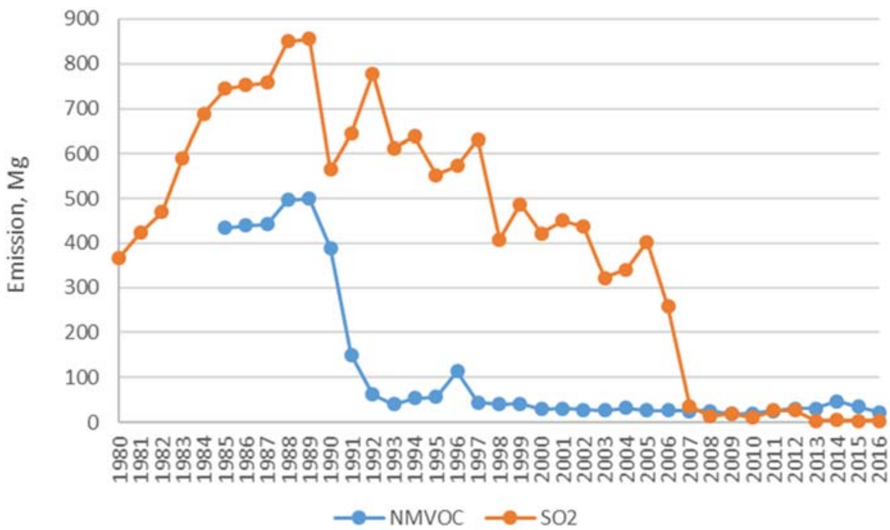


Figure 4.5.1 Emissions of SO_2 and NMVOC from pesticide production.

Table 4.5.3 Emissions from production of pesticides, Mg.

	1980	1985	1990	1995	2000	2005	2010	2015	2016
NMVOC	-	435.0	390.0	57.0	29.0	26.8	20.0	34.6	22.0
SO2	368.1	743.6	565.0	553.0	422.0	403.0	10.8	3.3	3.2

4.5.4 Time series consistency and completeness

There is an inconsistency between the methodology applied for 1990-2016 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 4.5.4.

Table 4.5.4 Input data for calculating emissions from production of pesticides.

	Year	Parameter	Comment/Source
Surrogate data	1980-2007	Production of pesticides,value	Statistics Denmark (2017)
Activity data	1996-2009	Production of pesticides, intermediate products, etc.	Cheminova (2010)
Emissions	1985-1989; 2001-2012	NMVOC	Estimated
	1990-2000	NMVOC	Cheminova (2010)
	2013-2016	NMVOC	Lundhus (2017)
	1980-1989	SO_2	Estimated
	1990-2009	SO_2	Cheminova (2010)
	2001; 2004; 2007-2014	SO_2	Cheminova (2015)
	2015-2016	SO_2	Lundhus (2017)

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: PAH

4.6.1 Process description

The description of the process is based on the environmental report by the company (Koppers, 2014). 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 °C 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 2002-2016 (Koppers, 2017) and estimated using surrogate data for 1980-2001. The emissions are known from measurements reported in the environmental reports (Koppers, 2017). 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 16-1.

Table 4.6.1 Activity data for Production of tar products, Gg.

	1980	1985	1990	1995	2000	2005	2010	2015	2016
Tar products	108	108	181	235	199	164	133	236	285

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	Mg/Gg	1.0	2002-2006	1980-2000
NMVOC	kg/Gg	5.0	2002-2006	1985-2000
Hg	g/Gg	67.8	2008	1990-2007
PAH	g/Gg	0.68	2005	1990-2016

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.

Trends for emissions of NMVOC, SO_2, Hg and PAH from *Production of tar products* are presented in Table 4.6.3 and Annex 16-2.

Table 4.6.3 Emissions from Production of tar products.

	Unit	1980	1985	1990	1995	2000	2005	2010	2015	2016
SO_2	Mg	108	108	181	235	199	212	105	153	33
NMVOC	Mg	-	0.54	0.91	1.18	1.00	1.00	1.40	0.93	9.91
Hg	kg	-	-	12.3	15.9	13.5	11.1	1.5	1.0	13.0
PAH	kg	-	-	0.12	0.16	0.14	0.11	0.09	0.16	0.19

4.6.4 Time series consistency and completeness

There is an inconsistency between the methodology applied for 1980-2001 (2007 for Hg) and the one applied for 2002-2016. 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). The source category of *Production of tar products* is 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 (2017)
Activity data	2002-2016	Production of tar products	Koppers (2017)
Emissions	1985-2000	NMVOC	Estimated
	2001-2016	NMVOC	Koppers (2017)
	1980-2000	SO_2	Estimated
	2001-2016	SO_2	Koppers (2017)
	1990-2007	Hg	Estimated
	2008-2016	Hg	Koppers (2017)

5. Metal industry

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

- Iron and steel production; see section 5.2
- Red bronze production; see section 5.3
- Magnesium production; see section 5.4
- Secondary aluminium production; see section 5.5
- Secondary lead production; see section 5.6

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

5.1 Emissions

The time series for emission of CO_2 from metal industry is presented in Figure 5.1.1 below.

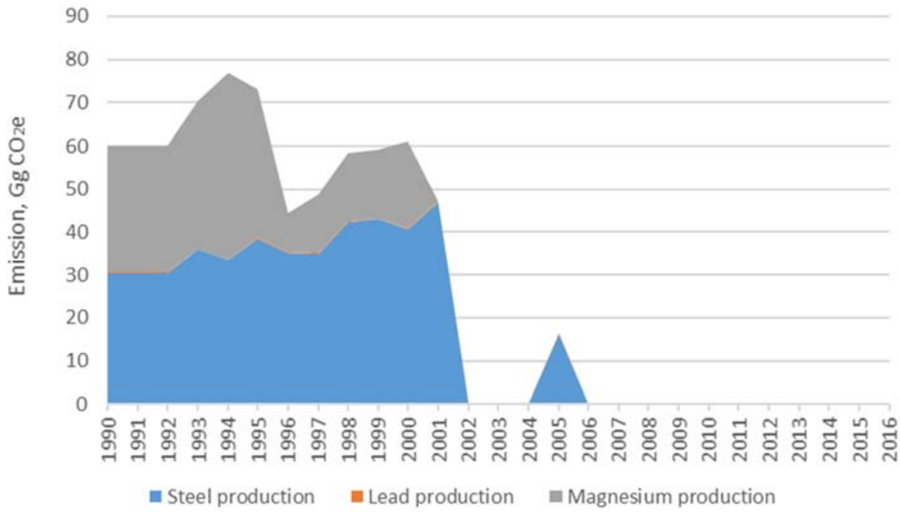


Figure 5.1.1 Emission of greenhouse gases from the individual source categories compiling 2C *Metal Industry*, Gg CO_2 equivalents.

From 1990 to 2001, the CO_2 emission from the electro steelwork increased by 55 % and from 1990-2000 SF_6 from *Magnesium production* decreased with 31 %. 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 (1990-2000).

Greenhouse gas emissions from *Secondary lead production* are miniscule (0.3-0.4 % for 1990-2000), but are the only greenhouse gas emissions in *Metal industry* that occur for the entire time series.

The electro steelwork was shut down in 2001, reopened and closed down again in 2005. In 2000, the SF_6 emission from the *Magnesium production* ceased. Grey iron foundries, *Secondary aluminium production* and *Red bronze production* are active for the entire time series but emit no process greenhouse gas emissions.

An overview of the 2016 emission of NMVOC, particulate matter, heavy metals, and POPs from *Metal industry* is available in Table 5.1.1.

Table 5.1.1 Overview of 2016 emissions from *Metal industry*.

	Total emission from metal industries		Fraction of IPPU	Largest contributor in metal industries	Emission from largest contributor		Fraction of metal industries
NMVOC	0.004	Gg	0.02%	2C1 Iron and steel production	0.004	Gg	100.0%
TSP	0.20	Gg	3.1%	2C1 Iron and steel production	0.20	Gg	99.4%
HMs	2.05	Mg	36.4%	Zn from 2C7c Other metal production	0.56	Mg	27.4%
POPs	0.06	kg	0.1%	PCBs from 2C1 Iron and steel production	0.05	kg	83.9%

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 interesting 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 reported for the year 2002. 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 they have not been subject to the same requirements to analyse emissions of heavy metals to air.

5.2 Iron and steel production

The production of semi-manufactured steel products (e.g. steel sheets/plates and bars) is 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.

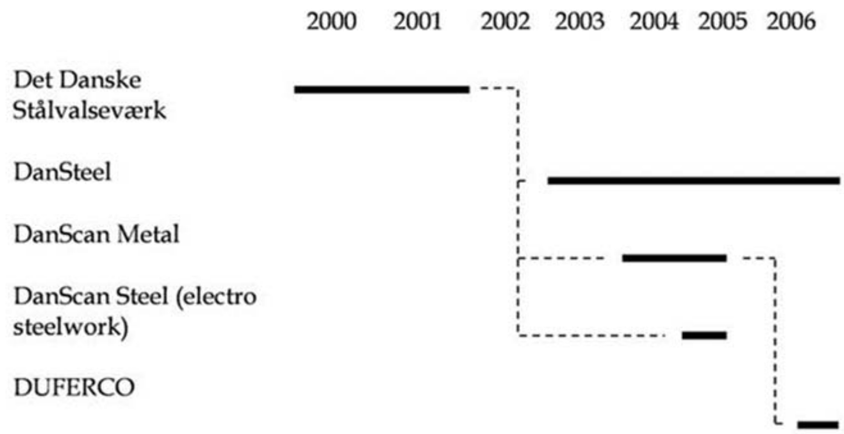


Figure 5.2.1 Timeline for production at the Danish steelwork.

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.

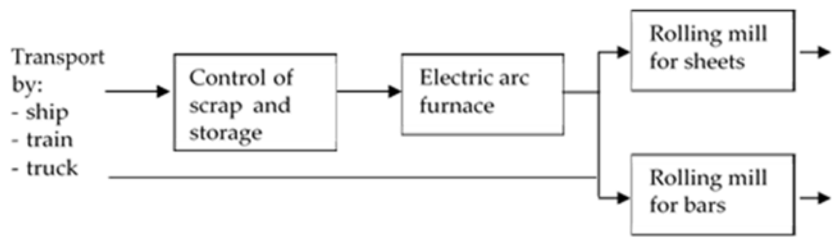


Figure 5.2.2 Overall flow-sheet for "Det Danske Stålvalseværk" (Stålvalseværket, 2002; DanSteel, 2014).

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 stochiometri:

- 3.667 Mg CO_2 per Mg 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 production of 1 Mg steel sheets - 2001 (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 Mg of product) has been almost constant from 1993 to 2001; steel sheets: 0.012-0.018 Mg metallurgical coke per Mg and steel bars: 0.011-0.017 Mg metallurgical coke per Mg.

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 been extrapolated.

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 Mg per year. The emissions from iron foundries are based on yearly production statistics from Statistics Denmark (2017), 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) supplemented with other literature (Jensen & Markussen, 1993). 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 17-1.

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

		1980	1985	1990	1995	2000	2005	2010	2015	2016
Det danske stålvalseværk										
Raw material	Iron and steel scrap	-	-	-	657	731	-			
Intermediate product	Steel slabs etc.	-	-	-	654	803	-			
Product	Steel sheets	-	-	444[1]	478	380	162			
	Steel bars	-	-	170[1]	239	251	88			
	Products, total	614	614	614	717	631	250[2]			
DanSteel										
Raw material	Steel slabs						515	457	525	566
Product	Steel sheets						433	381	441	480
Duferco										
Raw material	Steel billets							141	137	130
Product	Steel bars							129	129	123

[1]Extrapolation, [2]Assumed.

The mass balances/flow sheets presented in the annual environmental reports do not for all years provide information on 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 (2017) for the entire time series. The activity data are presented in Table 5.2.3 and Annex 17-2.

Table 5.2.3 Activity data, iron foundries, Gg.

	1990	1995	2000	2005	2010	2015	2016
Grey iron foundries	105	100	108	107	86	96	99

Emission factors

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

The applied steel production emission factors for the 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/Mg	60[6]	-
NO_x	g/Mg	130[6]	-
NMVOC	g/Mg	46[6]	7[6]
CO	kg/Mg	1.7[6]	-
TSP	g/Mg	61-68[4]	2.5-11.1[4]
PM_{10}	g/Mg	80 % of TSP[6]	2.4-10.5[4]
$PM_{2.5}$	g/Mg	70 % of TSP[6]	1.5-6.6[4]
BC	g/Mg	0.36 % of $PM_{2.5}$[6]	0.36 % of $PM_{2.5}$[6]
As	mg/Mg	15[6]	-
Cd	mg/Mg	10-80[2]	0.1-0.4[4]
Cr	mg/Mg	100[6]	-
Cu	mg/Mg	20[6]	-
Hg	mg/Mg	50-400[2,6]	-
Ni	g/Mg	0.4-1.4[2]	0.004-0.010[4]
Pb	g/Mg	1.0-5.0[2]	0.005[5]
Se	g/Mg	0.02[6]	-
Zn	g/Mg	3.6-19.0[2,6]	0.005[5]
HCB	mg/Mg	3.2[3]	-
PCDD/F	mg/Mg	0.8[6]	-
Total 4 PAHs	g/Mg	0.48[1,6]	-
PCB	mg/Mg	2.5[3]	-

[1] Divided by four for an estimate of the individual pollutants. [2] Illerup et al. (1999). [3] Nielsen et al. (2013a). [4] Implied emission factor. [5] Expert judgement. [6] EMEP/EEA (2016).

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/Mg	2000	CEPMEIP[1]
PM_{10}	g/Mg	600	CEPMEIP[1]
$PM_{2.5}$	g/Mg	90	CEPMEIP[1]
BC	% of $PM_{2.5}$	10	EMEP/EEA (2016)[2]
As	g/Mg	0.3	EMEP/Corinair (2007)[3]
Cd	g/Mg	0.1	EMEP/Corinair (2007)[3]
Cr	g/Mg	1.0	EMEP/Corinair (2007)[3]
Cu	g/Mg	1.0	EMEP/Corinair (2007)[3]
Hg	g/Mg	0.04	EMEP/Corinair (2007)[3]
Ni	g/Mg	0.3	EMEP/Corinair (2007)[3]
Pb	g/Mg	3.0	EMEP/Corinair (2007)[3]
Se	g/Mg	0.01	EMEP/Corinair (2007)[3]
Zn	g/Mg	5.0	EMEP/Corinair (2007)[3]
HCB	mg/Mg	0.04	Nielsen et al. (2013a)
PCB	mg/Mg	0.5	Nielsen et al. (2013a)

[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. The production ceased in 2001, reopened, and closed again in 2005; see Figure 5.2.1.

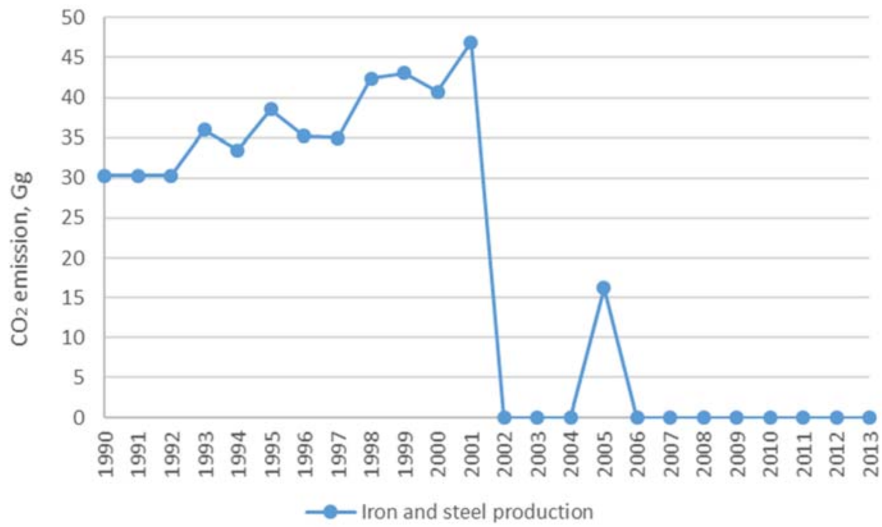


Figure 5.2.3 Emission of greenhouse gases from the production of steel from scrap.

Emissions from the electro steelwork, rolling mills and grey iron foundries are presented in Table 5.2.6 and Annex 17-3.

Table 5.2.6 Emissions from the electro steelwork, rolling mill and grey iron foundries.

