THE DANISH EMISSION INVENTORY FOR FUGITIVE EMISSIONS FROM FUELS

Scientific Report from DCE – Danish Centre for Environment and Energy No. 463 2021

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DCE – DANISH CENTRE FOR ENVIRONMENT AND ENERGY

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Data sheet

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Abstract:	This report presents the methodology and data used in the Danish inventory of fugitive emissions from fuels for years until 2019. The inventory of fugitive emissions includes the air pollutants SO_2, NO_x, NMVOC, CO, particulate matter (PM), black carbon (BC), heavy metals (HM), dioxin and PAHs, and the greenhouse gases CO_2, CH_4 and N_2O. Refining of oil products is the major source of fugitive emissions of SO_2, while NO_x, and CO mainly come from flaring at refineries and at oil and gas production facilities. The fugitive emissions of NMVOC originate predominantly from refining of oil products, production of oil and natural gas, service stations and oil loading of ships. The major source of PM emissions in the fugitive sector is storage of solid fuels, due to dust from stockpiles of coal for use in power and heating plants. Fugitive emissions from fuels account for approximately 1 % of the total Danish greenhouse gas emissions excluding Land use, Land use change and forestry (LULUCF) in 2019. The major part of the fugitive greenhouse gas emissions are emitted as CO_2. Flaring, the largest contribution being flaring offshore in upstream oil and gas production, is by far the major source of CO_2 in the fugitive sector. The major sources of fugitive emissions of CH_4 are extraction of oil and gas, refining of oil, transport of oil in pipelines, loading of oil onto ships, and flaring.

Keywords:	Fugitive emissions from fuels, Greenhouse gases, Air pollution, Emissions, SO_2, NO_x, NMVOC, CO, particulate matter, black carbon, heavy metals, dioxin, PAH, CO_2, CH_4, N_2O, HFCs, PFCs, SF_6
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Preface

The Danish Centre for Environment and Energy (DCE), Aarhus University prepares the national inventories of emissions to the air and carries out the reporting to the UNFCCC (United Nations Framework Convention on Climate Change) and to the UNECE CLRTAP (United Nations Economic Commission for Europe Convention on Long-range Transboundary Pollutants) on an annual basis. Furthermore, the greenhouse gas emission inventory is reported to the EU MMR (EU's Monitoring Mechanism Regulation for greenhouse gases) and the Kyoto Protocol, while the air pollution inventory forms the basis of the reporting under the NEC directive (National Emission Ceilings Directive for certain atmospheric pollutants).

This report summarises the methods and the data used for quantification of fugitive emissions from fuels, and updates the earlier version published in 2015 (Plejdrup et al., 2015). Fugitive emissions from non-fuel sources, e.g. agricultural operations, are not included in the fugitive sector. The report includes the latest updates and improvements to the emission inventory of fugitive emissions. Data given in this report is based on the national emission inventory for the year 2019, which are described in full in Denmark's National Inventory Report (Nielsen et al., 2021a) and Denmark's Informative Inventory Report (Nielsen et al., 2021b).

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Sammenfatning

DCE - Nationalt Center for Miljø og Energi, Aarhus Universitet udarbejder de nationale opgørelser af emissioner til luft og varetager årlig rapportering til UNFCCC (United Nations Framework Convention on Climate Change) og til UNECE CLRTAP (United Nations Economic Commission for Europe Convention on Long-range Transboundary Pollutants). Desuden rapporteres emissionsopgørelsen for drivhusgasser til EU's moniteringsmekanisme (mekanisme til overvågning og rapportering af drivhusgasemissioner og rapportering af andre oplysninger vedrørende klimaændringer på nationalt plan) og til Kyotoprotokollen, mens emissionsopgørelsen for luftforurening rapporteres til NEC direktivet (direktivet om nationale emissionslofter for visse luftforurenende stoffer).

De nationale emissionsopgørelser omfatter fem sektorer, jf. definitionerne i internationale retningslinjer og rapporteringsskabeloner (IPCC, 2000; IPCC, 2006; EMEP / EEA, 2019). "Flygtige emissioner fra brændsler" er en undersektor i energisektoren. Denne rapport dokumenterer metoderne, der anvendes i opgørelsen for flygtige emissioner, herunder information om aktivitetsdata, emissionsfaktorer og emissioner for tidsserien 1990-2019. Denne rapport er en opdatering af den tidligere versionen publiceret i 2015 (Plejdrup et al., 2015).

Sektoren flygtige emissioner omfatter udvinding, håndtering, lagring, behandling, transmission og distribution af faste, flydende og gasformige brændsler, samt fra flaring (afbrænding uden nyttiggørelse) og venting (afblæsning). Blandt de vigtigste udledende sektorer er platformene på Nordsøen til udvinding af olie og gas samt raffinaderier.

Den samlede danske emission af drivhusgasser i 2019 er 43 971 kt CO_2 ækvivalenter (CO_2-ækv.) eksklusiv LULUCF-sektoren (Land Use, Land Use Change and Forestry, som dækker emissioner og optag forårsaget af ændringer i arealanvendelse og ændringer af skovarealer). I samme år er drivhusgasemissionen fra energisektoren 29 995 kt CO_2-ækv., svarende til 68 %. Hovedparten af drivhusgasemissionen i energisektoren stammer fra brændselsforbrug til energiproduktion og til transport. Flygtige emissioner udgør 1,0 % af den samlede drivhusgasemission fra energisektoren.