Pollutant	Process	Unit	1980	1985	1990	1995	2000	2005	2010	2015	2016
CO_2	Electric furnace steel plant	Gg	-	-	30	39	41	16	NO	NO	NO
SO_2	Electric furnace steel plant	Mg	37	37	37	43	38	15	NO	NO	NO
NO_x	Electric furnace steel plant	Mg	-	80	80	93	82	33	NO	NO	NO
NMVOC	Total	Mg	-	28	28	33	29	15	3.6	4.0	4.2
	Electric furnace steel plant	Mg	-	28	28	33	29	12	NO	NO	NO
	Rolling mills	Mg	-	NO	NO	NO	NO	3.0	3.6	4.0	4.2
CO	Electric furnace steel plant	Mg	-	1.0	1.0	1.2	1.1	0.4	NO	NO	NO
TSP	Total	Mg	-	-	299	304	257	233	176	198	202
	Electric furnace steel plant	Mg	-	-	89	103	41	16	NO	NO	NO
	Rolling mills	Mg	-	-	NO	NO	NO	2.5	3.4	5.9	4.4
	Grey iron foundries	Mg	-	-	210	201	216	214	173	192	197
$PM_{2.5}$	Total	Mg	-	-	59	66	33	20	10	12	12
	Electric furnace steel plant	Mg	-	-	50	57	23	9	NO	NO	NO
	Rolling mills	Mg	-	-	NO	NO	NO	1.5	2.0	3.5	2.7
	Grey iron foundries	Mg	-	-	9	9	10	10	8	9	9
BC	Total	Mg	-	-	1.1	1.1	1.1	1.0	0.8	0.9	0.9
	Electric furnace steel plant	Mg	-	-	0.18	0.21	0.08	0.03	NO	NO	NO
	Rolling mills	Mg	-	-	NO	NO	NO	0.01	0.01	0.01	0.01
	Grey iron foundries	Mg	-	-	0.9	0.9	1.0	1.0	0.8	0.9	0.9
As	Total	kg	-	-	41	41	42	36	26	29	30
	Electric furnace steel plant	kg	-	-	9	11	9	4	NO	NO	NO
	Grey iron foundries	kg	-	-	31	30	32	32	26	29	30
Cd	Total	kg	-	-	49	32	27	18	9	10	10
	Electric furnace steel plant	kg	-	-	39	22	16	7	NO	NO	NO
	Grey iron foundries	kg	-	-	10	10	11	11	9	10	10
	Rolling mills	kg	-	-	NO	NO	NO	0.12	0.12	0.10	0.17
Cr	Total	kg	-	-	166	172	171	132	86	96	99
	Electric furnace steel plant	kg	-	-	61	72	63	25	NO	NO	NO
	Grey iron foundries	kg	-	-	105	100	108	107	86	96	99
Cu	Total	kg	-	-	117	115	120	112	86	96	99
	Electric furnace steel plant	kg	-	-	12	14	13	5	NO	NO	NO
	Grey iron foundries	kg	-	-	105	100	108	107	86	96	99
Hg	Total	kg	-	-	250	147	67	17	3.5	3.8	3.9
	Electric furnace steel plant	kg	-	-	246	143	63	13	NO	NO	NO
	Grey iron foundries	kg	-	-	4.2	4.0	4.3	4.3	3.5	3.8	3.9
Ni	Total	kg	-	-	788	460	284	136	30	32	33
	Electric furnace steel plant	kg	-	-	757	430	252	100	NO	NO	NO
	Grey iron foundries	kg	-	-	31	30	32	32	26	29	30
	Rolling mills	kg	-	-	NO	NO	NO	3.6	3.9	2.8	3.0
Pb	Total	kg	-	-	3282	2021	993	590	262	290	299
	Electric furnace steel plant	kg	-	-	2967	1720	669	266	NO	NO	NO
	Grey iron foundries	kg	-	-	315	301	324	322	259	288	296
	Rolling mills	kg	-	-	NO	NO	NO	2.2	2.5	2.8	3.0
Se	Total	kg	-	-	13	15	14	6.1	0.9	1.0	1.0
	Electric furnace steel plant	kg	-	-	12	14	13	5	NO	NO	NO
	Grey iron foundries	kg	-	-	1.0	1.0	1.1	1.1	0.9	1.0	1.0
Zn	Total	kg	-	-	12016	7049	3624	1438	434	482	496
	Electric furnace steel plant	kg	-	-	11492	6547	3085	900	NO	NO	NO
	Grey iron foundries	kg	-	-	524	502	539	536	432	479	493
	Rolling mills	kg	-	-	NO	NO	NO	2.2	2.5	2.8	3.0
HCB	Total	kg	-	-	2.0	2.3	2.0	0.8	0.003	0.004	0.004
	Electric furnace steel plant	kg	-	-	2.0	2.3	2.0	0.8	NO	NO	NO
	Grey iron foundries	kg	-	-	0.004	0.004	0.004	0.004	0.003	0.004	0.004
PCDD/F	Electric furnace steel plant	g	-	-	12	8	0.5	0.8	NO	NO	NO
PAH	Electric furnace steel plant	kg	-	-	295	344	303	120	NO	NO	NO
PCB	Total	kg	-	-	1.6	1.8	1.6	0.7	0.04	0.05	0.05
	Electric furnace steel plant	kg	-	-	1.5	1.8	1.6	0.6	NO	NO	NO
	Grey iron foundries	kg	-	-	0.05	0.05	0.05	0.05	0.04	0.05	0.05

NO: Not occurring.

Due to the change in production process in the beginning of the 2000s, the emissions (and even more so the implied emission factors) change drastically form 2001 to 2002 and from 2002 to 2003. Please refer to Figure 5.2.1 and Table 5.2.2.

5.2.4 Time series consistency and completeness

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

5.2.5 Input to CollectER

The input data / data sources for calculating emissions are presented in Table 5.2.7.

Table 5.2.7 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
	2003-2016	Final products	DanSteel (2016, 2017) and Duferco (2016, 2017)
	1990-2016	Sales statistics for grey iron products	Statistics Denmark (2017)
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)
	1990-2001	PM_{10}, $PM_{2.5}$	Distribution between TSP, PM_{10} and $PM_{2.5}$ from EMEP/EEA (2016)

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* pro- cesses:

- 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 are known to vary from 5 grams up to 2.5 Mg.

5.3.2 Methodology

Production data are available for 1991-1997 (Illerup et al., 1999), 1998-2009 (DSBF, 2010) and 1990-2016 (Statistics Denmark, 2017). Data from the Danish Foundry Industry Association (DSBF) are assumed to be most reliable (also the highest), while data from Statistics Denmark is used as surrogate data to ensure consistency.

Activity data

The activity data for calculating emissions are presented in Table 5.3.1 and Annex 18-1.

Table 5.3.1 Activity data for red bronze production, Mg.

	1990	1995	2000	2005	2010	2015	2016
Red bronze production	3895	4499	4304	5495	4632	3844	4018

Emission factors

The applied emission factors are presented in Table 5.3.2 and are all referenced to Illerup et al. (1999).

Table 5.3.2 Emission factors for *Red bronze production*.

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

5.3.3 Emission trends

Emissions trends for Cd, Cu, Pb, and Zn from *Red bronze production* are presented in Table 5.3.3 and Annex 18-2.

Table 5.3.3 Emissions from *Red bronze production*, kg.

	1990	1995	2000	2005	2010	2015	2016
Cd	3.9	4.5	4.3	5.5	4.6	3.8	4.0
Cu	39	45	43	55	46	38	40
Pb	58	67	65	82	69	58	60
Zn	545	630	603	769	648	538	563

5.3.4 Time series consistency and completeness

Data from DSBF is not consistent, but 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 assumed to be complete.

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 from DSBF	Illerup et al. (1999) and DSBF (2010)
	1990, 2010-2016	Production statistics	Estimated using surrogate data
Emission factors	1990-2016	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 in the magnesium production is known from Poulsen (2018). The production ceased to use SF_6 in 2000. Activity data can be calculated from the cover gas (SF_6) consumption and the default Tier 1 emission factor (A release of 100 %) is based on the IPCC guidelines (IPCC, 2006).

Activity data

Table 5.4.1 presents the calculated activity data.

Table 5.4.1 Production of magnesium, Mg.

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

Emission factors

The applied emission factor is 1 kg SF_6 per Mg produced magnesium (IPCC, 2006).

5.4.3 Emission trends

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.

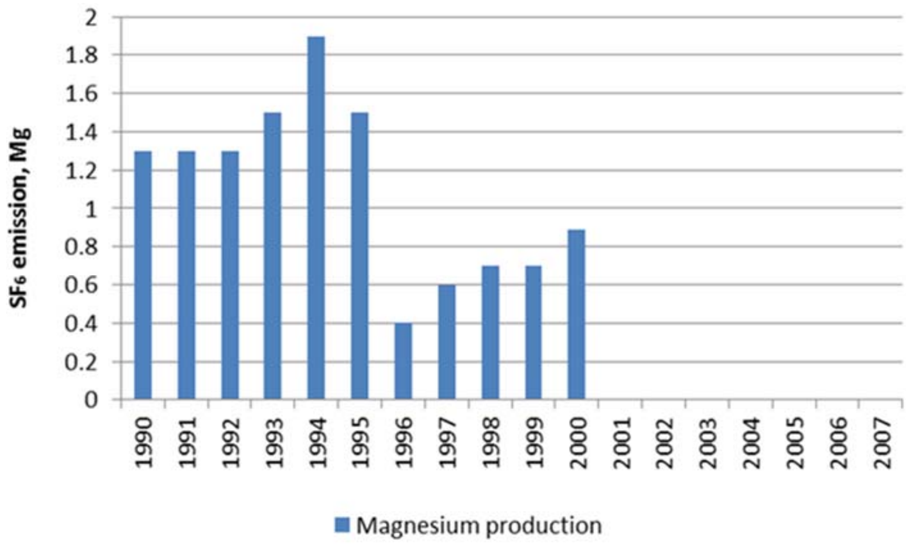


Figure 5.4.1 Emission of greenhouse gases from *Magnesium production*.

5.4.4 Time series consistency and completeness

The time series for *Magnesium production* is considered both consistent and complete.

5.4.5 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	1990-2000	Magnesium production	Poulsen (2018)
Emission	1990-2000	SF_6 emission factor	IPCC (2006)

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, reverbatory 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 ultimo 2008.

Activity data

The activity data are known from the company's environmental reports (Stena Aluminium, 2008) for 1996-2008 and are presented in Table 5.5.1 and Annex 19-1.

Table 5.5.1 Activity data for *Secondary aluminium production*, Gg.

	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	Source
TSP	kg/Mg	0.12	Average IEF (1998-2000)
PM_{10}	% of TSP	70.0	EMEP/EEA (2016)
$PM_{2.5}$	% of TSP	27.5	EMEP/EEA (2016)
BC	% of $PM_{2.5}$	2.3	EMEP/EEA (2016)
Cd	g/Mg	0.03	Average IEF (1998-2000)
Pb	g/Mg	0.15	Average IEF (1998-2000)
HCB	mg/Mg	20.0	Nielsen et al. (2013a)
PCDD/F	mg/Mg	0.035	EMEP/EEA (2016)
PCB	mg/Mg	3.4	Nielsen et al. (2013a)

5.5.3 Emission trends

Emissions from *Secondary aluminium production* are available in Table 5.5.3 and Annex 19-2.

Table 5.5.3 Emissions from Secondary aluminium production.

	Unit	1990	1995	2000	2005	2006	2007	2008
TSP	Mg	3.6	3.6	3.9	2.8	3.8	4.2	4.3
PM_{10}	Mg	2.5	2.5	2.8	2.0	2.6	2.9	3.0
$PM_{2.5}$	Mg	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 (2017). These two data sets show good agreement with only smaller fluctuations; see Figure 5.5.1.

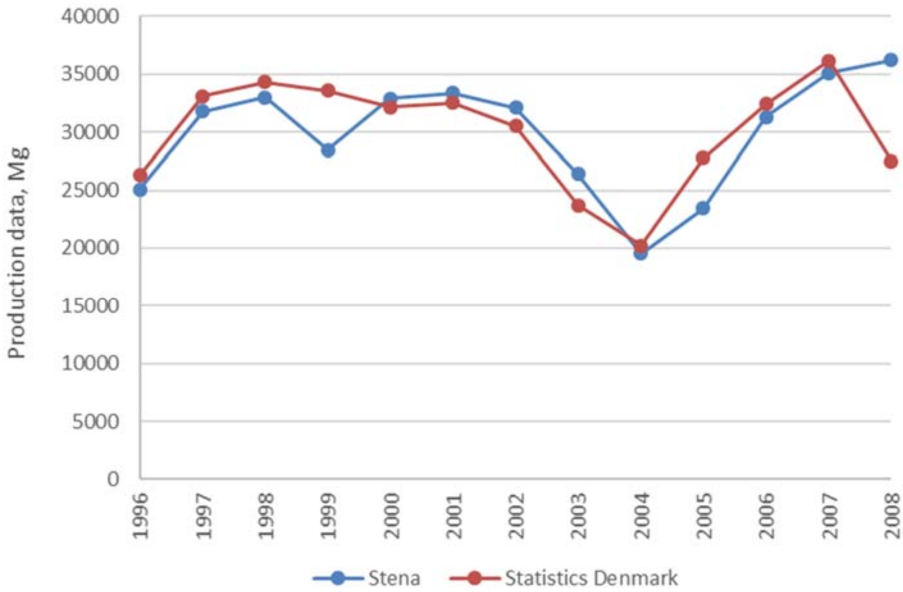


Figure 5.5.1 Comparison of production data from Stena and Statistics Denmark.

5.5.5 Time series consistency and completeness

The time series for *Secondary aluminium production* is considered 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	Calculated
Emission	1990-2008	Emission factors	Stena (2008), EMEP/EEA (2016), Nielsen et al. (2013a)

5.6 Secondary lead production

Only one Danish company; Hals Metal, has been identified as producing secondary lead from scrap 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 following SNAP category is covered:

- 03 03 07 Secondary lead production

Emissions of the following pollutants are included for the *Secondary lead production*:

- CO_2
- Particulate matter: TSP, PM_{10}, $PM_{2.5}$
- Heavy metals: As, Cd, Pb, Zn
- Persistent organic pollutants: HCB, PCDD/F, PCBs

5.6.1 Process description

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 is 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 from Hals Metal are provided by the company for the entire time series (Hals Metal, 2017). A clause affected in 2002 meant that Hals Metal could no longer burn cables containing lead. The processing of cables was therefore stopped and the company's activity changed to melting. 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 craftsmen and poorly regulated. However, an estimate by Lassen et al. (2004) stated that 200-300 Mg lead tiles were recast in 2000. Since the building stock worthy of preservation is constant, it is considered reasonable to let the activity of recasting of lead tiles be constant at this level.

Activity data

Activity data for *Secondary lead production* are shown in Table 5.6.1 and Annex 20-1.

Table 5.6.1 Activity data for *Secondary lead production*, Mg.

	1990	1995	2000	2005	2010	2015	2016
Hals metal	540	750	540	691	635	745	475
Lead tiles	250	250	250	250	250	250	250
Total	790	1000	790	941	885	995	725

Emission factors

The applied emission factors are presented in Table 5.6.2.

Table 5.6.2 Emission factors for *Secondary lead production*.

Pollutant	Value	Unit	Reference
CO_2	0.2	Mg/Mg	IPCC (2006)
TSP	1.63	kg/Mg	EMEP/EEA (2013)
PM_{10}	1.30	kg/Mg	EMEP/EEA (2013)
$PM_{2.5}$	0.65	kg/Mg	EMEP/EEA (2013)
As	3.5	g/Mg	EMEP/EEA (2013)
Cd	1.1	g/Mg	EMEP/EEA (2013)
Hg	0.47	g/Mg	Average IEF (2008-2010)
Pb	426	g/Mg	EMEP/EEA (2013)
Zn	2.6	g/Mg	EMEP/EEA (2013)
HCB	0.3	mg/Mg	Nielsen et al. (2013a)
PCDD/F	8.0	µg/Mg	EMEP/EEA (2013)
PCB	7.3	mg/Mg	Nielsen et al. (2013a)

5.6.3 Emission trends

Emissions from secondary lead production are presented in Table 5.6.3, Annex 20-2 and for CO_2, also in Figure 5.6.1.

Table 5.6.3 Emissions from *Secondary lead production*.

	Unit	1990	1995	2000	2005	2010	2015	2016
CO_2	Gg	0.2	0.2	0.2	0.2	0.2	0.2	0.1
TSP	Mg	1.3	1.6	1.3	1.5	1.4	1.6	1.2
PM_{10}	Mg	1.0	1.3	1.0	1.2	1.2	1.3	0.9
$PM_{2.5}$	Mg	0.5	0.7	0.5	0.6	0.6	0.6	0.5
As	kg	2.8	3.5	2.8	3.3	3.1	3.5	2.5
Cd	kg	0.9	1.1	0.9	1.0	1.0	1.1	0.8
Hg	kg	0.4	0.5	0.4	0.4	0.4	0.5	0.3
Pb	kg	337	426	337	401	377	424	309
Zn	kg	2.1	2.6	2.1	2.4	2.3	2.6	1.9
HCB	g	0.2	0.3	0.2	0.3	0.3	0.3	0.2
PCDD/F	mg	6.3	8.0	6.3	7.5	7.1	8.0	5.8
PCB	g	5.7	7.3	5.7	6.8	6.4	7.2	5.3

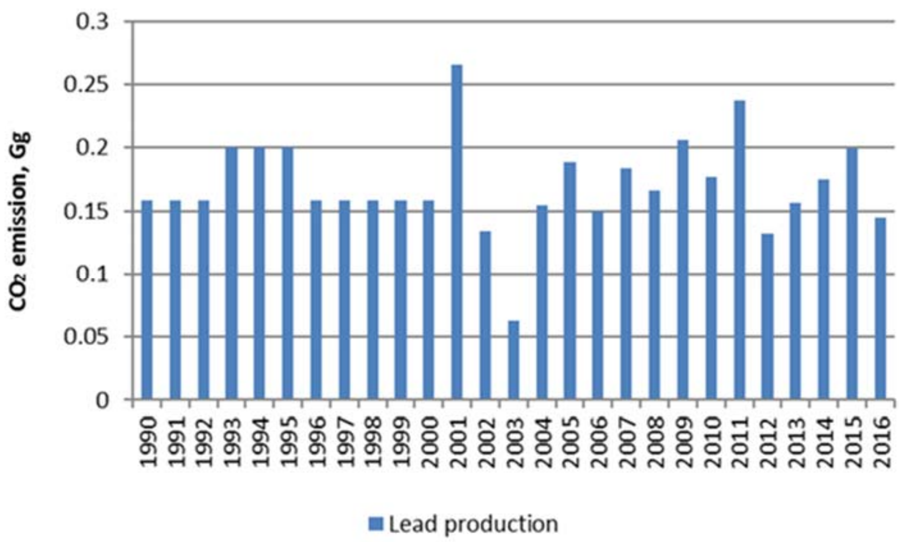


Figure 5.6.1 Emission of greenhouse gases from *Secondary lead production*.

5.6.4 Time series consistency and completeness

The time series for *Secondary lead production* is considered both consistent and complete.

5.6.5 Input to CollectER

The input data / data sources A clause affected 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	1990-2016	Production data	Hals Metal (2017), estimated from Lassen et al. (2004)
Emission	1990-2016	Emission factor	IPCC (2006), EMEP/EEA (2013), Nielsen et al. (2013a)

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; see section 6.2
- Paraffin wax use; see section 6.3
- Solvent use; see section 6.4
- Road paving with asphalt; see section 6.5
- Asphalt roofing; see section 6.6
- Urea-based catalysts; see section 6.7

6.1 Emissions

The time series for emission of greenhouse gases from *Non-Energy Products from Fuels and Solvent Use* (2D) is presented in Annex 21-1 and in Figure 6.1.1 below.

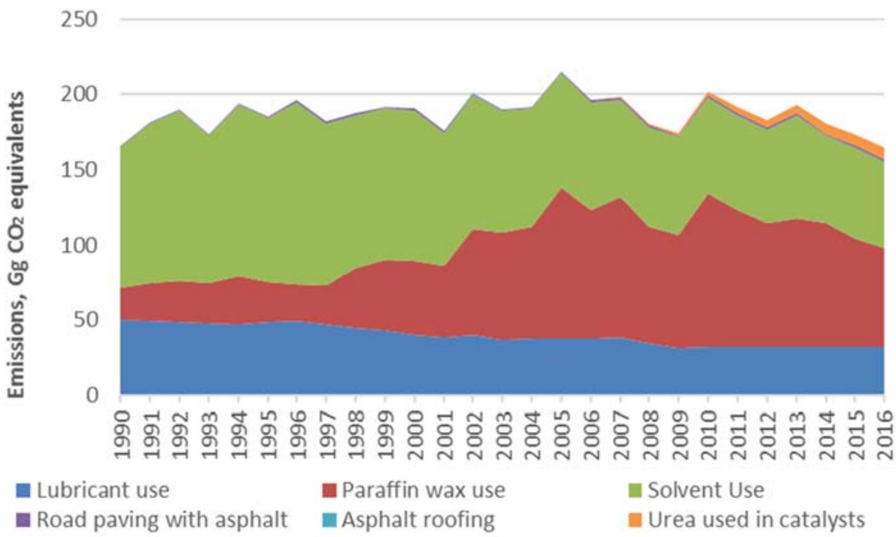


Figure 6.1.1 Emission of greenhouse gases from the individual source categories compiling *2D Non-Energy Products from Fuels and Solvent Use*, Gg CO_2 equivalents.

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 (36 % 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 from 2005 forth.

An overview of the 2016 emission of NMVOC, CO, particulate matter and POPs from *Non-energy products from fuels and solvent use* is available in Table 6.1.1.

Table 6.1.1 Overview of 2016 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	25.32	Gg	90.6%	2D3i Other solvent use	18.36	Gg	72.5%
CO	0.66	Gg	24.8%	2D3b Road paving with asphalt	0.43	Gg	65.6%
TSP	0.22	Gg	3.3%	2D3b Road paving with asphalt	0.18	Gg	84.3%
POPs	0.21	kg	0.4%	PAHs from 2D3h Paraffin wax use	0.21	kg	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 emissions 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):

$$E_{CO_2} = LC \bullet CC_{lubricant} \bullet ODU_{lubricant} \bullet 44/12$$

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 DEA (2017) along with the calorific value of 41.9 GJ/Mg. The consumption is presented in Table 6.2.1 and the complete time series in Annex 22-1.

Table 6.2.1 Consumption of lubricants, Gg.

	1990	1995	2000	2005	2010	2015	2016
Lubricants	80.5	79.1	64.3	60.9	51.3	51.3	51.3

Emission factors

The emission factor is calculated as the product: $CC_{lubricant} * ODU_{lubricant} * 44/12$ in the equation above, and yields an emission factor of 14.7 kg CO_2 per TJ or 0.617 Mg CO_2 per Mg 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 lubricants	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 trends

The time series for CO_2 emission from oxidation of lubricants during use is presented in Table 6.2.3 and Annex 21-1.

Table 6.2.3 Emissions from oxidation of lubricants during use, Gg.

	1990	1995	2000	2005	2010	2015	2016
Lubricants	49.7	48.8	39.7	37.6	31.7	31.7	31.7

6.2.4 Time series consistency and completeness

The applied methodology has been the same for all years with activity data based on information from the Danish Energy Agency and using the same emission factor. Since activity data are available from the energy statistics (DEA, 2017) 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	1990-2016	Consumption	DEA (2017)
Emission factor	1990-2016	Emission factor based on default factors	IPCC (2006)

6.3 Paraffin wax use

The category *Paraffin wax use* (CRF 2D2 / NFR 2D3h[9]) covers the following activity:

- 06 06 06 Paraffin wax use (Combustion of 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

[9] There is no NFR category for paraffin wax use, emissions from this category have therefore been placed in NFR 2D3h (Printing).

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 incinerated or used in wastewater treatment. The latter cases should be reported in the *Energy* or *Waste* sectors, respectively. These are therefore not included in this report.

In the Danish inventory, emissions only include the main emission source; i.e. combustion of candles.

6.3.2 Methodology

The emissions are calculated from activity data and emission factors. The methodology complies to a Tier 2 (IPCC, 2006).

Activity data

The activity data are derived from import, export and production data from Statistics Denmark (2017) and are expressed in Gg used candles. The activity data are presented in Table 6.3.1 and Annex 23-1.

Table 6.3.1 Activity data for *Paraffin wax use*, Gg.

	1985	1990	1995	2000	2005	2010	2015	2016
Paraffin wax use	10.9	7.4	9.1	16.9	34.4	35.2	24.9	22.7

Emission factors

Default emission factors that are constant for the entire time series are compiled from the scientific literature, see Table 6.3.2.

Table 6.3.2 Emission factors for *Paraffin wax use*.

	Unit	Paraffin wax use	Source
CO_2	Gg/Gg	2.91	Shires et al. (2004)
CH_4	Mg/Gg	0.121	Shires et al. (2009)
N_2O	Mg/Gg	0.024	Shires et al. (2009)
CO	Mg/Gg	10	Hamins et al. (2005)
TSP	Mg/Gg	1.34	Fine et al. (1999)
PM_{10}	Mg/Gg	1.34	Expert judgement
$PM_{2.5}$	Mg/Gg	1.34	Expert judgement
PCDD/F	mg/Gg	0.027	Lau et al. (1997)
Benzo(k)fluoranthene	g/Gg	4.64	Fine et al. (1999)
Benzo(a)pyrene	g/Gg	3.71	Fine et al. (1999)
Indeno(1,2,3-cd)pyrene	g/Gg	0.93	Fine et al. (1999)

6.3.3 Emission trends

Emissions from *Paraffin wax use* are presented in Table 6.3.3 and Annex 23-2.

Table 6.3.3 Emissions from the use of paraffin wax use.

	Unit	1985	1990	1995	2000	2005	2010	2015	2016
CO_2	Gg	-	21.7	26.5	49.3	100.2	102.3	72.6	65.9
CH_4	Mg	-	0.9	1.1	2.0	4.2	4.3	3.0	2.7
N_2O	Mg	-	0.2	0.2	0.4	0.8	0.8	0.6	0.5
CO_2e	Gg	-	21.7	26.6	49.4	100.6	102.7	72.8	66.1
CO	Mg	109	74	91	169	344	352	249	227
TSP	Mg	-	10	12	23	46	47	33	30
PM_{10}	Mg	-	10	12	23	46	47	33	30
$PM_{2.5}$	Mg	-	10	12	23	46	47	33	30
PCDD/F	mg	-	0.20	0.25	0.46	0.93	0.95	0.67	0.61
Benzo(k)fluoranthene	g	-	35	42	79	160	163	116	105
Benzo(a)pyrene	g	-	28	34	63	128	130	93	84
Indeno(1,2,3-cd)pyrene	g	-	6.9	8.5	15.7	32.0	32.7	23.2	21.1

The emissions have increased since 1990, which is caused by an increase in the used amounts since the emission factors are constant throughout the time series.

The decrease in the later years is believed to be caused by an increased awareness on indoor climate / pollution and an increased sale of LED candles.

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	1985-2016	Used amount (Import + Production – Export)	Statistics Denmark (2017)
Emission factors	1985-2016	Emission factors	Literature study

6.4 Solvent use

The category *Solvent use* (CRF / NFR 2D3 Other) is aggregated according to the following four categories, which correspond to the grouping in IPCC (2006):

- 06 01 Paint application
- 06 02 Degreasing, dry cleaning and electronics
- 06 03 Chemical products manufacturing or processing
- 06 04 Other use of solvents and related activities

Only NMVOC, which is subsequently oxidised to CO_2 in the atmosphere, is relevant for these categories.

6.4.1 Process description

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 typically the dominant source of anthropogenic NMVOC emissions (UNFCCC, 2008; Pärt, 2005; Karjalainen, 2005). 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 indoor and outdoor and the majority of solvent eventually 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. The sum of emissions of all estimated pollutants used as solvents equals the pollutant emission from solvent use. The model is readily updated on a yearly basis.

The method is mainly based on the detailed approach and methodology described in EMEP/EEA (2016) and IPCC (2006), and emissions are calculated for industrial sectors, households for the four categories (listed in Chapter 6.4 Solvent use), as well as for individual pollutants.

For each pollutant or product, a mass balance is formulated:

Consumption = (production + import) – (export + destruction/disposal + hold-up)

Data on produced, imported and exported amounts of solvents and solvent containing products are collected from Statistics Denmark (2017). Manufacturing and trading industries are committed to reporting production and trade figures to the Danish Customs & Tax Authorities in accordance with the Combined Nomenclature, from 1990 to present.

Destruction and disposal of solvents lower the pollutant emissions. In principle, this amount must be estimated for each pollutant 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 pollutants, 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. 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 pollutants may be represented as individual pollutants and in chemical groups, e.g. “o-xylene”, “mixture of xylenes” and “xylene”. Some pollutants are better inventoried as a group rather than individual pollutants due to missing information on use or emission for the individual pollutants. The Danish inventory considers single pollutants with a few exceptions.

Pollutant list

The definitions of solvents and (NM)VOC that are used in the Danish emission inventory, are as defined in the solvent directive (Directive 1999/13/EC) of the EU legislation. This states that: “Organic solvent shall mean any VOC which is used alone or in combination with other agents, and without undergoing a chemical change, to dissolve raw materials, products or waste materials, or is used as a cleaning agent to dissolve contaminants, or as a dissolver, or as a dispersion medium, or as a viscosity adjuster, or as a surface tension adjuster, or a plasticiser, or as a preservative”. VOCs are defined as follows: “Volatile organic compound shall mean any organic compound having at 293.15 K a vapour pressure of 0.01 kPa or more, or having a corresponding volatility under the particular condition 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).

The Danish list of NMVOCs comprises approx. 30 pollutants or pollutant groups representing more than 95 % of the total emission from solvent use, see Table 6.4.1

Table 6.4.1 2016 NMVOC emissions of single pollutants or pollutant groups.

Pollutant	CAS no	Emissions, Mg
ethanol	64-17-5	8379
turpentine (white spirit: stoddard	64742-88-7	5736
solvent and solvent naphtha)	8052-41-3	
propyl alcohol	67-63-0	2456
pentane	109-66-0	1943
propylene glycol	57-55-6	1358
cyanates	79-10-7	1236
methanol	67-56-1	1231
acetone	67-64-1	604
1-butanol	71-36-3	316
butanone	78-93-3	194
glycol ethers	110-80-5	283
	107-98-2	
	108-65-6	
	34590-94-8	
	112-34-5	
	and others	
propane	74-98-6	282
butane	106-97-8	282
ethylene glycol	107-21-1	212
xylenes	1330-20-7	199
	95-47-6	
	108-38-3	
	106-42-3	
cyclohexanones	108-94-1	118
toluene	108-88-3	93.1
formaldehyde	50-00-0	89.2
butanoles	78-92-2	66.6
	2517-43-3	
	and others	
styrene	100-42-5	44.9
phenol	108-95-2	42.9
ethyl acetate	141-78-6	36.8
acyclic aldehydes	78-84-2	31.9
	111-30-8	
	and others	
butyl acetate	123-86-4	24.6
tetrachloroethylene	127-18-4	0.5
Total		25,260

Activity data

Activity data for pollutants are primarily calculated from the equation presented in Chapter 6.4.2 Methodology with input from Statistics Denmark (2017). 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 pollutants by assessing the amount of pollutants that is comprised within products belonging to each of the four categories. The complete time series is presented in Annex 24-1.

Table 6.4.2 Activity data for *Solvents use*, Gg.

	1985	1990	1995	2000	2005	2010	2015	2016
Coating applications	165.2	82.2	91.1	104.3	74.2	44.8	42.9	41.0
Degreasing and Dry cleaning	2.09	1.41	1.53	0.59	0.37	0.25	0.15	0.06
Chemical products manufacturing or processing	267	406	504	567	740	641	500	474
Other use of solvents and related activities[1]	315	207	256	240	213	178	178	168

[1]Domestic solvent use including fungicides, Printing and Other solvent use.

Emission factors

For each pollutant, the emission is calculated by multiplying the consumption with the fraction emitted (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).

In Table 6.4.3 and Annex 24-2 the emission factors are listed. Emission factors are based on values from EMEP / EEA (2016) 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	2016
Coating applications	NMVOC	Mg/Gg	70	60	63	60	56	58	61	62
	CO_2	Mg/Gg	-	156	160	152	139	144	147	153
Degreasing and Dry cleaning	NMVOC	kg/Gg	50	50	50	50	50	50	50	50
	CO_2	kg/Gg	-	27	27	27	27	27	27	27
Chemical products manufacturing/processing	NMVOC	Mg/Gg	42	20	18	12	8	8	9	9
	CO_2	Mg/Gg	-	48	44	30	21	20	24	23
Other use of solvents and related activities	NMVOC	Mg/Gg	128	123	119	119	100	112	109	109
	CO_2	Mg/Gg	-	298	281	283	234	251	239	241

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, scientific reports and information from the internet.

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 (CRF 3D3 Other-Solvent Use) include the propellant (propane and butane) and solvents. Propellants comprise, according to communication with the Association of Danish Aerosol Industries (Aerosol Industriens Brancheforening) and FORCE (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. Ninety % 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 Gg 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 trends

Table 6.4.4, Figure 6.4.1, Figure 6.4.2 and Annex 24-3 show the emissions of CO_2 and NMVOC, where the used amounts of single pollutants have been assigned to specific products and NFR sectors. A general increase is seen for all sectors from 1990 to 1996 followed by a decrease from 1997 to 2006 and stagnation in the period 2007 to 2016, with a slight increase in 2013.

Table 6.4.4 Emissions from *Solvent use*

	Unit	1985	1990	1995	2000	2005	2010	2015	2016
CO_2 emissions									
Coating applications	Gg	-	12.8	14.6	15.8	10.3	6.5	6.3	6.3
Degreasing and Dry cleaning	Mg	-	0.037	0.041	0.016	0.010	0.007	0.004	0.002
Chemical products manufacturing or processing	Gg	-	19.4	22.0	17.0	15.6	12.5	11.8	11.0
Other use of solvents and related activities	Gg	-	61.4	72.1	67.6	49.9	44.7	42.5	40.6
Total CO_2	Gg	-	93.6	108.6	100.4	75.8	63.7	60.6	57.8
NMVOC emissions									
Coating applications	Gg	11.6	5.0	5.8	6.3	4.2	2.6	2.6	2.6
Degreasing and Dry cleaning	Mg	0.104	0.071	0.077	0.029	0.018	0.012	0.008	0.003
Chemical products manufacturing or processing	Gg	11.2	8.1	9.3	7.0	6.2	5.0	4.7	4.3
Other use of solvents and related activities	Gg	40.4	25.3	30.6	28.4	21.4	20.0	19.4	18.4
Total NMVOC	Gg	63.3	38.4	45.6	41.6	31.8	27.7	26.8	25.3

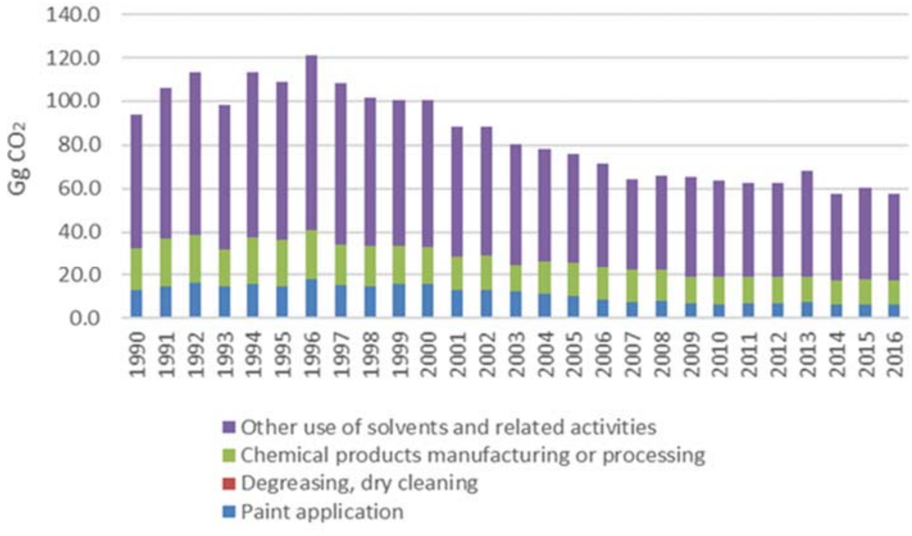


Figure 6.4.1 CO_2 emissions from *Solvent use*, Gg.

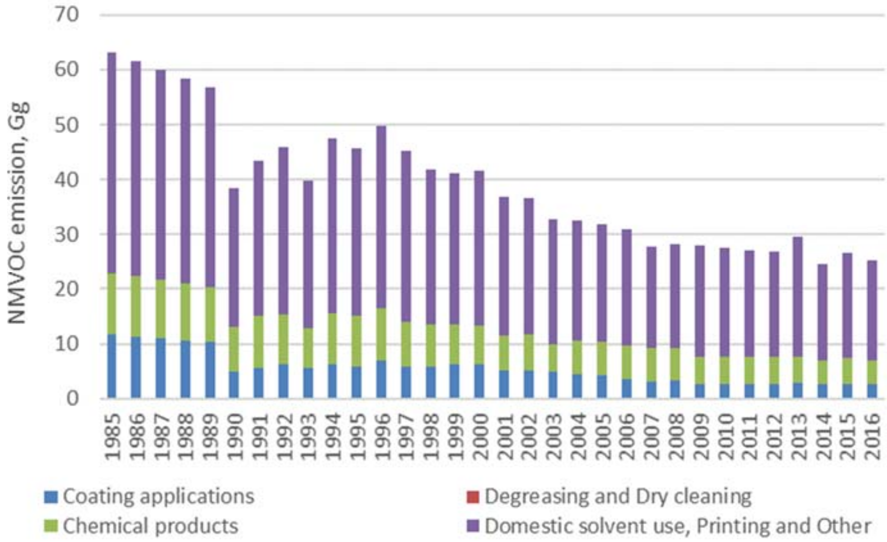


Figure 6.4.2 NMVOC emissions from *Solvent use*, Gg.

In Table 6.4.1, the emission for 2016 is split into individual pollutants. 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.

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, the total emission values are similar to the emissions found in the present approach.

Production and import/export data from Statistics Denmark for single chemicals can be directly compared with data from Eurostat for other countries. This has been done for a few chosen products/chemicals and countries.

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 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	1985-2016	Import, Export, Production	Statistics Denmark (2017), Expert judgement
Emission factors	1985-2016	Emission factors	EMEP/EEA (2016), Expert judgement

6.5 Road paving with asphalt

The category *Road paving with asphalt* (CFR / NFR 2D3) 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. The raw materials for road paving are prepared on a plant 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.

6.5.2 Methodology

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)

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 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 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.