Ud over drivhusgasserne CO_2, CH_4 and N_2O omfatter emissionsopgørelsen for sektoren flygtige emissioner fra brændsler også svovldioxid (SO_2), kvælstofilter (NO_x), andre flygtige kulbrinter end metan (NMVOC), kulilte (CO), partikler (PM), sod (BC), tungmetaller (HM) og persistente organiske forbindelser (POP'er). Partikelemissioner estimeres for tre størrelsesfraktioner; total mængde luftbårne partikler (TSP), partikler med en aerodynamisk diameter mindre end 10 µm (PM_{10}) og mindre end 2,5 µm ($PM_{2,5}$). Flygtige emissioner udgør 8,5 %, 7,3 % og 1,2 % af den totale nationale emission af hhv. SO_2, NMVOC og BC. For de øvrige stoffer bidrager sektoren kun i begrænset omfang til de nationale emissioner (< 0.1 %).

Summary

The Danish Centre for Environment and Energy (DCE), Aarhus University prepares the national inventories of emissions to the air and carries out the reporting to the UNFCCC (United Nations Framework Convention on Climate Change) and to the UNECE CLRTAP (United Nations Economic Commission for Europe Convention on Long-range Transboundary Pollutants) on an annual basis. Furthermore, the greenhouse gas emission inventory is reported to the EU's Climate Monitoring Regulation and the Kyoto Protocol, while the air pollution inventory forms the basis of the reporting under the NEC directive (National Emission Ceilings for certain atmospheric pollutants).

The national emission inventories covers five sectors as defined in the international guidelines and reporting templates (IPCC, 2000; IPCC, 2006; EMEP/EEA, 2019). "Fugitive emissions from fuels" is a subsector in the Energy sector. This report document the methodologies used in the emission inventory for fugitive emissions from fuels, including information on activity data, emission factors and emissions for the time series 1990-2019. This report updates the version published in 2015 (Plejdrup et al., 2015).

The fugitive sector covers emissions from extraction, handling, storage, treatment, transmission and distribution of solid, liquid, and gaseous fuels, and from venting and flaring. Among the major sources in the fugitive sector are offshore installations in upstream oil and gas production, and the refineries.

The total Danish GHG emission in 2019 is 43 971 kt CO_2 equivalents (CO_2 eqv.) excluding Land use, Land use change and forestry (LULUCF). In the same year the GHG emission from the energy sector is 29 995 kt CO_2-eqv., corresponding to 68 %. The majority of the GHG emissions is in the energy sector and stems from fuel combustion in energy industries and in transport. The fugitive sector accounts for 1.0 % of the GHG emissions from the energy sector as a whole.

Besides the greenhouse gases carbon dioxide (CO_2), methane (CH_4) and nitrous oxide (N_2O) the inventory of fugitive emissions from fuels includes emissions of sulphur dioxide (SO_2), nitrogen oxide (NO_x), non-methane volatile organic compounds (NMVOC), carbon monoxide (CO), particulate matter (PM), black carbon (BC), heavy metals (HM), and persistent organic pollutants (POPs). Emissions of particulate matter are estimated in three size fractions; total suspended particulate matter (TSP) and particles with an aerodynamic diameter less than 10 µm (PM_{10}) and less than 2.5 µm ($PM_{2.5}$). The fugitive sector contribute 8.5 %, 7.3 % and 1.2 % to the national total emissions of SO_2, NMVOC and BC, respectively. For the remaining pollutants, the fugitive sector contributed only little to the national total (< 0.1 %).

1 Total Danish emissions, international conventions and reduction targets

The Danish emission inventories follow the IPCC Guidelines (IPCC, 2006) and IPCC Good practice guidance (IPCC, 2000). The inventories are based on the European programme for emission inventories, the CORINAIR system, which includes methodology, structure and software. The methodology is outlined in the EMEP/EEA Guidebook (EMEP/EEA, 2019). The emission data are stored in a MS Access database, from where it is transferred to the reporting formats.

In the national inventory, the emissions are organised in six categories, according to the reporting formats for the Convention on Long-range Transboundary Pollutants (UNECE CLRTAP) and the United Nations Framework Convention on Climate Change (UNFCCC). These categories cover emissions from Energy, Industrial Processes and Product Use (IPPU), Agriculture, Land use - Land use change and forestry (LULUCF), Waste, and Other. The Danish emission database is organized according to the Selected Nomenclature for Air Pollution (SNAP) as defined in the CORINAIR system. The emission inventories are prepared from a complete emission database based on the SNAP sectors. Aggregation to the sector codes used for both the CLRTAP in accordance with the Nomenclature for Reporting (NFR) and the UNFCCC in accordance with the Common Reporting Format (CRF) is based on a correspondence list between SNAP and NFR or CRF sectors. Data presented in the present report are based on the Danish emission inventories 2021 including emissions for the year 2019.