Activity data

The use amounts of asphalt for road paving have been compiled from production, import and export statistics of asphalt products in Statistics Denmark (2017) and are presented in Table 6.5.1 and Annex 25-1.

Table 6.5.1 Activity data for asphalt in road paving, Gg.

	1985	1990	1995	2000	2005	2010	2015	2016
Road paving with asphalt	2743	2535	3144	2933	3879	3005	3440	3600

Emission factors

Default tier 1 emission and abatement factors are derived from EMEP/EEA (2016) and US EPA (2004).

Table 6.5.2 Emission factors for *Road paving with asphalt*.

	Unit	Road paving with asphalt (incl. cutback)	Abatement factors[1], %
CO_2	kg/Mg	0.23[2]	-
CH_4	g/Mg	4.4	-
NMVOC	g/Mg	16	-
CO	g/Mg	120	-
TSP	g/Mg	50	99.6
PM_{10}	g/Mg	49	98.4
$PM_{2.5}$	g/Mg	6.6	98.4
BC	g/Mg	0.37	98.4

[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.

6.5.3 Emission trends

Emissions from *Road paving with asphalt* are presented in Table 6.5.3 and Annex 25-2.

Table 6.5.3 Emissions from *Road paving with asphalt*, Mg.

	1985	1990	1995	2000	2005	2010	2015	2016
CO_2	-	583	723	675	892	691	791	828
CH_4	-	11	14	13	17	13	15	16
NMVOC	44	41	50	47	62	48	55	58
CO	330	305	378	353	466	361	414	433
TSP	-	128	158	148	195	151	173	181
PM_{10}	-	125	155	144	191	148	169	177
$PM_{2.5}$	-	16.6	20.6	19.2	25.4	19.7	22.6	23.6
BC	-	0.95	1.18	1.10	1.45	1.12	1.29	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 6.4.5 Input data for calculating emissions from *Road paving with asphalt*.

	Year	Parameter	Comment/Source
Activity data	1985-2016	Use amounts	Statistics Denmark (2017)
Emission factors	1985-2016	Emission factors	EMEP/EEA (2016), 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 the process of polymerising and stabilising asphalt to improve its weathering characteristics, and it may take place in an asphalt processing or roofing plant, or in a refinery. Only asphalt blowing is covered in IPCC (2006) and in the Danish inventory, as it leads to the highest emissions of NMVOC and CO in the total production and roofing process.

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.

Activity data

The use amounts of asphalt for roofing have been compiled from production, import and export statistics of asphalt products in Statistics Denmark (2017). Activity data are presented in Table 6.6.1 and Annex 26-1.

Table 6.6.1 Activity data for *Asphalt roofing*, Gg.

	1985	1990	1995	2000	2005	2010	2015	2016
Asphalt roofing	40.6	42.5	42.6	67.1	54.9	33.0	39.9	35.7

Emission factors

Default emission and abatement factors are derived from EMEP/EEA (2016) and US EPA (2004) and are presented in Table 6.6.2.

Table 6.6.2 Emission factors for *Asphalt roofing* (asphalt blowing).

	Unit	Asphalt roofing	Abatement factors[1], %
CO_2	kg/Mg	0.40[2]	-
NMVOC	g/Mg	130	-
CO	g/Mg	9.5	-
TSP	g/Mg	96	94
PM_{10}	g/Mg	24	94
$PM_{2.5}$	g/Mg	4.8	94
BC	mg/Mg	0.60	94

[1]The abatement factors have already been subtracted from the presented emission factors. [2]Indirect CO_2 emissions calculated from NMVOC and CO.

6.6.3 Emission trends

Emissions from *Asphalt roofing* are presented in Table 6.6.3 and Annex 26-2.

Table 6.6.3 Emissions from *Asphalt roofing*.

	Unit	1985	1990	1995	2000	2005	2010	2015	2016
CO_2	Mg	-	17.0	17.0	26.8	22.0	13.2	16.0	14.3
NMVOC	Mg	5.3	5.5	5.5	8.7	7.1	4.3	5.2	4.6
CO	Mg	0.39	0.40	0.40	0.64	0.52	0.31	0.38	0.34
TSP	Mg	-	4.1	4.1	6.4	5.3	3.2	3.8	3.4
PM_{10}	Mg	-	1.0	1.0	1.6	1.3	0.8	1.0	0.9
$PM_{2.5}$	Mg	-	0.20	0.20	0.32	0.26	0.16	0.19	0.17
BC	kg	-	0.026	0.026	0.040	0.033	0.020	0.024	0.021

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	1985-2016	Use amounts	Statistics Denmark (2017)
Emission factors	1985-2016	Emission factors	EMEP/EEA (2016), US EPA (2004)

6.7 Urea-based catalysts

The category *Urea-based catalysts* (CRF 2D3 Other) covers:

- 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.

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 27-1.

Table 6.7.1 Activity data for use of urea in catalysts, Gg.

	2001	2005	2010	2013	2014	2015	2016
Urea	0.002	0.040	11.0	25.5	28.7	30.3	32.8

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/cm3. 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/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/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 estimated as the product of urea consumption and a CO_2 emission factor of 0.26 kg CO_2/l urea (EMEP/EEA, 2016).

6.7.3 Emission trends

CO_2 emissions from the use of urea in catalysts are presented in Table 6.7.2 and Annex 27-2.

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, Gg.

	2001	2005	2010	2013	2014	2015	2016
CO_2	0.001	0.009	2.6	6.1	6.8	7.2	7.8

6.7.4 Time series consistency and completeness

The time series is considered 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	2001-2016	Use amounts	DCE emission model
Emission factor	2001-2016	CO2 emission factor	EMEP/EEA (2016)

7. Electronics Industry

The sector *Electronics industry* (CRF 2E) covers the use of HFCs and PFCs in the production of fibre optics and to a small extent refrigerant in laboratory freezers. There is no *Integrated circuit or semiconductor* (CRF 2E1), *TFT flat panel display* (CRF 2E2), *Photovoltaics* resulting in use of F-gases (CRF 2E3) and no HFCs or PFCs used as *Heat transfer fluid* (CRF 2E4) 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 Poulsen (2018). For further details, please see that report.

7.1 Greenhouse gas emissions

The use of F-gases in the production of fibre optics did not start until 2006 and hence the time series covers the years 2006-2014; as no emissions occurred in 2015-2016. The emission time series for *Electronics industry* is presented in Figure 7.1.1.

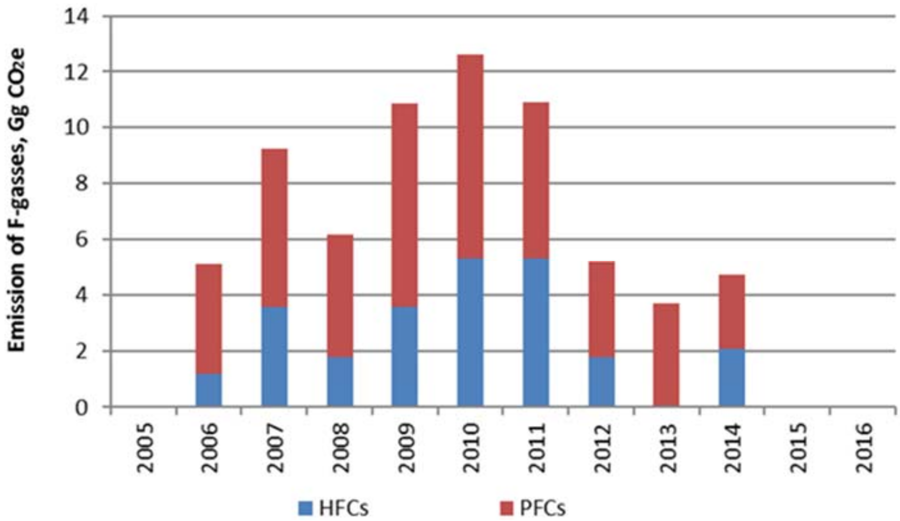


Figure 7.1.1 Emissions of HFCs and PFCs from *Electronics industry*.

7.2 Other electronics industry

The following source categories are covered:

- Fibre optics
- Refrigerants at extremely low temperatures

The following pollutants are included for *Other electronics industry*:

- F-gases: HFC-23, PFC-14 (CF_4), PFC-318 (c-CF_4F_8)

7.2.1 Process description

Both HFCs and PFCs are used for technical purposes in Danish optics fibre production. HFC-23 and PFCs (PFC-14 & PFC-318) are used as protection and 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 one (1), i.e. 100 % release in the production year (i.e. year of consumption). The methodology corresponds to the IPCC Tier 2 method.

Activity data

The consumption of PFCs from fibre optics production was 0.3 Mg in 2014 and HFCs 0.1 Mg. There was no use of HFC-23 or PFC-318 in 2013 and no use of either PFCs or HFCs in 2015 or 2016. The use of PFC-14 in 2013 stems from use in laboratory freezers for export. The consumption data are provided in Table 7.2.1 below.

Table 7.2.1 Consumption of F-gases in *Other electronics industry*, Mg.

	2006	2007	2008	2009	2010	2011	2012	2013	2014
HFC-23	0.08	0.24	0.12	0.24	0.36	0.36	0.12	NO	0.14
PFC-14 (CF_4)	0.25	0.14	0.11	0.36	0.36	0.20	0.18	0.50	0.08
PFC-318 (c-CF_4F_8)	0.20	0.45	0.35	0.45	0.45	0.40	0.20	NO	0.20

NO: Not occuring

The increase in PFC-14 from 2012 to 2013 is caused by a new application as refrigerant in extremely low temperatures in laboratory freezers for export. The producer was contacted in 2017 and informed about the EU F-gas regulation. It is expected they will apply DEPA for a dispensation to continue the use for this special purpose.

Emission factors

Since both HFC-23 and the PFCs are used as protection and cleaning gases in the production process, the emission factor is defined as 100 % release during production of fibre optics.

7.2.3 Emission trends

Emission trends are presented in Table 7.2.2 below.

Table 7.2.2 Emission from *Electronics industry*, Gg CO_2e.

	2006	2007	2008	2009	2010	2011	2012	2013	2014
HFC-23	1.18	3.55	1.78	3.55	5.33	5.33	1.78	NO	2.07
PFC-14 (CF_4)	1.86	1.03	0.80	2.66	2.66	1.48	1.33	3.70	0.59
PFC-318 (c-CF_4F_8)	2.06	4.64	3.61	4.64	4.64	4.12	2.06	NO	2.06
Total	5.11	9.22	6.18	10.85	12.62	10.93	5.17	3.70	4.72

In 2015 and 2016 there has been no consumption of HFC-23, PFC-14 or PFC-318 for fibre optics. It is considered a confirmation of the assumption that fibre optic emission is 100% in the consumption year and that F-gases are phased out in fibre optic production.

7.2.4 Time series consistency and completeness

The estimates are based on information directly from the importers supplying this sector in Denmark. As Denmark is a small country with a limited consumption of F-gases, there are only few importers. Data collection for the F-gas report (Poulsen 2018) 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 (2F1); see section 8.3
- Foam blowing agents (2F2); see section 8.4
- Fire protection; see section 8.5
- Aerosols (2F4); see section 8.6
- Solvents (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 (2018). For further details, please see that report.

8.1 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-152a	HFC-143a	PFC-218
2F1	x	x	x	x	x	x
2F2			x	x		
2F4			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.

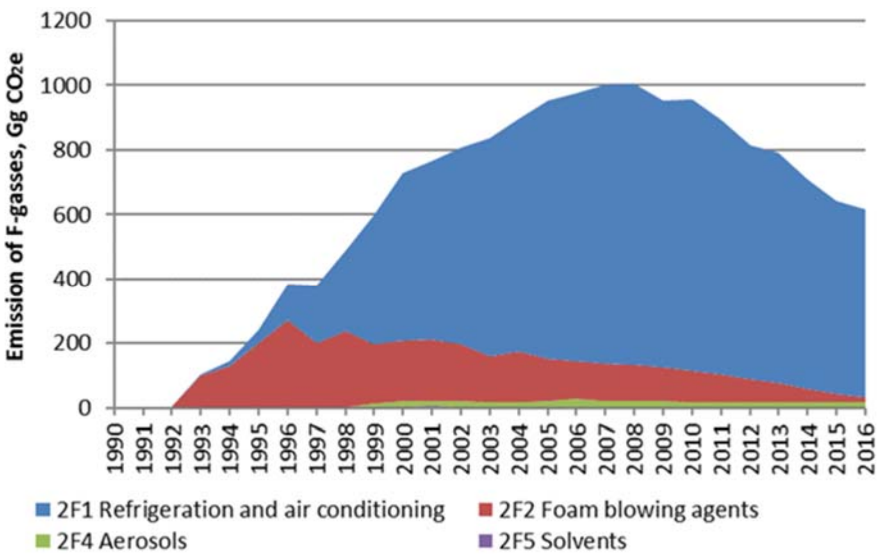


Figure 8.1.1 Emission of F-gases from the individual source categories within *Product uses as substitutes for ODS*, Gg CO_2e.

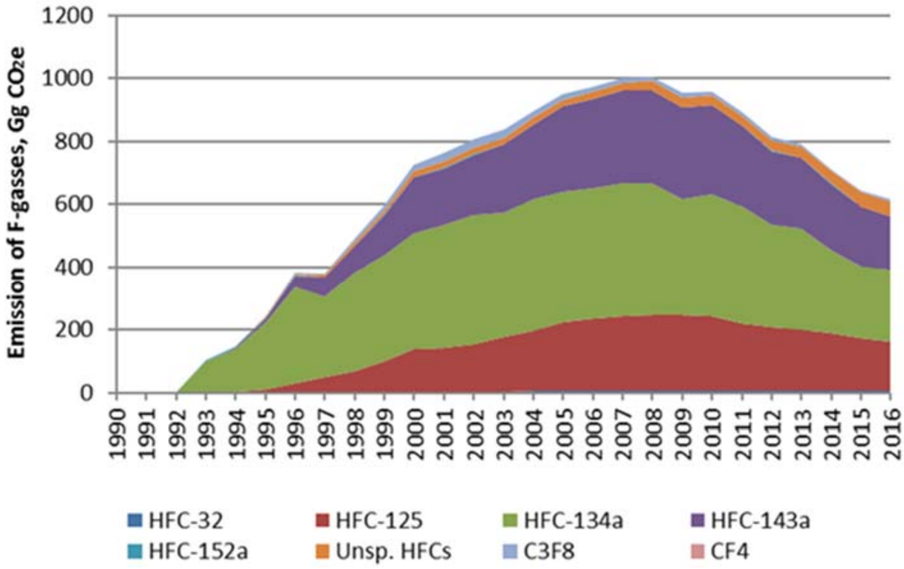


Figure 8.1.2 Emission of F-gases from the individual gases within *Product uses as substitutes for ODS*, Gg CO_2e.

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 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 in the latest years a decreasing trend can be observed.

8.1.1 General trends

The phase out of F-gases has in particular been effective within the *Foam blowing agents* sector and in *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 decreased from foams, but the emission of HFCs for refrigeration continued to increase until 2008, 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. 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 2008 and it is expected that this refrigerant will be phased out of the marked. The vast majority of emissions occur from the existing stock, and are therefore naturally decreasing. The use of PFC-218 (C_3F_8) as a solvent only occurred from 2000 to 2003.

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 inventory of F-gases, a Tier 2 bottom-up approach is generally used. In an annex to the F-gas inventory report (Poulsen, 2018), 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
- 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 emission.

Import / export data for sub-source categories where import / export is relevant (MAC, 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 (2018).

The Tier 2 bottom-up analysis used for determination of emissions from HFCs and PFCs 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 on the basis of 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.

Whenever possible, 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 Gobel Warming Potential (GWP) values. However, the continued use of a category for *Unspecified mix of HFCs* has been necessary since not all importers and suppliers have specified records of sales for individual substances.

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 8.2.1 have been used.

Table 8.2.1 Content (w/w%)[1] of "pure" HFC in HFC-mixtures, used as trade names.

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 %.

The national F-gas inventory is provided and documented in the annual report; Poulsen (2018). 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 - included under 2F1a

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.

For *Stationary air conditioning*, the same gases as frequently used in *Commercial refrigeration* are used, e.g. HFC-404a and HFC-407c. It is difficult to estimate the share of these gases going to the different uses as the same suppliers are servicing both types of units. Consequently, the 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 see to Poulsen (2018).

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.

The data collection is described in the Chapter 8.2 General methodology.

Activity data

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 28-1), Table 8.3.2 (Annex 28-2) and Table 8.3.3 (Annex 28-3) respectively. In addition, Annex 28-5 presents data for the recovered amounts of F-gases from refrigeration and air conditioning units.

Table 8.3.1 Filled into new manufactured refrigeration products, Mg.

		Unit	1995	2000	2005	2010	2015	2016
HFC-32	Commercial	Mg	NO	10.3	14.2	9.7	6.4	8.6
HFC-125	Total	Mg	62.1	118.3	89.6	60.7	47.3	46.2
	Commercial	Mg	59.3	106.4	84.7	57.4	44.7	43.4
	Domestic	Mg	0.9	4.0	1.6	0.6	0.4	0.3
	Transport	Mg	0.6	NO	3.3	2.7	2.2	2.5
	Mobile A/C	Mg	1.3	7.9	NO	NO	NO	NO
HFC-134a	Total	Mg	381.9	477.1	256.5	181.3	127.6	160.2
	Commercial	Mg	114.7	203.0	150.9	106.5	80.3	94.8
	Domestic	Mg	267.1	240.4	65.7	6.8	5.6	6.0
	Transport	Mg	NO	NO	0.8	0.7	0.4	0.4
	Mobile A/C	Mg	0.1	33.7	39.1	67.3	41.3	59.0
HFC-143a	Total	Mg	63.4	121.6	87.2	58.4	46.5	42.3
	Commercial	Mg	60.8	107.5	81.4	54.5	43.3	39.0
	Domestic	Mg	1.0	4.7	1.9	0.8	0.5	0.4
	Transport	Mg	NO	NO	3.9	3.2	2.7	2.9
	Mobile A/C	Mg	1.6	9.4	NO	NO	NO	NO
HFC-152a	Commercial	Mg	NO	1.3	NO	NO	NO	NO
Unspec.								
HFCs	Commercial	Gg	29.2	50.1	30.3	43.8	87.5	74.7
CF_4	Domestic	Mg	NO	NO	NO	NO	0.3	0.04
C_3F_8	Commercial	Mg	1.5	6.3	0.5	NO	NO	NO

NO: Not occuring.

Table 8.3.2 In operating refrigerating systems (average annual stocks).