Documentation reports for the National Emission Inventory 2021 are published on the homepage for The Danish Centre for Environment and Energy (DCE), Aarhus University, as are annual updated figures on emissions and emission factors:

https://envs.au.dk/en/research-areas/air-pollution-emissions-and-effects/air-emissions/

Furthermore, the data reported can be found on the EIONET homepage:

UNFCCC reportings: http://cdr.eionet.europa.eu/dk/Air_Emission_Inventories/Submission_UNFCCC/

CLRTAP reportings: http://cdr.eionet.europa.eu/dk/un/clrtap/inventories/

EU MMR reportings: http://cdr.eionet.europa.eu/dk/eu/mmr/art07_inventory/ghg_inventory/

1.1 International conventions and reduction targets

Denmark is a Party to two international conventions with regard to air emissions; the CLRTAP (the Geneva Convention) and the UNFCCC (the Climate Convention).

CLRTAP is a framework convention and has expanded to cover eight protocols:

- EMEP Protocol, 1984 (Geneva).
- Protocol on the Reduction of Sulphur Emissions, 1985 (Helsinki).
- Protocol concerning the Control of Emissions of Nitrogen Oxides, 1988 (Sofia).
- Protocol concerning the Control of Emissions of Volatile Organic Compounds, 1991 (Geneva).
- Protocol on Further Reduction of Sulphur Emissions, 1994 (Oslo).
- Protocol on Heavy Metals, 1998 (Aarhus) and its 2012 amended version.
- Protocol on Persistent Organic Pollutants (POPs), 1998 (Aarhus) and its 2009 amended version.
- Protocol to Abate Acidification, Eutrophication and Ground-level Ozone, 1999 (Gothenburg) and its 2012 amended version.

The Climate Convention (UNFCCC) is a framework convention from 1992. The objective of the convention is “to achieve (…) stabilization of greenhouse gas concentrations in the atmosphere at a level that would prevent dangerous anthropogenic interference with the climate system”. The convention does not hold obligations concerning reduction of emissions but encourage the parties to reduce the emissions of greenhouse gases to their 1990 level. An important point is that the Parties to the convention are obligated to make national inventories of anthropogenic emissions of sources and removals by sinks of greenhouse gases. Denmark has ratified the Climate Convention without territorial exceptions for Greenland and the Faroe Islands, and the national reporting to UNFCCC therefore includes the entire Kingdom of Denmark. The information contained in this report only relates to Denmark.

The Kyoto Protocol is a protocol to the Climate Convention. The Kyoto Protocol sets legally binding emission targets and timetables for the following greenhouse gases: CO_2, CH_4, N_2O, HFCs, PFCs and SF_6 (expanded to also cover NF_3 for the second commitment period (2013-2020)). The greenhouse gas emissions of the pollutants are converted to CO_2-equivalents, which can be summarised to total greenhouse gas (GHG) emissions. Denmark (including Greenland, excluding the Faroe Islands) was a Party to the Kyoto Protocol for the first commitment period and was obligated to reduce the emission of GHG in the years 2008-2012 by 8 % compared to the base year emission level (1990 for CO_2, CH_4 and N_2O and 1995 for the F-gases). EU was also a Party to the Kyoto Protocol for the first commitment period with an individual reduction obligation of 8 %. The 15 EU countries (EU-15) that compose EU as a Party to the Kyoto Protocol for the first commitment period have distributed this reduction obligation among themselves according to the Burden Sharing Agreement. Hereby, the countries have obligated themselves to submit emission data to the EU monitoring mechanism for CO_2 and other greenhouse gases. According to the Burden Sharing Agreement Denmark (excluding Greenland and the Faroe Islands) was obligated to reduce its GHG emission by 21 % in 2008-2012 according to the emission in the base year.

For EU-15 the 8 % commitment has been achieved by a wide margin. On average for the period 2008-2012, annual emissions (without LULUCF and the use of Kyoto mechanism) were 11.7 % below base year levels (https://ec.europa.eu/clima/policies/strategies/progress/kyoto_1_en). Denmark has reduced national emissions excluding LULUCF by 14 % on average for the period 2008-2012, the remaining part of the emissions reduction commitment being fulfilled through credits from LULUCF under the Kyoto Protocol (article 3.3 and 3.4), Clean Development Mechanism (CDM) projects (projects in developing countries that have no reduction commitments under the Kyoto Protocol) and Joint Implementation (JI) projects (project located in a country with a reduction commitment of its own).

At the Doha Climate Change Conference of Parties (COP18) in 2012, an amendment to the Kyoto Protocol was adopted. The Doha Amendment establishes the second commitment period of the Kyoto Protocol, covering the years 2013-2020. For the second commitment period, the EU has a target of 20 % reduction compared to the base year. The reduction commitment within the EU distinguishes between the emissions covered by the EU Emission Trading System (ETS) and the non-ETS emissions. For the ETS there is a reduction of 24 % in allowances. For the non-ETS emissions, each Member State has a separate target set out in the Effort Sharing Decision (ESD, Decision No 406/2009/EC). In the ESD, Denmark has a reduction commitment of 20 % in 2020 compared to the emission level in 2005. In accordance with the Kyoto Protocol, Denmark's base year emissions include the emissions of CO_2, CH_4 and N_2O in 1990 in CO_2 eqv. and Denmark has chosen 1995 as the base year for the emissions of HFCs, PFCs and SF_6 and NF_3.

The Paris Agreement was adopted at the Paris Climate Change Conference of Parties (COP21) in 2015, establishing the new commitment period 2020-2030. The Paris Agreement entered into force on 4 November 2016. The EU submitted a provisional target under the Paris Agreement, called the Intended Nationally Determined Contribution (INDC), to reduce its greenhouse gas emissions by at least 40 % by 2030 compared to 1990. The Nationally Determined Contributions (NDCs) have to be updated or renewed every fifth year, next time in 2025. In December 2020, the EU submitted its updated and enhanced NDC of 55 % reduction by 2030 from 1990 levels. Thereby the EU and its Member States, acting jointly, are committed to a binding target of a net domestic reduction of at least 55 % in greenhouse gas emissions by 2030 compared to 1990.

1.2 Total Danish emissions

The national Danish emissions in 2019 as reported to the conventions are summarised in Table 1.1, 1.2, 1.3 and 1.4. The emissions are aggregated on sector level according to the reporting formats.

Table 1.1 GHG emission 2019 as reported to UNFCCC (Nielsen et al., 2021a).

Sector	CO_2	CH_4	N_2O	HFCs	PFCs	SF_6	NF_3	Total GHG
				kt CO_2 eqv.				
Energy	29 279	331	385					29 995
Industrial Processes and Product Use	1 410	3	19	336	1	71	NO,NA	1 840
Agriculture	185	5 840	4 872					10 898
Land Use, Land-Use Change and Forestry	-2 581	3	20					-2 558
Waste	23	997	218					1 238
Denmark Total excl. LULUCF	30 897	7 171	5 494	336	1	71	NO,NA	43 971
Denmark Total incl. LULUCF	33 029	7 410	5 536	336	1	71	NO,NA	46 383

NA: Not applicable, NO: Not occurring

Table 1.2 Danish emissions of other air pollutants in 2019 as reported to CLRTAP (Nielsen et al., 2021b).

Sector	NO_x	NMVOC	SO_x	NH_3	$PM_{2.5}$	PM_{10}	TSP	BC	CO
					kt				
Energy	79.30	29.51	7.43	2.56	10.67	11.78	13.39	1.95	200.45
Industrial Processes and Product Use	0.07	27.73	2.01	0.36	0.71	2.28	5.50	0.01	3.05
Agriculture	19.15	44.99	0.03	71.66	1.32	8.83	67.61	0.03	3.81
Waste	0.10	0.59	0.97	0.70	0.31	0.31	0.31	>0.01	1.37
Denmark Total	98.62	102.82	10.44	75.29	13.02	23.20	86.82	1.99	208.68

NA: Not applicable, NO: Not occurring

Table 1.3 Danish emissions of other air pollutants in 2019 as reported to CLRTAP (Nielsen et al., 2021b).

Sector	Pb	Cd	Hg	As	Cr	Cu	Ni	Se	Zn
					kt				
Energy	7.96	0.63	0.22	0.17	1.44	41.24	2.44	0.40	50.03
Industrial Processes and Product Use	1.90	0.02	0.01	0.05	0.17	2.02	0.17	0.04	2.17
Agriculture	0.01	0.05	0.01	>0.01	>0.01	>0.01	>0.01	>0.01	0.03
Waste	2.14	0.01	>0.01	>0.01	0.01	0.07	0.01	>0.01	8.34
Denmark Total	12.01	0.71	0.23	0.23	1.63	43.34	2.62	0.44	60.57

NA: Not applicable, NO: Not occurring

Table 1.4 Danish emissions of other air pollutants in 2019 as reported to CLRTAP (Nielsen et al., 2021b).

Sector	Dioxin	Benzo(a)-pyrene	Benzo(b)-fluoranthene	Benzo(k)-fluoranthene	Indeno-(1,2,3-cd)-pyrene	HCB	PCB
				t			
Energy	23.04	1.35	1.43	0.89	0.82	1.91	0.31
Industrial Processes and Product Use	0.16	0.02	0.02	0.01	0.01	0.01	0.06
Agriculture	0.03	0.02	0.07	0.03	0.04	0.28	>0.01
Waste	8.53	0.06	0.07	0.05	0.08	0.01	0.03
Denmark Total	31.77	1.46	1.59	0.98	0.96	2.21	0.40

NA: Not applicable, NO: Not occurring

2 Fugitive emissions from fuels (sector 1B)

2.1 Overview of the sector

The Danish emission inventory for the sector Fugitive emissions from fuels includes emissions from production, storage, refining, transport, venting and flaring of coal, oil and gas. The relevant CRF categories for the Danish fugitive sector are:

- 1B1a Coal mining and handling
- 1B2a Oil
- 1B2b Natural gas
- 1B2c Venting and flaring

Coal mining is not occurring in Denmark for the entire time series, and there is no solid fuel transformation processes such as coke or charcoal production in Denmark. Consequently, the only fugitive emissions related to solid fuels are emissions in connection with the storage and handling. Denmark has a large domestic production of oil and gas, all production taking place offshore in the North Sea west for Jutland. In addition to the offshore activities, there are two operating refineries in Denmark (a third refinery closed in 1996). Town gas is used to a limited extent in Denmark and for the time series considered in the emission inventory town gas is based on diluted natural gas.