		Unit	1995	2000	2005	2010	2015	2016
HFC-32	Commercial	Mg	NO	23.7	87.1	104.0	94.3	92.6
HFC-125	Total	Mg	73.8	429.3	658.6	626.1	437.8	436.0
	Commercial	Mg	70.8	366.9	607.8	574.1	404.5	406.0
	Domestic	Mg	0.9	25.9	35.1	37.5	17.9	15.6
	Transport	Mg	0.6	12.8	15.7	14.4	15.4	14.4
	Mobile A/C	Mg	1.6	23.8	NO	NO	NO	NO
HFC-134a	Total	Mg	354.0	1540.9	2173.6	1883.4	1169.2	1034.5
	Commercial	Mg	187.9	754.0	1113.4	1032.1	728.8	648.9
	Domestic	Mg	166.0	634.5	838.5	846.1	435.5	383.3
	Transport	Mg	NO	0.9	4.7	5.2	4.9	2.3
	Mobile A/C	Mg	0.1	151.5	217.0	NA	NA	NA
HFC-143a	Total	Mg	74.3	436.8	639.1	589.1	382.9	383.0
	Commercial	Mg	71.5	366.0	580.1	528.1	343.6	347.6
	Domestic	Mg	1.0	30.6	41.5	44.4	21.2	18.5
	Transport	Mg	NO	12.1	17.5	16.6	18.1	16.9
	Mobile A/C	Mg	1.8	28.2	NO	NO	NO	NO
HFC-152a	Commercial	Mg	NO	7.0	4.5	2.7	0.9	0.8
Unspec. HFCs	Commercial	Gg	28.8	196.0	226.6	311.6	478.0	502.1
CF_4	Domestic	Mg	NO	NO	NO	NO	0.2	0.17
C_3F_8	Commercial	Mg	1.9	25.9	19.5	11.4	4.5	4.0

NO: Not occuring

Table 8.3.3 Remaining in refrigeration products at decommissioning.

		Unit	1995	2000	2005	2010	2015	2016
HFC-32	Commercial	Mg	NO	NO	NO	NO	1.0	0.8
HFC-125	Total	Mg	NO	0.03	NO	51.0	42.5	3.3
	Commercial	Mg	NO	NO	NO	50.3	39.2	0.9
	Domestic	Mg	NO	NO	NO	0.7	3.3	2.4
	Transport	Mg	NO	0.03	NO	NO	NO	NO
	Mobile A/C	Mg	NO	NO	NO	NO	NO	NO
HFC-134a	Total	Mg	NO	0.01	NO	116.0	167.0	153.1
	Commercial	Mg	NO	NO	NO	99.0	72.4	100.4
	Domestic	Mg	NO	NO	NO	17.0	94.6	50.3
	Transport	Mg	NO	NO	NO	NO	NO	2.4
	Mobile A/C	Mg	NO	0.01	NO	NO	NO	NO
HFC-143a	Total	Mg	NO	NO	NO	59.3	48.7	2.8
	Commercial	Mg	NO	NO	NO	58.4	44.8	NO
	Domestic	Mg	NO	NO	NO	0.9	3.9	2.8
	Transport	Mg	NO	NO	NO	NO	NO	NO
	Mobile A/C	Mg	NO	NO	NO	NO	NO	NO
HFC-152a	Commercial	Mg	NO	NO	NO	NO	0.1	NO
Unspec. HFCs	Commercial	Gg	NO	NO	NO	3.4	3.9	1.6
CF_4	Domestic	Mg	NO	NO	NO	NO	NO	NO
C_3F_8	Commercial	Mg	NO	NO	NO	0.2	0.5	0.1

NO: Not occuring

Emission factors

The applied emission factors are presented in Table 8.3.4. The emission factors for *Commercial refrigerators, Mobile A/C* (MAC), and *Transport refrigeration* has been assessed and compared with national conditions (Poulsen, 2003). This has been re-evaluated and the values have been found to still be applicable for Danish conditions (Poulsen, 2018).

Table 8.3.4 Applied emission factors for *Refrigeration and air-condition* systems.

	Assembly, %	Stock, % per annum	Lifetime
Household fridges and freezers	2	1	15 years
Commercial refrigerators	1.5	10	
Mobile air conditioning systems	0.5	33	
Transport refrigeration	0.5	17	6-8 years

Detailed information on the amount of HFCs used for refilling of MAC 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. HFCs for MAC are only used for refilling, and therefore the amount used for MAC is assumed to be the same as the amount emitted during use (Poulsen, 2018):

Consumption of HFC for MAC = refilled stock = emission

8.3.3 Emission trends

Figure 8.3.1, Table 8.3.5 and Annex 28-4 present the emissions of F-gases from consumption of HFCs and PFCs in the individual sub-categories of *Refrigeration and air-conditioning* systems.

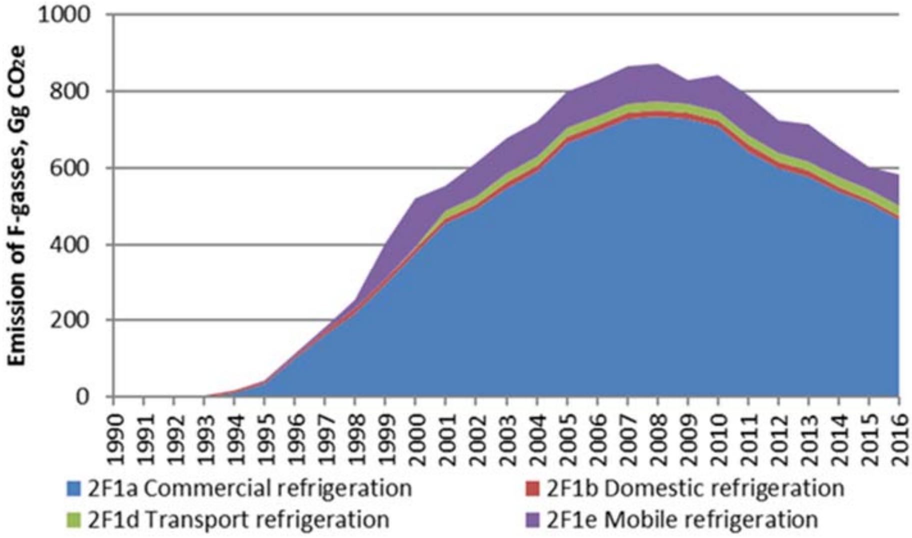


Figure 8.3.1 Emissions from *Refrigeration and air conditioning*.

Table 8.3.5 Emissions from *Refrigeration and air conditioning*, Mg.

		1995	2000	2005	2010	2015	2016
HFC-32	Commercial	NO	1.7	8.3	10.6	10.0	9.6
HFC-125	Total	2.5	39.0	62.7	66.9	48.2	44.1
	Commercial	2.3	30.7	59.5	64.0	45.1	41.1
	Domestic	0.02	0.3	0.4	0.4	0.2	0.2
	Transport	0.003	0.5	2.7	2.6	2.8	2.7
	Mobile A/C	0.2	7.4	NO	NO	NO	NO
HFC-134a	Total	15.5	117.0	183.8	192.8	129.3	138.8
	Commercial	10.0	64.6	109.5	115.6	81.4	74.3
	Domestic	5.4	8.6	8.9	9.3	6.0	4.9
	Transport	NO	NO	0.6	0.6	0.6	0.6
	Mobile A/C	0.02	43.8	64.9	67.3	41.3	59.0
HFC-143a	Total	2.4	39.6	60.3	63.5	42.7	38.4
	Commercial	2.2	30.5	56.8	60.0	39.1	34.9
	Domestic	0.02	0.36	0.46	0.51	0.28	0.24
	Transport	NO	NO	3.0	2.9	3.3	3.2
	Mobile A/C	0.2	8.8	NO	NO	NO	NO
HFC-152a	Commercial	NO	0.7	0.5	0.3	0.1	0.1
Unspec. HFCs	Commercial	438	17042	22322	30866	45282	48921
CF_4	Domestic	NO	NO	NO	NO	0.006	0.001
C_3F_8	Commercial	0.1	2.3	2.1	1.3	0.6	0.5

NO: Not occuring.

F-gas emissions from *Commercial refrigeration* are dominating the overall emissions from this source. Hence, the increasing trend from the mid-1990s to 2008 and the subsequent decrease in emissions are explained in Chapter 8.1 Greenhouse gas emissions.

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 2015-2016 amounts of HFC 125 (GWP 3500), HFC-134a (GWP 1430) and HFC 143a (GWP 4470) 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 for domestic appliances and biomedical coolers and freezers. The producer was not aware of the ban and is now informed and expected to comply.

8.3.4 Time series consistency and completeness

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 foam)
- Open cells (soft foam)

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 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 betwwen 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. On the other hand closed-cell foams are primarily used for insulating applications 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 the IPCC guidelines (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 see to Poulsen (2018).

Activity data

The data collection is described in the Chapter 8.2 General methodology.

There is no longer production of HFC-based hard polyurethane insulation foam in Denmark. This production has been banned in statutory order since 1 January 2006 (MIM, 2002).

Activity data are presented in Table 8.4.1 and Annex 29-1.

Table 8.4.1 Activity data for F-gases used as *Foam blowing agents*, Mg.

		1995	2000	2005	2010	2015	2016
Filled into new manufactured products							
HFC-134a	Total	298.0	263.9	64.7	0.2	NO	NO
	Closed cells	193.0	220.0	52.8	0.2	NO	NO
	Open cells	105.0	43.9	11.9	NO	NO	NO
HFC-152a	Total	47.0	16.4	5.5	15.0	7.0	4.0
	Closed cells	4.0	1.0	5.5	15.0	7.0	4.0
	Open cells	43.0	15.4	NO	NO	NO	NO
In operating systems							
HFC-134a	Closed cells	416.2	1413.9	1253.3	757.5	159.1	79.0
HFC-152a	Closed cells	3.6	16.4	26.0	76.7	97.8	96.4
Remaining in products at decommissioning							
HFC-134a	Closed cells	NO	NO	7.8	58.2	62.2	45.8
HFC-152a	Closed cells	NO	NO	NO	NO	10.7	NO

NO: Not occuring.

Emission factors

The applied emission factors for *Foam blowing agents* are presented in Table 8.4.2 (Poulsen, 2018 – Appendix 3).

Table 8.4.2 Applied emission factors for *Foam blowing agents*.

	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[10]). The emission factors for foaming of polyether are country-specific (Poulsen, 2018).

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 trends

Figure 8.4.1, Table 8.4.3 and Annex 29-2 presents the emissions of F-gases from consumption of HFCs in *Foam blowing agents*.

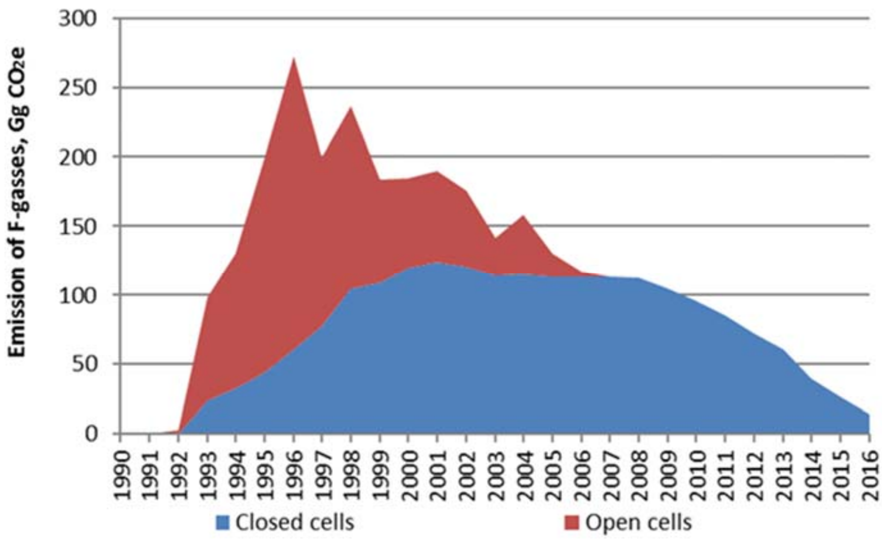


Figure 8.4.1 Emissions from *Foam blowing agents*.

[10] 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-gases used as *Foam blowing agents*, Mg.

			1995	2000	2005	2010	2015	2016
HFC-134a	Total	Total emission	135.8	127.6	91.2	66.7	17.9	9.2
		From manufacturing	124.3	66.2	12.0	NO	NO	NO
		From stocks	11.5	61.5	79.2	66.7	17.9	9.2
		Recovery	NO	NO	7.8	58.2	62.2	45.8
	Closed cells	Total emission	30.8	83.7	79.3	66.7	17.9	9.2
		From manufacturing	19.3	22.3	0.1	NO	NO	NO
		From stocks	11.5	61.5	79.2	66.7	17.9	9.2
		Recovery	NO	NO	7.8	58.2	62.2	45.8
	Open cells	From manufacturing	105.0	43.9	11.9	NO	NO	NO
HFC-152a	Total	Total emission	43.4	15.6	1.3	3.7	5.4	5.5
		From manufacturing	43.4	15.5	0.6	1.5	0.7	0.4
		From stocks	NO	0.1	0.7	2.2	4.7	5.1
		Recovery	NO	NO	NO	NO	10.7	NO
	Closed cells	Total emission	0.4	0.2	1.3	3.7	5.4	5.5
		From manufacturing	0.4	0.1	0.6	1.5	0.7	0.4
		From stocks	NO	0.1	0.7	2.2	4.7	5.1
		Recovery	NO	NO	NO	NO	10.7	NO
	Open cells	From manufacturing	43.0	15.4	NO	NO	NO	NO

NO: Not occuring.

The sharp fluctuations in the time series are caused by fluctuations in the consumption of HFCs in production of open cell foam with an emission factor of a 100 % in the given year. 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

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

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 while an emission factor of 100 % of the initial charge per year is used for metered dose inhalers.

Activity data

The general data collection process is described in the Chapter 8.2 General methodology.

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. The activity data are presented in Table 8.6.1 and Annex 30-1.

Table 8.6.1 Activity data for F-gases used as *Aerosols*, Mg.

F-gas	Activity	Sub-category	1995	2000	2005	2010	2015	2016
HFC-134a	Filled into new manufactured products	Total	NO	13.1	20.6	12.5	11.9	12.5
		Metered dose inhalers	NO	1.6	5.6	7.2	6.1	5.5
		Propellant in aerosols	NO	11.5	15.0	5.2	5.8	7.0
	In operating systems	Propellant in aerosols	NO	12.9	10.5	5.6	5.7	6.4

NO: Not occuring.

Emission factors

The applied emission factors are presented in Table 8.6.2 (Poulsen et al., 2018).

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 trends

Figure 8.6.1, Table 8.6.3 and Annex 30-2 presents the emissions of F-gases from consumption of HFCs in *Aerosols*.

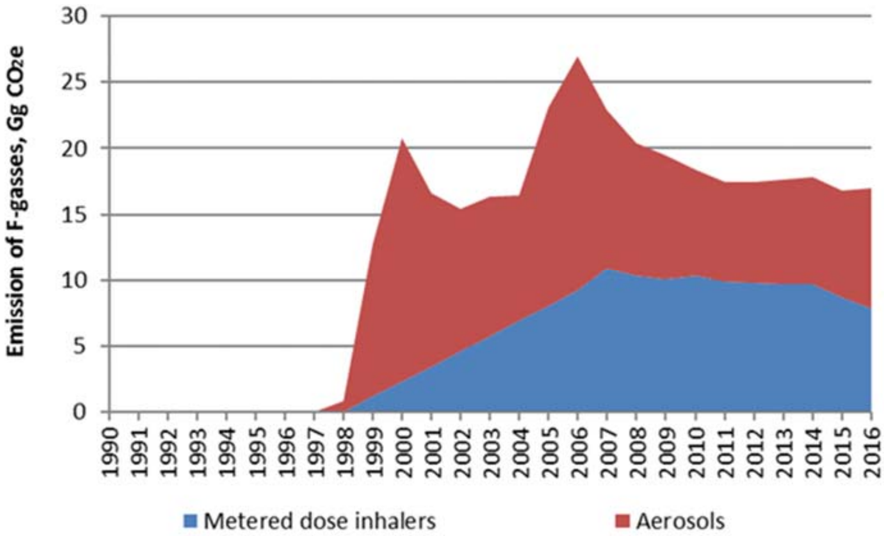


Figure 8.6.1 Emissions from HFCs from *Aerosols*.

Table 8.6.3 Emissions of F-gases used as aerosols, Mg.

F-gas	Emission	Sub-category	1995	2000	2005	2010	2015	2016
HFC-134a	Total	Total	NO	14.5	16.1	12.9	11.7	11.9
	From manufacturing	Metered dose inhalers	NO	1.6	5.6	7.2	6.1	5.5
	From stocks	Propellant in aerosols	NO	12.9	10.5	5.6	5.7	6.4

NO: Not occuring.

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 15 and 20 Gg CO_2 equivalents.

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 and the use then ceased following the ban in accordance with the Executive Order (MIM, 2002).

8.7.1 Process description

HFC / PFC solvent uses 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 % is assumed to be emitted in the second year and hence there is no subtraction of any destruction of solvents.

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, Mg.

F-gas	Activity	2000	2001	2002
C_3F_8	Filled into new manufactured products	0.54	0.50	0.50
	In operating systems	NO	NO	NO
	Remaining in products at decommissioning	NO	NO	NO

NO: Not occuring.

Emission factors

In accordance with IPCC (2006)[11], the emission factor is 50 % in year 1 and 50 % in year 2.

8.7.3 Emission trends

Figure 8.7.1 and Table 8.7.2 presents the emissions of F-gases from consumption of PFCs used as solvents.

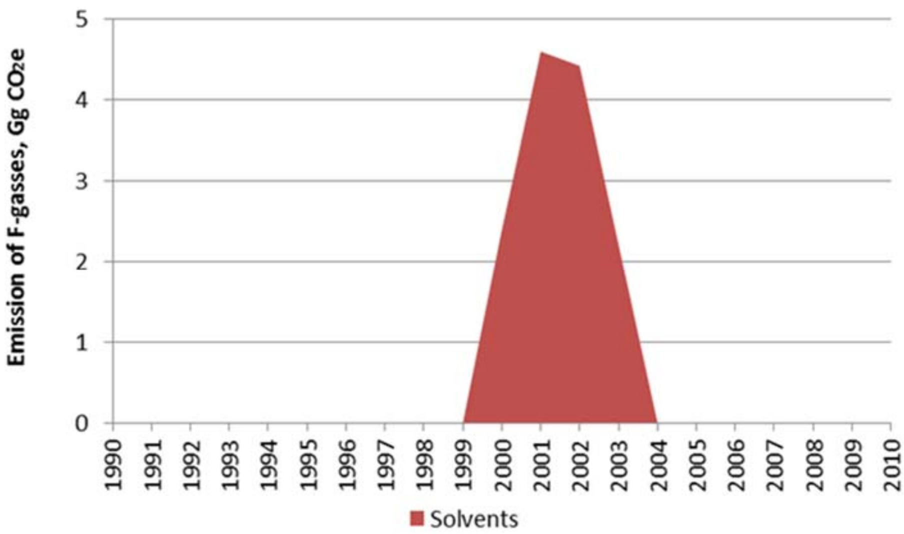


Figure 8.7.1 Emissions from PFCs used as solvents.