2.1.1 Greenhouse gas emissions

The total Danish GHG emission in 2019 was 43 971 kt CO_2 eqv. excluding Land use, Land use change and forestry (LULUCF) and 46 383 kt CO_2 eqv. including LULUCF. The fugitive sector is a rather small sector in Denmark contributing only little to the national total greenhouse gas emissions. To give an impression of the quantities of the GHG emissions on both national and sectoral level, the fugitive emissions of CO_2, CH_4 and N_2O are given in Table 2.1 as well as the national total GHG emission. Furthermore, the percentage of the national total is included in the table.

Table 2.1 National and fugitive emissions of CO_2, CH_4 N_2O and GHG in 2019, and the fugitive emissions share of national total emissions.

	National emission kt CO_2 eqv.	Fugitive emission kt CO_2 eqv.	Fugitive/national emission %
CO_2	30 897	195	0.6
CH_4	7 171	76	1.1
N_2O	5 494	34	0.6
GHG*	43 971	305	0.7

*excluding LULUCF.

Fugitive emissions from fuels is a subsector in the energy sector, accounting for 1.0 % of the GHG emissions from the energy sector as a whole in 2019. The majority of the GHG emissions in the energy sector stem from fuel combustion in energy industries and transport (see Table 2.2). Fugitive emissions from fuels arise from extraction, handling, storage, transmission and distribution of solid, liquid, and gaseous fuels. Also, flaring is an important source for fugitive emissions from fuels. Among the facilities that contribute to the fugitive emissions are the oil and gas production facilities in the North Sea, gas storage and treatment plants and refineries. Furthermore, transmission pipelines and distribution networks are sources of fugitive emissions.

Table 2.2 Emissions of greenhouse gases in the Energy sector in 2019.

CRF category		CO_2		CH_4		N_2O		GHG	
		kt	% of total	t	% of total	t	% of total	kt CO_2-eqv.	% of total
1A1	Energy industries	8 460.21	28.9	113.46	34.2	78.41	20.4	8 652.08	46.4
1A2	Manufacturing industries	3 657.68	12.5	25.01	7.5	55.10	14.3	3 737.79	10.3
1A3	Transport	12 985.64	44.4	9.73	2.9	138.71	36.0	13 134.09	29.2
1A4	Other sectors	3 782.56	12.9	107.31	32.4	76.65	19.9	3 966.52	12.8
1A5	Other	197.88	0.7	0.23	0.1	2.14	0.6	200.25	0.6
1B1	Fugitive emissions from solid fuels	NO		NO		NO		NO	
1B2	Fugitive emissions from oil and gas	194.67	0.7	75.72	22.8	34.21	8.9	304.61	0.7
	Sum	29 278.64		331.46		385.22		29 995.32	

Emissions of F-gases (HFCs, PFCs, SF_6, and NF_3) are only applicable to the Industrial Processes and Product Use (IPPU) sector, and therefore the total fugitive GHG emission from fuels, expressed as CO_2 eqv., refers to the sum of CO_2, CH_4 and N_2O emissions multiplied by their individual global warming potentials (GWP) of 1, 25 and 298, respectively, as given in the Working Group I Report of IPCC Fourth Assessment Report (IPCC, 2007).

Flaring, the largest contribution being flaring offshore in upstream oil and gas production, is by far the major source of CO_2 in the fugitive sector. The CO_2 emission from flaring in 2019 makes up 64 % of the total GHG emission in the fugitive sector.

The major sources of fugitive emissions of CH_4 are extraction of oil and gas, refining of oil, transport of oil in pipelines, loading of oil onto ships, and flaring. The CH_4 emission makes up 25 % of the total GHG emission in the fugitive sector in 2019.

Fugitive emissions of N_2O are dominated by flaring in oil and gas extraction, making up 99.9 % of the total fugitive N_2O emission in 2019. The N_2O emission makes up 11 % of the total GHG emission in the fugitive sector.

2.1.2 Air pollution emissions

Besides the greenhouse gases CO_2, CH_4 and N_2O the inventory on fugitive emissions from fuels also includes emissions of sulphur dioxide (SO_2), nitrogen oxide (NO_x), non-methane volatile organic compounds (NMVOC), carbon monoxide (CO), particulate matter (PM), black carbon (BC), heavy metals (HM), and persistent organic pollutants (POPs). Emissions of particulate matter are estimated in three size fractions; total suspended particulate matter (TSP) and particles with an aerodynamic diameter less than 10 µm (PM_{10}) and less than 2.5 µm ($PM_{2.5}$).

To give an impression of the quantities of emissions of air pollutants on both national and sector level, the emissions of SO_2, NO_x, CO, NMVOC, $PM_{2.5}$ and BC are given in Table 2.3. Furthermore, the percentage of the national total is included in the table. The fugitive sector has only minor emissions of NO_x, CO, and PM compared to the total Danish emissions of these components.

Table 2.3 Emissions of selected air pollutants in the fugitive sector and national total emission in 2019, and the share of fugitive to national total emissions.

	National emission Kt	Fugitive emission kt	Fugitive/national emission %
SO_2	10	0.89	8.5
NO_x	103	0.10	0.1
CO	209	0.17	0.1
NMVOC	103	7.49	7.3
$PM_{2.5}$	13	0.01	0.1
BC	2	0.02	1.2

Refining of oil products is the major source of fugitive emissions of SO_2, while NO_x and CO mainly come from flaring at refineries and at upstream oil and gas production facilities. The fugitive emissions of NMVOC originate predominantly from refining of oil products, production of oil and natural gas, service stations and oil loading and unloading activities from ships. The major source of PM emissions in the fugitive sector is storage of solid fuels, due to dust from stockpiles of coal for use in power and heating plants.

Fugitive emissions are important contributions of SO_2, NMVOC and BC to the Energy sector (see Table 2.4). The main sources for NMVOC in the fugitive sector are refineries (including flaring in refineries) contributing 71 %, offshore activities (exploration, extraction and loading of ships) contributing 10 % and onshore activities (loading of ships, transport of oil in pipelines and storage of raw oil in tanks) contributing 4 %. Fugitive SO_2 emissions are predominantly from sulphur recovery (87 %) and flaring in refineries (13 %). Storage of coal is the major source of fugitive emissions of TSP, PM_{10}, $PM_{2.5}$ and BC (91 %, 90 %, 72 % and 98 %, respectively).

Table 2.4 Emissions of selected air pollutants in the Energy sector in 2019, and share of the total emissions for the Energy sector.

NFR category		SO_2		NO_x		NMVOC		BC	
		kt	% of total	kt	% of total	kt	% of total	kt	% of total
1A1	Energy Industries	2.39	32.1	15.70	19.8	1.13	3.8	0.03	1.4
1A2	Manufacturing industries and Construction	2.33	31.4	8.27	10.4	1.67	5.7	0.17	8.9
1A3	Transport	0.45	6.1	40.31	50.8	6.73	22.8	0.49	25.1
1A4	Other Sectors	1.30	17.5	13.79	17.4	12.22	41.4	1.21	62.1
1A5	Other	0.07	0.9	1.13	1.4	0.27	0.9	0.02	1.2
1B1	Fugitive Emissions from fuels, Solid fuels	NO		NO		NO		0.02	1.2
1B2	Fugitive Emissions from fuels, Oil and Natural gas	0.89	12.0	0.10	0.1	7.49	25.4	0.00	0.0
Sum		7.43		79.30		29.51		1.95	

NO: Not occurring

It must be noted that the CH_4 emission from post-mining of coal (storage and transport) should be accounted for in the emission inventory of the mining countries according to the IPCC Guidelines and is therefore not included in the Danish emission inventory.

2.2 Source category description

According to the IPCC sector definitions the category *fugitive emissions from fuels* is a subcategory under the main category Energy (Sector 1). The category *fugitive emissions from fuels* (Sector 1B) is segmented into subcategories covering emissions from solid fuels *(*coal mining and handling (1B1a), solid fuel transformation (1B1b) and other (1B1c)), oil (oil (1B2a), natural gas (1B2b), venting and flaring *(1B2c)* and other *(1B2d)*. The subcategories relevant for the Danish emission inventory are shortly described below according to Danish conditions:

1B1a Fugitive emission from solid fuels: Coal mining is not occurring in Denmark. Accordingly, only emissions from storage in coal piles are included in the emission inventory.

1B2a Fugitive emissions from oil include emissions from exploration, production, storage, and transmission of crude oil, distribution of oil products and fugitive emissions from refining.

1B2b Fugitive emissions from natural gas include emissions from exploration, production and transmission of natural gas and distribution of natural gas and town gas.

1B2c Venting and flaring include activities onshore and offshore. Flaring occur both offshore in upstream oil and gas production, and onshore in gas treatment and storage facilities, in refineries and in natural gas transmission and distribution. Venting occurs in gas storage facilities. Venting of gas is assumed negligible in oil and gas production and in refineries, as controlled venting enters the gas flare system.

Activity data, emission factors and emissions are stored in the Danish emission database on SNAP categories (Selected Nomenclature for Air Pollution). In Table 2.5 the corresponding SNAP codes and IPCC sectors relevant to fugitive emissions are shown. Further, the table holds the SNAP names for the SNAP codes and the overall activity (e.g. oil and natural gas).

Table 2.5 Overview of the SNAP codes and the corresponding IPCC sources relevant for fugitive emissions.