Table 8.7.2 Emissions of F-gases used as solvents, Mg.

F-gas	Emission	2000	2001	2002	2003
C_3F_8	From manufacturing	0.27	0.52	0.50	0.25
	From stocks	NO	NO	NO	NO
	From disposal	NO	NO	NO	NO
	Recovery	NO	NO	NO	NO

NO: Not occuring.

As mentioned the use of PFCs as solvent only occurred from 2000 to 2002 and hence emissions only occurred from 2000 to 2003.

[11] Volume 3: Industrial Processes and Product Use, Chapter 7.2.2.1: Solvents (non-aerosol), Choice of method, Equation 7.5, page 7.23 and Chapter 7.2.2.2: Solvents (non-aerosol), Choice of activity data, page 7.24.

8.7.4 Time series consistency and completeness

The time series is considered complete and consistent.

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; see section 9.2
- SF_6 from other product use; see section 9.3
- Medical applications of N_2O; see section 9.4
- N_2O used as propellant for pressure and aerosol products; see section 9.5
- Other product use; see section 9.6

9.1 Emissions

The greenhouse gas emission time series for the source categories within *Other Product Manufacture and Use* are presented in Figure 9.1.1 and individually in the subsections below (Sections 9.2 – 9.6). The following figure gives an overview of which source categories contribute the most throughout the time series. The significant increase in SF_6 emission 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.

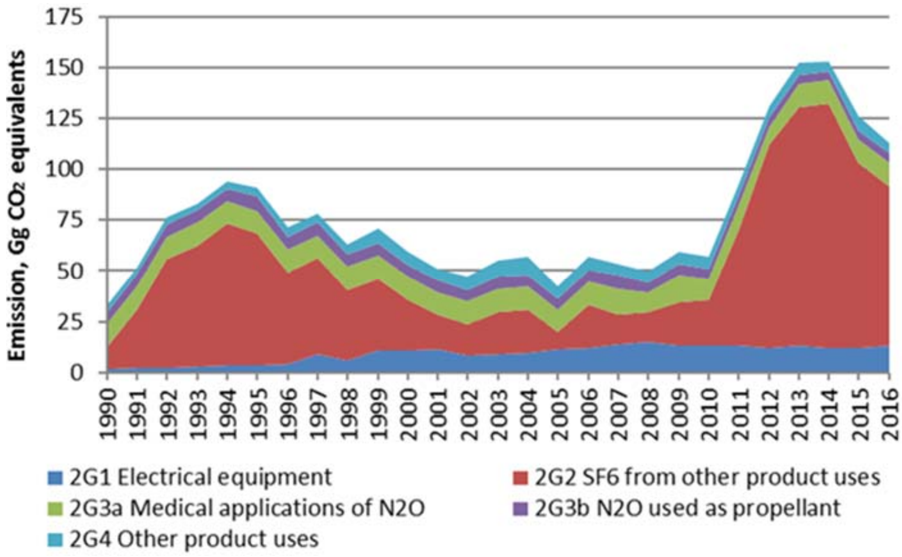


Figure 9.1.1 Emission of CO_2 equivalents from the individual source categories compiling *Other Product Manufacture and Use*.

Air pollution emissions only occur from *Other product use*; i.e. use of fireworks, use of tobacco and use of charcoal for barbeques (BBQ). The time series for air pollution emissions are available in Annex 33-2. Table 9.1.1 presents an overview of emissions in 2016.

Table 9.1.1 Overview of 2016 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	0.03	Gg	2.8	Charcoal for barbeques	0.02	Gg	66.5
NO_x	0.04	Gg	61.0	Charcoal for barbeques	0.02	Gg	60.6
NMVOC	0.06	Gg	0.2	Use of tobacco	0.04	Gg	61.6
CO	1.97	Gg	74.3	Charcoal for barbeques	1.54	Gg	78.0
NH_3	0.03	Gg	9.3	Use of tobacco	0.03	Gg	97.7
TSP	0.31	Gg	4.6	Use of fireworks	0.18	Gg	58.4
HMs	3.46	Mg	61.5	Cu from use of fireworks	2.00	Mg	57.8
POPs	54.1	kg	53.2	PAH from charcoal for barbeques	82.1	kg	100.0

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 Tier 3c methodology of IPCC (2006).

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 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 31-1 presents the activity data.

Table 9.2.1 Activity data for SF_6 used in *Electrical equipment*, Mg.

	1995	2000	2005	2010	2015	2016
Filled into new manufactured products	1.4	4.0	3.6	3.2	1.4	2.4
In operating systems (average annual stocks)	26.2	57.3	68.0	86.3	93.5	95.3

Emission factors

The applied emission factors 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, 2018).

	Consumption/ filling	Stock, per annum	Lifetime
Insulation gas in high voltage switches	5 %	0.5 %	-[1]

[1] Lifetime unknown.

9.2.3 Emission trends

Figure 9.2.1 and Annex 31-2 presents the emissions of SF_6 from *Electrical equipment*.

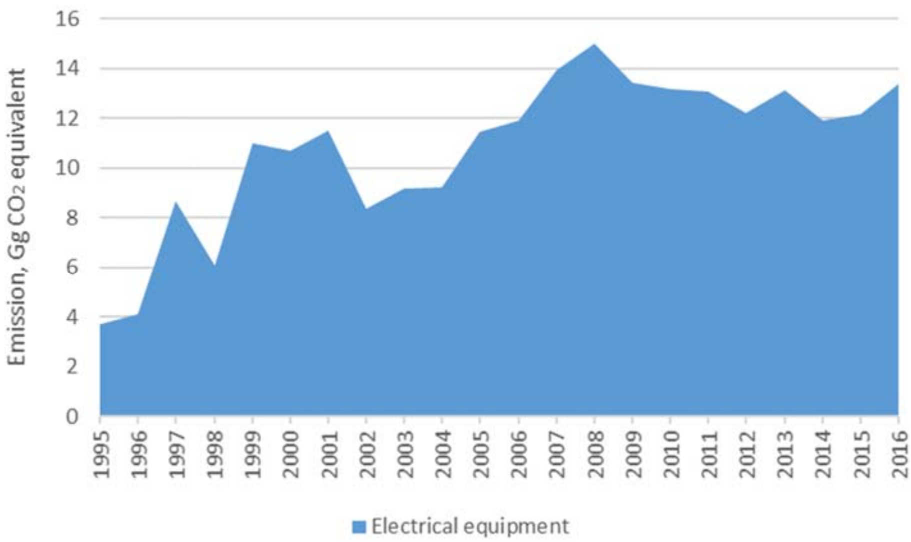


Figure 9.2.1 Emissions from SF_6 from *Electrical equipment*.

The emission trend 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	1990-2016	Consumption	Poulsen (2018)
Emission	1990-2016	Emission factor	Poulsen (2018)

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

9.3.1 Process description

Consumption of SF_6 in laboratories includes consumption for a particle accelerator, a radiotherapy device and electron microscopes. In addition, SF_6 is used in laboratories for plasma erosion in connection with the manufacture of microchips, in clean-room laboratories and to a limited extend purposes of chemical analysis.

Consumption of SF_6 in production of double glazed thermal windows started in 1991 and has been banned since 1 January 2003 (MIM, 2002).

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 (2018). Data on the consumption of SF_6 is 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. The yearly consumption reached a maximum of 1.1 Mg SF_6 in 2013 and is below 0.8 Mg for all other years in the time series. It is therefore not considered relevant to introduce national emission factors for the different laboratory uses of SF_6. As soon as individual emission factors are available in the Guidelines, Denmark will include these in the submission. But for now, consumption of SF_6 for these special purposes are reported as part of the consumption in laboratories.

Activity data

The data collection is described in the Chapter 8.2 General methodology.

Information on consumption of SF_6 in double glazing is derived from importers' sales reports to the application area. The importers account for 100% of the Danish sales of SF_6 for double glazing. In addition, the largest producer of windows in Denmark has provided consumption data, with which SF_6 import information is compared.

Importers have estimated imports to Denmark of SF_6 in training footwear.

Activity data are presented in Table 9.3.1 and Annex 31-1.

Table 9.3.1 Activity data for *SF_6 from other product use*, Mg.

		1995	2000	2005	2010	2015	2016
Soundproof	Filled into new manufactured products	13.5	4.1	NO	NO	NO	NO
windows	In operating systems	25.0	38.4	36.6	34.8	16.8	14.1
	Remaining in products at decommissioning	NO	NO	NO	NO	3.7	2.6
Running shoes	Filled into new manufactured products	0.1	0.1	NO	NO	NO	NO
	In operating systems	0.1	0.1	NO	NO	NO	NO
	Remaining in products at decommissioning	0.1	0.1	NO	NO	NO	NO
Laboratories	Filled into new manufactured products	0.5	NO	NO	0.6	0.1	0.7

NO: Not occuring.

Emission factors

The applied emission factors are presented in Table 9.3.2.

Table 9.3.2 Applied emission factors for *SF_6 from other product use* (Poulsen, 2018).

	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 Mg in 1995-2003.

9.3.3 Emission trends

Figure 9.3.1 and Annex 31-2 presents the emissions of SF_6 from shoes, double glazed windows and other uses (laboratories etc.).

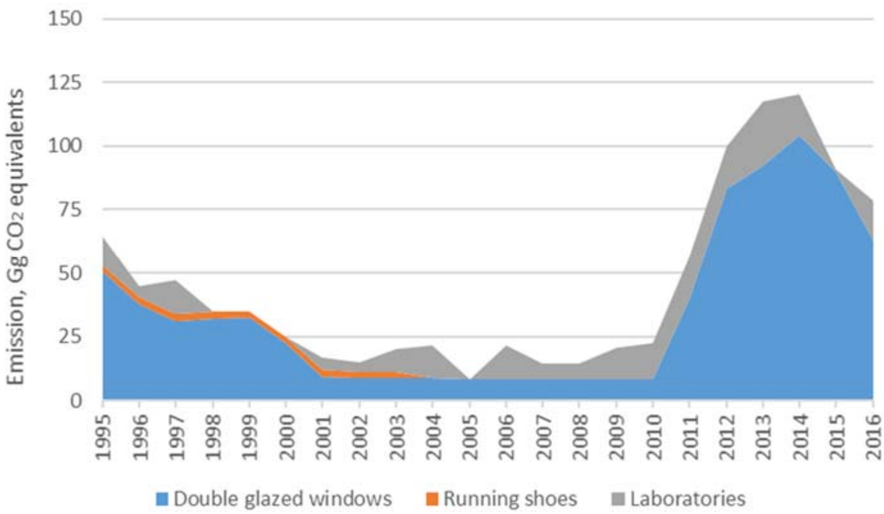


Figure 9.3.1 Emissions from *SF_6 from other product use*.

Double-glazed windows using SF_6 was introduced in 1991. While there is 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 production, i.e. first in 2011. Emissions of SF_6 from this source will therefore be quite high in the recent/coming 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 9.3.3.

Table 9.3.3 Input data for calculation of emissions of *SF_6 from other product use.*

	Year	Parameter	Comment/Source
Activity	1990-2016	Consumption	Poulsen (2018)
Emission	1990-2016	Emission factor	Poulsen (2018)

9.4 Medical applications of N_2O

The category *Medical applications of N_2O* (CRF 2G3a) covers the following SNAP-code:

- 06 05 01 Anaesthesia

9.4.1 Process description

N_2O has been used as anaesthetics for more than a hundred years 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, no data on produced amount are available and thus the emissions related to N_2O production are unknown. Sold amounts are obtained from the respective distributors and the produced amount is estimated from communication with the company. However, since consumption cannot be distinguished between these activities it is all reported under *Anaesthesia*.

Activity data

Data on total sold and estimated produced N_2O for sale in Denmark is only reliable for the years 2005-2012, activity data for the years 1990-2004 and 2013-2016 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, Mg.

	1990-2004	2005	2006	2007	2008	2009	2010	2011	2012	2013-2016
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 one (1) is assumed for all uses, meaning 100 % release during consumption.

9.4.3 Emission trends

The emission trend for the N_2O emission from medical applications is presented in Figure 9.4.1 below.

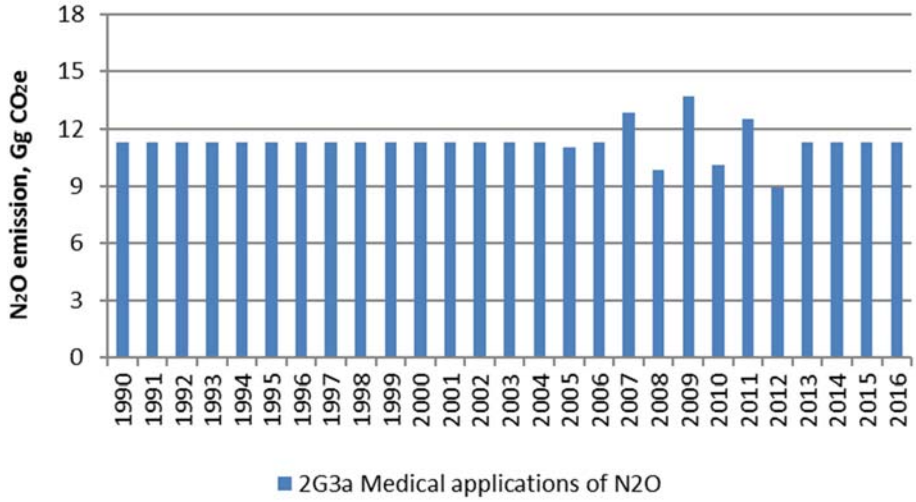


Figure 9.4.1 N_2O emissions from the use of anaesthetics.

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 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	1990-2016	Consumption	Direct contact with distributors
Emission	1990-2016	Emission factor	Expert 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 that 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 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 100 % 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 32-1.

Table 9.5.1 Consumption of cream in Denmark, Mg.

	1990	1995	2000	2005	2010	2015	2016
Fresh cream[1]	37378	46279	39380	37333	34835	31772	32275
Canned cream	374	463	394	373	348	318	323

[1]Statistics Denmark (2017).

Emission factors

The applied emission factor is 0.05 Mg N_2O per Mg canned cream sold; 5 % propellant and 100 % release.

9.5.3 Emission trends

The emission trend for the *N_2O used as propellant for pressure and aerosol products* is available in Annex 32-2 but is also presented in Figure 9.5.1 below.

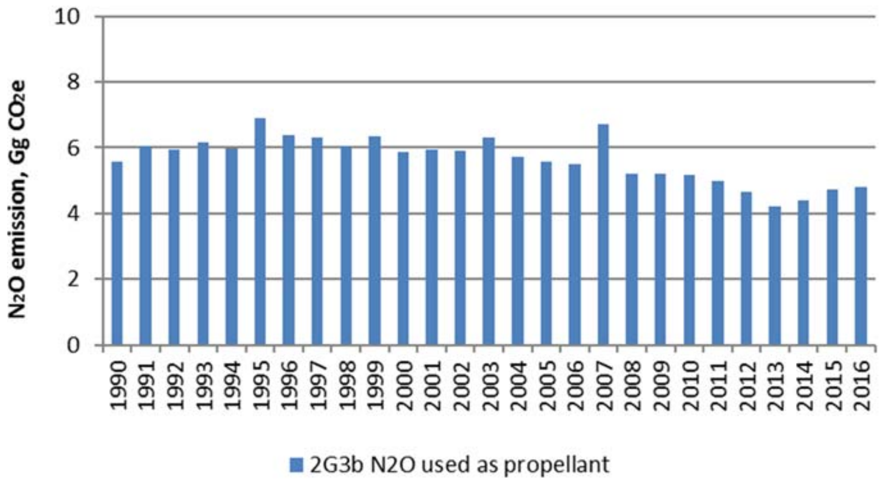


Figure 9.5.1 N_2O emissions from the use of canned whipped cream (Emission 2A from Figure 9.5.2).

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 100 % release of the propellant.

Table 9.5.2 N_2O released as propellant (2012), Gg.

	Assumption 1 1 can used per household per year	Assumption 2 1 % market share of canned cream
Assumption A		
5 % propellant	0.033	0.016
Assumption B		
5 g N_2O per can	0.013	0.006

Using the four assumptions presented in the table above, the time series are calculated; see Figure 9.5.2.

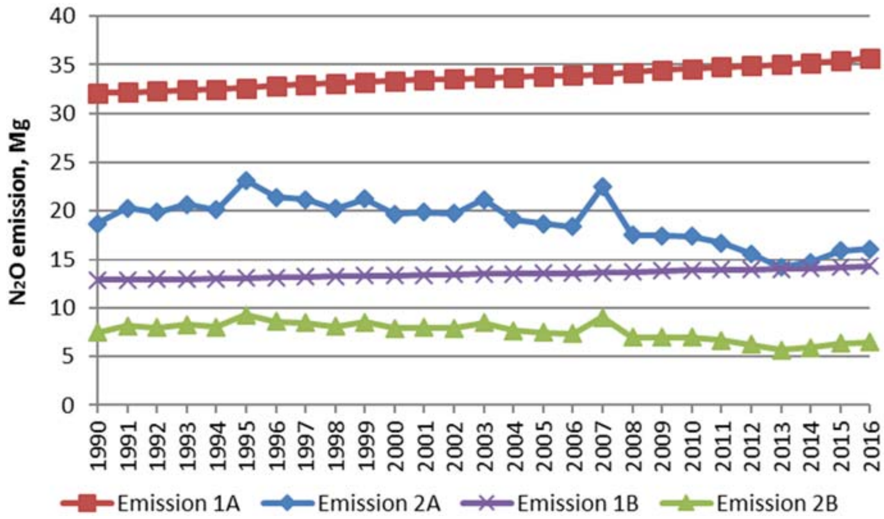


Figure 9.5.2 N_2O emissions from the use of canned whipped cream.