SNAP code	SNAP name	NFR code	NFR name	CRF code	CRF name	Activity
040101	Petroleum products processing	1B2aiv	Refining / storage	1B2a4	Refining/storage	Oil
040103	Sulphur recovery plants	1B2aiv	Refining / storage	1B2a4	Refining/storage	Oil
040104	Storage and handling of petroleum products in refinery	1B2aiv	Refining / storage	1B2a4	Refining/storage	Oil
050103	Storage of solid fuel	1B1a	Coal mining and handling	1B1a	Coal mining and handling	Coal
050204	Exploration of oil	1B2ai	Exploration, production, transport	1B2a1	Exploration	Oil
050205	Production of oil	1B2ai	Exploration, production, transport	1B2a2	Production	Oil
050206	Offshore loading of oil	1B2ai	Exploration, production, transport	1B2a3	Transport	Oil
050207	Onshore loading of oil	1B2ai	Exploration, production, transport	1B2a3	Transport	Oil
050208	Storage of crude oil	1B2ai	Exploration, production, transport	1B2a4	Refining/storage	Oil
050304	Exploration of gas	1B2b	Fugitive emissions from natural gas	1B2b1	Exploration	Gas
050305	Production of gas	1B2b	Fugitive emissions from natural gas	1B2b2	Production	Gas
050503	Service stations (including refuelling of cars)	1B2av	Distribution of oil products	1B2a5	Distribution of oil products	Oil
050601	Natural gas transmission	1B2b	Fugitive emissions from natural gas	1B2b4	Transmission and storage	Gas
050603	Natural gas distribution	1B2b	Fugitive emissions from natural gas	1B2b5	Distribution	Gas
050604	Town gas distribution	1B2b	Fugitive emissions from natural gas	1B2b5	Distribution	Gas
050699	Venting in gas storage	1B2c	Venting and flaring (oil, gas, combined oil and gas)	1B2c1ii	Venting, gas	Venting
090203	Flaring in oil refinery	1B2c	Venting and flaring (oil, gas, combined oil and gas)	1B2c2i	Flaring, oil	Flaring
090206	Flaring in gas and oil extraction	1B2c	Venting and flaring (oil, gas, combined oil and gas)	1B2c2iii	Flaring, combined	Flaring
090298	Flaring in gas storage	1B2c	Venting and flaring (oil, gas, combined oil and gas)	1B2c2ii	Flaring, gas	Flaring
090299	Flaring in gas transmission and distribution	1B2c		1B2c2ii	Flaring, gas	Flaring

CRF sector, NFR sector and activity is only given for categories included in the Danish emission inventory.

Table 2.6 summarizes the Danish fugitive emissions in 2019 for selected pollutants. The methodologies, activity data and emission factors used for calculation are described in the following chapters.

Table 2.6 Summary of the Danish fugitive emissions in 2019.

IPCC category	Sector	Pollutant	Emission [t]	Share of total fugitive [%]
1B1a	Storage of solid fuel	TSP	35.254	91.5
1B1a	Storage of solid fuel	PM_{10}	31.023	90.4
1B1a	Storage of solid fuel	$PM_{2.5}$	8.461	72.1
1B1a	Storage of solid fuel	BC	23.502	97.5
1B2a i	Production of oil	NMVOC	4.330	<0.01
1B2a i	Production of oil	CH_4	3.453	<0.01
1B2a i	Production of oil	CO_2	0.252	<0.01
1B2a i	Offshore loading of oil	NMVOC	717.608	9.6
1B2a i	Offshore loading of oil	CH_4	35.880	1.2
1B2a i	Onshore loading of oil	NMVOC	12.480	<0.01
1B2a i	Onshore loading of oil	CH_4	3.120	<0.01
1B2a i	Storage of crude oil	NMVOC	304.000	4.1
1B2a i	Storage of crude oil	CH_4	247.999	8.2
1B2a i	Storage of crude oil	CO_2	2.986	<0.01
1B2a iv	Petroleum products processing	NMVOC	5 263.800	70.3
1B2a iv	Petroleum products processing	CH_4	538.200	17.8
1B2a iv	Sulphur recovery plants	SO_2	776.000	87.1
1B2a v	Service stations (including refuelling of cars)	NMVOC	712.975	9.5
1B2b	Production of gas	NMVOC	277.095	3.7
1B2b	Production of gas	CH_4	1 157.100	38.2
1B2b	Production of gas	CO_2	42.630	<0.01
1B2b	Natural gas transmission	NMVOC	27.662	<0.01
1B2b	Natural gas transmission	CH_4	139.620	4.6
1B2b	Natural gas transmission	CO_2	3.199	<0.01
1B2b	Natural gas distribution	NMVOC	11.201	<0.01
1B2b	Natural gas distribution	CH_4	56.534	1.9
1B2b	Natural gas distribution	CO_2	1.334	<0.01
1B2b	Town gas distribution	NMVOC	21.178	<0.01
1B2b	Town gas distribution	CH_4	56.760	1.9
1B2b	Town gas distribution	CO_2	0.882	<0.01
1B2c	Venting in gas storage	NMVOC	5.600	<0.01
1B2c	Venting in gas storage	CH_4	28.000	0.9
1B2c	Venting in gas storage	CO_2	0.782	<0.01
1B2c	Flaring in oil refinery	SO_2	114.300	12.8
1B2c	Flaring in oil refinery	NO_x	11.795	11.7
1B2c	Flaring in oil refinery	NMVOC	21.054	<0.01
1B2c	Flaring in oil refinery	CH_4	4.997	<0.01
1B2c	Flaring in oil refinery	CO	36.629	21.5
1B2c	Flaring in oil refinery	CO_2	15 778.343	8.1
1B2c	Flaring in oil refinery	N_2O	0.130	<0.01
1B2c	Flaring in oil refinery	TSP	0.245	0.6
1B2c	Flaring in oil refinery	PM_{10}	0.245	0.7
1B2c	Flaring in oil refinery	$PM_{2.5}$	0.245	2.1
1B2c	Flaring in oil refinery	BC	0.061	<0.01
1B2c	Flaring in gas and oil extraction	SO_2	0.932	<0.01