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 Mg and 36 Mg. 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 2016 "Emission 1A" is 0.02 % 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	1990-2016	Consumption	Statistics Denmark (2017), Expert judgement
Emission	1990-2016	Emission factor	Expert judgement

9.6 Other product use

The category *Other Product Use* (CRF 2G4) covers the following categories:

- 06 06 01 Use of fireworks
- 06 06 02 Use of tobacco
- 06 06 05 Use of charcoal for barbeques
- 06 06 03 Use of shoes

The following pollutants are included for *Other product use*:

- 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 papers and polymers, a propeller 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 (Webb et al., 2003). Different metal compounds produces 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 DS/EN-14035.

Use of tobacco

The combustion 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 (ETS), 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).

The product called Heat Beads® BBQ briquettes have won marked 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 footwear is a cause of emissions of TSP.

9.6.2 Methodology

Data on the used amounts of product are obtained from Statistics Denmark (2017), emission factors are primarily from international literature and guidelines. The Tier 2 technology-specific approach from EMEP/EEA (2016)[12] is used for calculating emissions from fireworks, tobacco and charcoal for barbeques (BBQ).

Use of fireworks

Emissions from fireworks are calculated by multiplying the activity data available from Statistics Denmark (2017) 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 (NEM)) 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.

In November 2004, an accidental explosive burning of vast amounts of fireworks occurred in Denmark. It was estimated that the explosion involved around 284 Mg 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 last decade and are now legally banned, but there are still cases where trace content of HCB has been detected during random checks (Danish EPA, 2012). 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.

The average NEM content in fireworks is estimated to be 20 % (Report Seest, 2005; Passant et al., 2003; Miljöförvaltningen, 1999).

[12] 2.D.3.i, 2.G Other solvent and product use, Chapter 3.3 Tier 2 technology-specific approach.

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 crossborder shopping of tobacco are available from the Danish Ministry of Taxation (Skatteministeriet, 2016) for 2000-2015 and estimated for the remaining years in the time series. From 2000 to 2015 the cross-border shopping of tobacco decreased from 14 % of retail sale to 7 % in 2009, and then increased again to 10 % in 2015. Cross-border shopping is highly influenced by regulations in the Danish tax system. It is assumed that all purchased tobacco is smoked within the same year.

The assumption of the weight of cigarettes and cigars of 1 g and 5 g respectively 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.

Activity data for charcoal for barbeques are determined from import/export data collected from Statistics Denmark, and includes:

- Charcoal, including coal of nutshells or nuts, also agglomerated
- Bamboo, including coal of nutshells or nuts, also agglomerated (except for medical use, charcoal mixed with incense, activated charcoal and charcoal for drawing)
- Charcoal, including coal of nutshells or nuts, also agglomerated (except bamboo, charcoal dosed or packaged as medicines, charcoal mixed with incense, activated charcoal and charcoal for drawing)

It is assumed that the entire quantum 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 33-1.

Table 9.6.1 Activity data for *Other product use*.

	Unit	1980	1985	1990	1995	2000	2005	2010	2015	2016
Fireworks	Gg	1.0	1.0	1.3	3.0	4.9	3.7	5.4	5.8	4.5
Tobacco	Gg	14.5	14.3	13.1	11.7	11.4	10.5	9.5	7.4	7.3
BBQ	Gg	1.9	4.4	7.2	7.9	13.4	14.9	7.8	17.2	7.5
Shoes	Million inhabitants	-	-	5.1	5.2	5.3	5.4	5.5	5.7	5.7

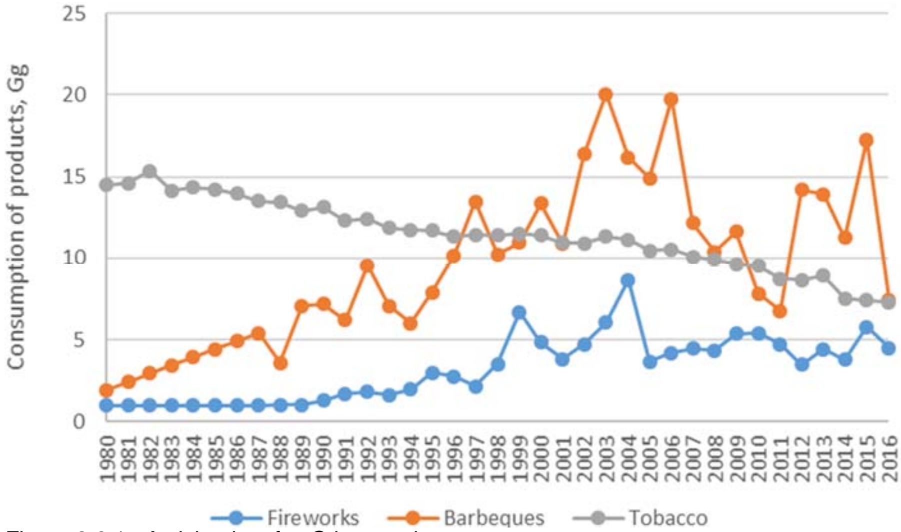


Figure 9.6.1 Activity data for *Other product use*.

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 Mg NEM corresponding to a gross weight of about 1,500 Mg 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, but the increasing trend continued.

Emission factors

Table 9.6.2 shows the applied emission factors for calculating the emissions from 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 here from, 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/Mg	43.25 (a)	NA	NA	-
CH_4	kg/Mg	0.83 (a)	3.19 (e)	6.00(j)[4]	-
N_2O	kg/Mg	1.94 (a)	0.06 (e)	0.03(j)[4]	-
SO_2	kg/Mg	1.94 (a)	0.40 (e)	3.10 (i)	-
NO_X	kg/Mg	0.26 (f)	1.80 (f)	2.95 (j)[4]	-
NMVOC	kg/Mg	-	4.84 (f)	2.95 (j)[4]	-
CO	kg/Mg	6.90 (a)	55.10 (f)	206.5 (j)[4]	-
NH_3	kg/Mg	-	4.15 (f)	0.10 (e)	-
TSP	kg/Mg	39.66 (b)	13.67 (g)	3.10 (i)	0.75 (l)[5]
PM_{10}	kg/Mg	35.69 (b/f)	13.67 (g)	3.10 (i)	NO
$PM_{2.5}$	kg/Mg	19.83 (b/f)	13.67 (g)	3.10 (i)	NO
BC	% of $PM_{2.5}$	-	0.45 (f)	14.7 (e)	-
As	g/Mg	1.33 (f)	0.16 (h)	0.10 (i)	-
Cd	g/Mg	0.67 (c)	0.02 (e)	0.04 (i)	-
Cr	g/Mg	15.56 (f)	0.15 (h)	0.04 (e)	-
Cu	g/Mg	444.4 (f)	0.35 (h)	0.15 (e)	-
Hg	g/Mg	0.06 (f)[1]	0.01 (e)	0.07 (i)	-
Ni	g/Mg	30 (f)	0.03 (e)	0.13 (i)	-
Pb	g/Mg	2200 (d)[2] 666.7 (c)[3]	0.64 (e)	4.45 (i)	-
Se	g/Mg	-	0.01 (e)	0.65 (i)	-
Zn	g/Mg	260 (f)	1.61 (e)	1.90 (e)	-
HCB	mg/Mg	-	-	0.10 (e)	-
PCDD/Fs	µg/Mg	-	0.10 (f)	10.50 (k)	-
Benzo(b)fluoranthene	g/Mg	-	0.05 (f)	2.14 (e)	-
Benzo(k)fluoranthene	g/Mg	-	0.05 (f)	1.25 (e)	-
Benzo(a)pyrene	g/Mg	-	0.11 (f)	2.16 (e)	-
Indeno(1,2,3-cd)pyrene	g/Mg	-	0.05 (f)	1.46 (e)	-
PCB	mg/Mg	-	-	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]Calculated from default uncontrolled combustion and a net calorific value of 30 MJ/kg. [5]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/Mg), (f) EMEP/EEA (2016), (g) Martin et al. (1997), (h) Finstad & Rypdal (2003), (i) Environment Australia (1999), (j) IPCC (2006), calculated using default EFs[13] and net calirific value[14], (k) Hansen (2000), (l) Sambat et al. (2001).

9.6.3 Emission trends

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 33-2.

[13] Volume 2: Energy, Chapter 2.3.2.1 Stationary combustion, Tier 1, Table 2.4, page 2.21, solid biofuels, charcoal.
[14] Volume 2: Energy, Chapter 1.4.1.3 Introduction, Activity data sources, Table 1.2, page 1.19, solid biofuels, charcoal.

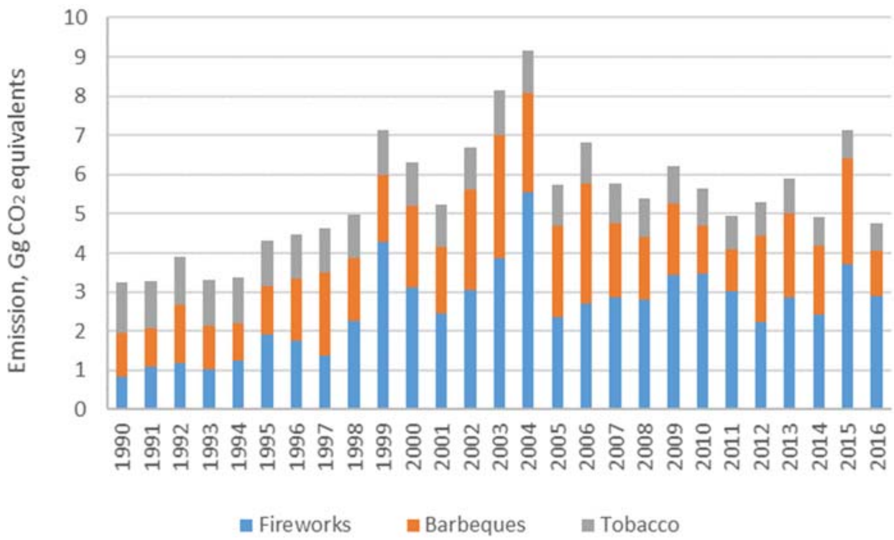


Figure 9.6.2 Greenhouse gas emissions from *Other product use*.

Table 9.6.3 Excerpt of the emissions from Other product use.

		Unit	1985	1990	1995	2000	2005	2010	2015	2016
NO_x	Fireworks	Mg	0.3	0.3	0.8	1.3	1.0	1.4	1.5	1.2
	Tobacco	Mg	25.7	23.7	21.1	20.6	18.9	17.2	13.3	13.1
	BBQ	Mg	13.1	21.2	23.3	39.4	44.0	23.1	50.9	22.0
	Total	Mg	39.0	45.1	45.2	61.2	63.9	41.7	65.7	36.3
CO	Fireworks	Mg	6.9	8.8	20.7	33.5	25.4	37.4	39.8	31.1
	Tobacco	Mg	785.2	723.6	646.2	629.0	577.3	524.9	408.0	402.2
	BBQ	Mg	914.6	1481.1	1630.3	2758.4	3082.0	1617.8	3562.0	1540.7
	Total	Mg	1706.8	2213.6	2297.2	3420.8	3684.7	2180.2	4009.9	1974.0
$PM_{2.5}$	Fireworks	Mg	-	25.4	59.4	96.3	73.1	107.5	114.5	89.2
	Tobacco	Mg	-	179.6	160.4	156.1	143.3	130.3	101.3	99.8
	BBQ	Mg	-	22.2	24.5	41.4	46.3	24.3	53.5	23.1
	Total	Mg	-	227.2	244.3	293.8	262.6	262.1	269.3	212.2
Cu	Fireworks	kg	-	568.4	1332.3	2157.5	1637.1	2409.8	2566.5	1999.9
	Tobacco	kg	-	4.6	4.2	4.0	3.7	3.4	2.6	2.6
	BBQ	kg	-	1.1	1.2	2.0	2.3	1.2	2.6	1.1
	Total	kg	-	574.2	1337.6	2163.6	1643.1	2414.3	2571.8	2003.7
Hg	Fireworks	kg	-	0.1	0.2	0.3	-	-	-	-
	Tobacco	kg	-	0.08	0.07	0.07	0.06	0.06	0.04	0.04
	BBQ	kg	-	0.5	0.5	0.9	1.0	0.5	1.1	0.5
	Total	kg	-	0.6	0.8	1.2	1.0	0.6	1.2	0.5
Pb	Fireworks	kg	-	2813.9	6595.4	3236.7	2456.0	-	-	-
	Tobacco	kg	-	8.5	7.6	7.4	6.7	6.1	4.8	4.7
	BBQ	kg	-	31.9	35.1	59.4	66.4	34.9	76.8	33.2
	Total	kg	-	2854.3	6638.1	3303.5	2529.2	41.0	81.5	37.9
Zn	Fireworks	kg	-	332.6	779.5	1262.3	957.8	1409.8	1501.6	1170.1
	Tobacco	kg	-	21.1	18.9	18.4	16.9	15.3	11.9	11.8
	BBQ	kg	-	13.6	15.0	25.4	28.4	14.9	32.8	14.2
	Total	kg	-	367.3	813.3	1306.0	1003.0	1440.1	1546.3	1196.0
POPs	Tobacco	kg	-	3.2	2.9	2.8	2.6	2.3	1.8	1.8
	BBQ	kg	-	50.3	55.3	93.6	104.6	54.9	120.9	52.3
	Total	kg	-	53.5	58.2	96.4	107.2	57.3	122.7	54.1

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	1988-2016	Import/Export for charcoal and fireworks	Statistics Denmark (2017)
	1980-2016	Sale of tobacco, population	Statistics Denmark (2017)
	2000-2015	Cross-border shopping of tobacco	Skatteministeriet (2016)
Emission	1990-2016	Emission factor	Literature, see Table 9.6.2

10. Other production

The sector *Other production* (NFR 2H) covers the following processe relevant for the Danish inventory:

- Food and beverages industry (NFR 2H2); see section 10.2

10.1 Emissions

The relevant pollutants from *Food and beverages industry* are NMVOC and particles. NMVOC emissions are presented in Figure 10.1.1 on a SNAP-code level. For more detailed data, please refer to Chapter 10.2.3 Emission trend and Annex 34-2.

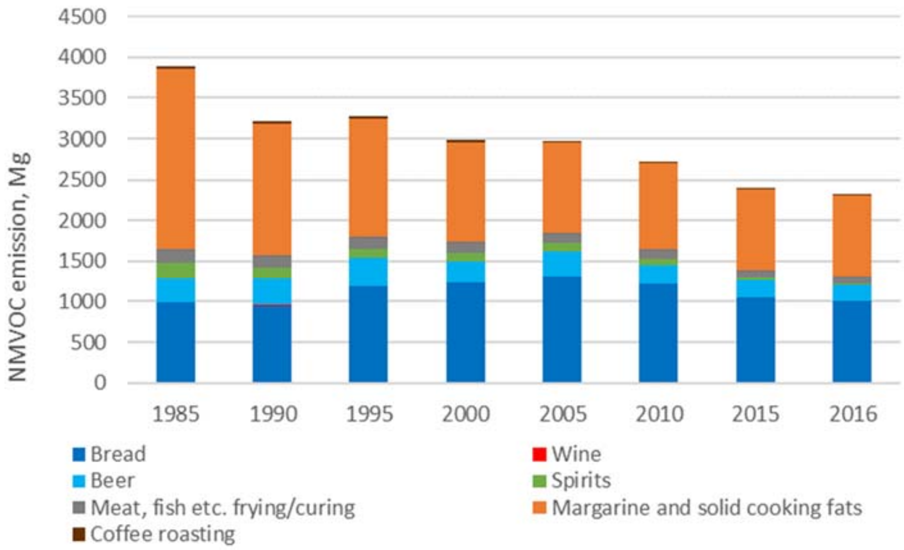


Figure 10.1.1 NMVOC emissions from the production of foods and beverages.

For the historic 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 (1999-2016) 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 stored 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, 2013).

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, 2013).

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, 2013; Nordic Sugar Nykøbing, 2013).

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, 2013; Nordic Sugar Nykøbing, 2013) 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 potatoflour and potatoprotein leads to particle emissions during the drying process. Potatoflour 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 mechanicly and then washed. Potatoflour 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 estimated from production statistics (Statistics Denmark, 2017), standard emission factors from the EMEP/EEA Guidebook (2016) and a country specific emission factor for sugar refining.

Activity data and particle emissions from flour production are available for 2007-2014 (and partly for 2004-2006), data for 2015-2016 are estimated using surrogate data and data for 1990-2004 as the constant average of 2005-2007.

Total sales statistics for produced sugar are available from Statistics Denmark (2017). 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, 2009; Nordic Sugar Nykøbing, 2009). Therefore, the yearly production does not correspond with the yearly sale registered by Statistics Denmark (2017). 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 34-1. 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 Activity data for production in *Food and beverages industry*.

		1985	1990	1995	2000	2005	2010	2015	2016
Bread (rye and wheat)	Gg	119	99	148	139	157	118	111	115
Biscuits, cakes and other bakery products	Gg	193	190	231	244	257	245	208	198
Red wine	ml	12	10	5	5	1	4	1	1
White wine	ml	NO	3.2	0.5	0.9	3.1	18	10	5
Beer	ml	836	930	990	746	868	651	631	569
Malt whisky	ml	0.24	0.02	NO	NO	0.001	0.011	0.032	0.050
Grain whisky	ml	NO	NO	NO	NO	NO	0.003	0.008	0.015
Other spirits	ml	39	33	27	24	26	17	4	1
Sugar production	Gg	533	506	444	443	503	262	468	581
Flour production	Gg	-	164	164	164	168	140	239	268
Poultry curing	Gg	4	11	14	24	35	54	64	58
Fish and shellfish curing	Gg	35	52	31	44	41	73	69	70
Other meat curing	Gg	531	448	464	393	361	303	211	194
Margarine and solid cooking fats	Gg	222	161	144	123	109	105	100	99
Coffee roasting	Gg	53	52	49	56	37	37	17	19

mL: million Litre
NO: Not occuring.

Emission factors

The emission factors used to calculate the NMVOC emissions from *Food and beverages industry* 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 of 0.6 kg C/kg NMVOC.

It is assumed that all Danish whisky is stored for six years.

The emission factor for particles from flour production is the calculated implied emission factor for 2004-2014; 0.10-0.13 Mg PM_{10} per Gg flour produced. A factor of 0.13 Mg PM_{10} per Gg flour produced for 1990-2003.

Table 10.2.2 Emission factors for NMVOC emission from food and beverages production.

Production	Unit	Value	Reference
Bread (rye and wheat)	kg/Mg bread	4.5	EMEP/EEA (2016)
Biscuits, cakes and other bakery products	kg/Mg product	1	EMEP/EEA (2016)
Red wine	kg/m^3 wine	0.8	EMEP/EEA (2016)
White wine	kg/m^3 wine	0.35	EMEP/EEA (2016)
Beer	kg/m^3 beer	0.35	EMEP/EEA (2016)
Malt whisky	kg/m^3 alcohol	150	EMEP/EEA (2016)
Grain whisky	kg/m^3 alcohol	75	EMEP/EEA (2016)
Other spirits	kg/m^3 alcohol	4	EMEP/EEA (2016)
Sugar production	kg/Mg sugar	0.2	Nielsen (2011)
Meat, fish and poultry	kg/Mg product	0.3	EMEP/EEA (2016)
Margarine and solid cooking fats	kg/Mg product	10	EMEP/EEA (2016)
Coffee roasting	kg/Mg beans	0.55	EMEP/EEA (2016)

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 34-2.

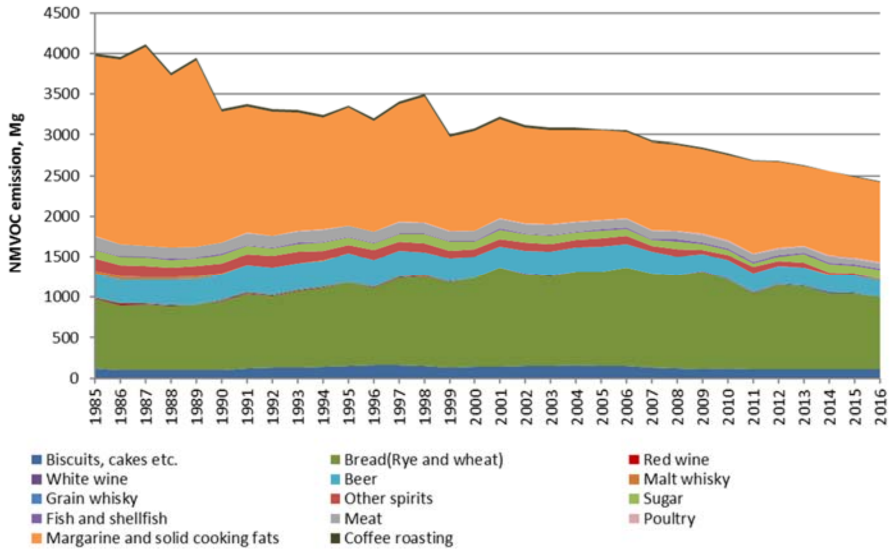


Figure 10.2.1 NMVOC emissions from the *Food and beverages industry*.

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.

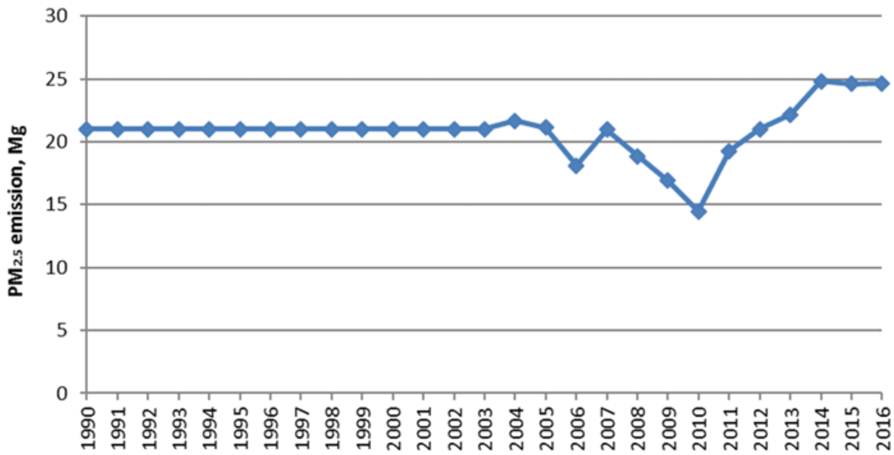


Figure 10.2.2 $PM_{2.5}$ emissions from the production of flour.

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.

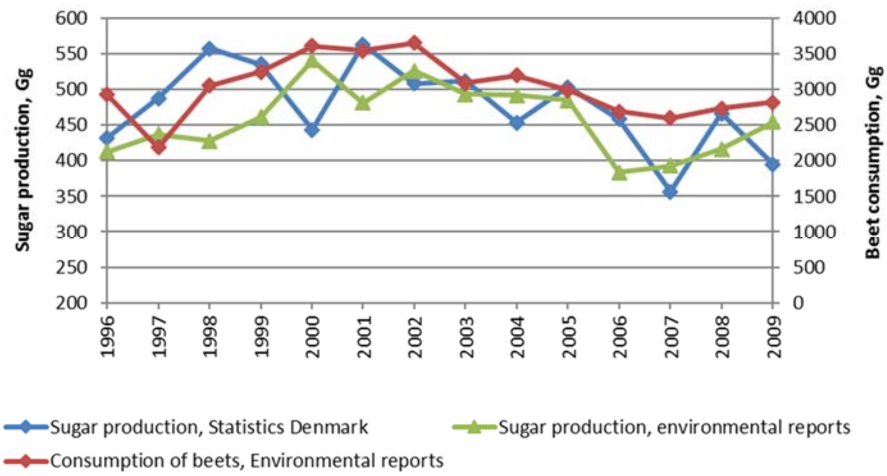


Figure 10.2.3 Comparison of production data and beet consumption data.

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 1st March to 30th February (1996-2006) and 1st May to 30th April (2007-2009) respectively, while data from Statistics Denmark are valid for 1st January to 30th December. However, this should not have a significant influence on the production data, since the production “campaigne” 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	1985-2016	Sales data	Statistics Denmark (2017)
	2006-2016	Whisky production	Contact with producers, expert judgement
	2005-2014	Production of flour	Producers' environmental reports
Emission	1985-2016	Emission factors	EMEP/EEA (2016)
	1985-2016	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 Emission

The relevant pollutants from *Wood processing* are particles. $PM_{2.5}$ emissions are presented in Figure 11.1.1 and Annex 35-2.

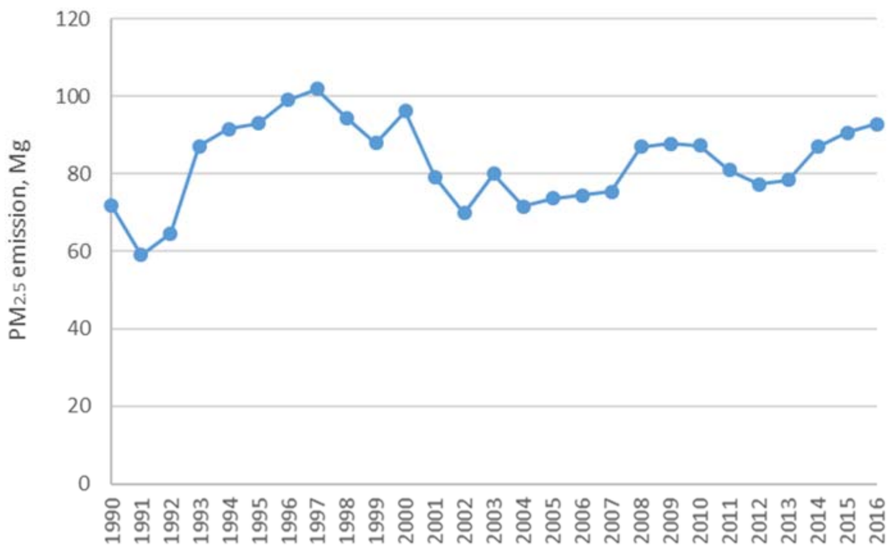


Figure 11.1.1 $PM_{2.5}$ emissions from *Wood processing*.

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 (2016) 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 production statistics (Statistics Denmark, 2017), and validated based on a questionnaire that supplements with data from smaller producers not included in the national statistics (Schou et al., 2015). All the following semi-finished wood product categories are included: sawn wood, wood-based panels and paper, and paper products with default half-lives of 35, 25 and two years, respectively, stipulated by IPCC (2013).

In addition to this, activity data from Statistics Denmark (m^3) are multiplied by a country specific density to gain the unit of Gg wood product.

Activity data

The production data from Statistics Denmark (2017) are multiplied with the density 0.522 Mg per m^3 for sawn wood and 0.595 Mg per m^3 for wood-based panels (IPCC, 2013, Table 2.8.1). The density for sawn wood is calculated from the carbon content of 0.261 Mg C per m^3 (Schou et al., 2015) and the carbon fraction of 0.5 (IPCC, 2013, Table 2.8.1). The resulting activity data are presented in Table 11.2.1 and Annex 35-1.

Table 11.2.1 Activity data *Wood processing*, Gg.

	1990	1995	2000	2005	2010	2013	2014	2015	2016
Wood processing	359.3	464.8	481.3	368.3	436.6	392.5	435.0	453.4	464.2

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	Mg/Gg	1	EMEP/EEA (2016)
PM_{10}	% of TSP	40	Expert judgement
$PM_{2.5}$	% of TSP	20	Expert judgement

11.2.3 Emission trends

The emission trends for particles are available in Table 11.2.3 and Annex 35-2.

Table 11.2.3 Particle emissions from *Wood processing*, Mg.

	1990	1995	2000	2005	2010	2015	2016
TSP	359.3	464.8	481.3	368.3	436.6	453.4	464.2
PM_{10}	143.7	185.9	192.5	147.3	174.6	181.4	185.7
$PM_{2.5}$	71.9	93.0	96.3	73.7	87.3	90.7	92.8

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	1990-2016	Harvested wood products	Statistics Denmark (2017)
	1990-2016	Densities	IPCC (2013), Schou et al. (2015)
Emission	1990-2016	Emission factor	EMEP/EEA (2016)

12. Other production, consumption, storage, transportation or handling of bulk products

The sector *Other production, consumption, storage, transportation or handling of bulk products* (NFR 2L) covers the following proces relevant for the Danish inventory:

- Treatment of slaughterhouse waste; see section 12.2

12.1 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.

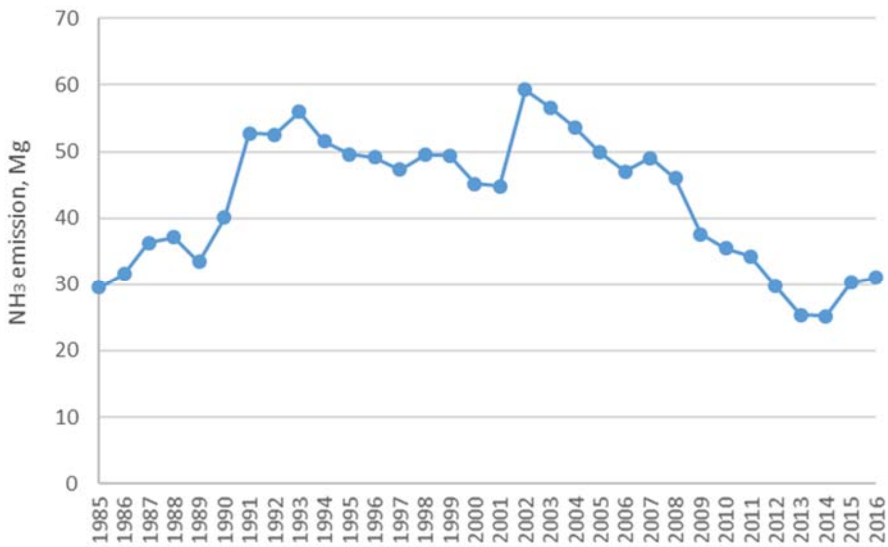


Figure 12.1.1 NH_3 emissions from treatment of slaughterhouse waste.

12.2 Treatment of slaughterhouse waste

One company treats slaughterhouse waste in Denmark: Daka with five departments located in Løsning, Randers, Lunderskov, Ortved, and Nyker. Daka is the result of the merger of Daka and Kambas. The departments 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.

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 1999-2009 (Daka, 2014). 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 (2017).

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 36-1.

Table 12.2.1 Activity data for treatment of slaughterhouse waste, Gg.

	1985	1990	1995	2000	2005	2010	2015	2016
Meat/bone meal	134.4	128.8	197.0	156.0	164.1	104.6	104.6	104.6
Animal fat	11.1	72.1	54.2	82.2	96.2	75.3	54.0	59.6
Blood meal	11.0	11.0	11.0	11.0	11.4	10.2	7.5	7.5
Total	156.5	211.9	262.2	249.2	271.8	190.1	166.1	171.7

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 2002/3 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 Mg product. The applied emission factor for NH_3 is the average 189 g per Mg product.

12.2.3 Emission trend

Emissions from the treatment of slaughterhouse waste are available in Table 12.2.2 and Annex 36-2.

Table 12.2.2 Emissions from the treatment of slaughterhouse waste, Mg.

	1985	1990	1995	2000	2005	2010	2015	2016
NH_3	29.6	40.0	49.6	45.1	49.9	35.4	30.2	31.0

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 and 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 Barley malting

This activity is part of the beverages category. During the drying / roasting of barley as part of the process for producing beer and some spirits, NMVOC is emitted.

13.1.3 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.

13.1.4 Concrete batching

Concrete batching is a potential emission source of particulate matter and also some heavy metals.

13.1.5 Meat/fish smokehouses

In addition to NMVOC emissions, smoking of fish and meat is a potential source of emissions of particulate matter and PAH.

13.1.6 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 IPCC Good Practice Guidance (IPCC, 2006). The uncertainty has been estimated by the "Approach 1" methodology, this is further described in Nielsen et al. (2018a, 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

The emission source categories applied are listed in Table 14.3.1.

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 Guidelines (2006) combined with assessment of the individual processes.

14.2.1 Mineral industry

For *Cement production*, the single Danish producer 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 1 % 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 *Lime production*, including non-marketed lime in the sugar production, are based on information compiled by Statistics Denmark. Due to the assumption of no lime kiln dust (LKD) the uncertainty for the entire time series is assumed to be 5 % 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 is 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, the activity data uncertainty is 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 30 % (see Chapter 3.7.5 Verification). For *Stone wool production* 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 30 % respectively. The overall activity data uncertainty for *Other process uses of carbonates* is assumed to be 30 %. 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 *Nitric acid production* 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 *Catalysts and fertiliser production.*

14.2.3 Metal industry

The uncertainty for the activity data and emission factor for CO_2 is assumed to be 5 % and 10 % respectively for *Secondary steel production*.

The uncertainty for the activity data and emission factor is assumed to be 10 % and 30 % respectively for *Magnesium production* (SF_6) and 10 % and 50 % respectively for *Secondary lead production*.

14.2.4 Non-energy products from fuels and solvent use

Emissions from *Lubricant use* is derived from the energy statistics and standard emission factors. Uncertainties are assumed to be 10 % and 20 % 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 15 % and 60 % 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 (1999) 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 EF 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 20 %), 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 % 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.

14.2.6 Product uses as substitutes for ozone depleting substances

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 10 %. 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 CO_2 equivalent greenhouse gas emission from the IPPU sector in 2016 is 2124 Gg CO_2e and the calculated Approach 1 uncertainty for the year is 14.3 %. The trend decreases with 19.7 % and the trend uncertainty is 13.6 %.

The dominant sources of uncertainty for greenhouse gas emissions in 2016 are emissions of HFCs from *Refrigeration and air conditioning* followed by CO_2 from *Paraffin wax use* and SF_6 from *SF_6 from other product 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	1	2					
2A2	Lime production	5	4					
2A3	Glass production	1	2					
2A4a	Ceramics	5	2					
2A4b	Other uses of soda ash	5	2					
2A4d	Other process uses of carbonates	30	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	10	20					
2D2	Paraffin wax use	15	60	60	60			
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	Road paving with asphalt	20	75	75				
2D3	Asphalt roofing	20	75					
2D3	Urea from fuel consumption	5	10					
2E5	Other electronics industry	-						
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	10	50	50	50			
2G4	Tobacco	10		50	50			
2G4	Barbeques	10		100	100			
Emission 2016, Gg			1396	0.1	0.1	611[4]	4.0[4]	91.8[4]
Overall uncertainty in 2016, %			3.6	53.0	49.7	48.4	51.0	44.2
Trend 1990-2016 (1995-2016), %			9.2	-7.9	-98.1	153	531	-10.3
Trend uncertainty, %			2.9	13.6	1.2	144.4	89.2	18.0

[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 1990 nor 2016. [4]CO_2e.

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 year 2016 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 1990-2016 %	Uncertainty trend %-age points
SO_2	192.42	-69.2	22.6
NO_x	82.45	-93.8	6.2
NMVOC	15.90	-34.2	7.1
CO	66.35	-81.0	32.1
NH_3	146.17	-51.0	75.7
TSP	315.53	-2.1	112.9
PM_{10}	126.51	-5.8	67.1
$PM_{2.5}$	104.35	-34.9	44.0
BC	171.56	-48.7	58.8
As	663.83	-53.1	123.5
Cd	546.27	-73.9	56.5
Cr	572.80	-29.3	125.2
Cu	285.09	193.4	375.5
Hg	427.24	-93.2	54.0
Ni	367.54	-80.1	154.0
Pb	576.20	-89.2	43.2
Se	425.19	-85.7	11.2
Zn	393.58	-82.6	132.0
HCB	729.22	-99.8	0.3
PCDD/F	203.41	-98.8	11.1
benzo(b)flouranthene	200.25	-81.8	151.3
benzo(k)flouranthene	198.17	-88.3	104.9
benzo(a)pyrene	197.11	-81.0	155.6
indeno(1,2,3-c,d)pyrene	199.88	-86.7	116.7
PCB	754.11	-96.2	8.0

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. (2013b) 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., 2018a).

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 Karsten Fuglsang from FORCE Technology. This report has been externally 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	Cement production	Improve process description and improve the transparency on where emissions of various pollutants are included.	1
Mineral industry	Ceramics	It will be investigated whether emissions of particulate matter can be included for production of ceramics	3
Mineral industry	Construction and demolition	EMEP/EEA (2016) provides emission factors for construction and demolition of roads. It will be investigated whether or not activity data can be collected to include this source.	2
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
Metal industry	Secondary lead production	The applied emission factors are currently from EMEP/EEA (2013), these will be updated to EMEP/EEA (2016)	1
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 http://envs.au.dk/videnudveksling/luft/emissioner/reportingsectors/industrialprocesses/

DANISH EMISSION INVENTORY FOR
INDUSTRIAL PROCESSES AND PRODUCT USE

Results of inventories up to 2016

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 2016 are included.

ISBN: 978-87-7156-359-7
ISSN: 2245-0203