Continued				
1B2c	Flaring in gas and oil extraction	NO_x	88.161	87.5
1B2c	Flaring in gas and oil extraction	NMVOC	106.080	1.4
1B2c	Flaring in gas and oil extraction	CH_4	756.893	25.0
1B2c	Flaring in gas and oil extraction	CO	132.600	77.9
1B2c	Flaring in gas and oil extraction	CO_2	177 468.464	91.2
1B2c	Flaring in gas and oil extraction	N_2O	114.681	99.9
1B2c	Flaring in gas and oil extraction	TSP	3.010	7.8
1B2c	Flaring in gas and oil extraction	PM_{10}	3.010	8.8
1B2c	Flaring in gas and oil extraction	$PM_{2.5}$	3.010	25.6
1B2c	Flaring in gas and oil extraction	BC	0.538	2.2
1B2c	Flaring in gas storage	SO_2	0.007	<0.01
1B2c	Flaring in gas storage	NO_x	0.729	0.7
1B2c	Flaring in gas storage	NMVOC	0.350	<0.01
1B2c	Flaring in gas storage	CH_4	0.424	<0.01
1B2c	Flaring in gas storage	CO	0.915	0.5
1B2c	Flaring in gas storage	CO_2	1 326.910	0.7
1B2c	Flaring in gas storage	N_2O	0.001	<0.01
1B2c	Flaring in gas storage	TSP	0.021	<0.01
1B2c	Flaring in gas storage	PM_{10}	0.021	<0.01
1B2c	Flaring in gas storage	$PM_{2.5}$	0.021	<0.01
1B2c	Flaring in gas storage	BC	0.000	<0.01
1B2c	Flaring in gas transmission and distribution	SO_2	0.000	<0.01
1B2c	Flaring in gas transmission and distribution	NO_x	0.024	<0.01
1B2c	Flaring in gas transmission and distribution	NMVOC	0.001	<0.01
1B2c	Flaring in gas transmission and distribution	CH_4	0.008	<0.01
1B2c	Flaring in gas transmission and distribution	CO	0.030	<0.01
1B2c	Flaring in gas transmission and distribution	CO_2	42.801	<0.01
1B2c	Flaring in gas transmission and distribution	N_2O	0.000	<0.01
1B2c	Flaring in gas transmission and distribution	TSP	0.001	<0.01
1B2c	Flaring in gas transmission and distribution	PM_{10}	0.001	<0.01
1B2c	Flaring in gas transmission and distribution	$PM_{2.5}$	0.001	<0.01

3 Methodology

The following chapters give descriptions on the methods of calculation used in the Danish emission inventory.

3.1 Fugitive emissions from solid fuels

The emissions of PM and BC from storage of coal are estimated on the basis of the imported amount of coal and emission factors for TSP, PM_{10}, $PM_{2.5}$ and BC (equation 3.1).

Equation 3.1

$$E_{coal\ storage} = EF_{coal\ storage} \cdot AD_{coal}$$

where $EF_{coal\ storage}$ is the emission factor for storage of coal in coal piles and AD_{coal} is the amount of coal imported in the actual year.

3.2 Fugitive emissions from oil

The emissions from oil derive from production, refining, storage and handling of oil. Emissions from offshore activities include emissions from exploration, production and offshore loading of ships. Transport and storage covers emissions from the oil terminal and onshore loading of ships at the harbour terminal. Service stations are a source of emissions from reloading of tanker trucks and refuelling of vehicles. The emissions from refineries include fugitive losses from the petroleum products processing. Emissions from flaring in refineries and in oil production are included in the Chapter 3.4. The total fugitive emission from oil can be expressed as:

Equation 3.2

$$E_{oil} = E_{exploration} + E_{production} + E_{loading\ of\ ships} + E_{oil\ terminal} + E_{servive\ stations} + E_{refineries}$$

where $E_{oil\ terminal}$ cover the emissions from transport in pipelines and storage in tanks at the oil terminal and where $E_{refineries}$ does not include emissions from flaring.

3.2.1 Exploration of oil

Exploration of oil and gas in the North Sea involves the drilling and preparing of exploration and appraisal wells (E/A wells), which leads to fugitive emissions. The oil and gas operators provide information to the Danish Energy Agency (DEA) for each exploration drilling, including volume of oil and gas extracted. All oil and gas from exploration drilling is flared on-site. Oil and gas composition is available for most E/A wells. As calorific values and densities are not available per drilling, data from a gas test in 1992 are applied.

3.2.2 Extraction of oil

The methodology for calculation of emissions from oil and gas extraction in the North Sea is based on the amount of produced oil and standard emission factors from the 2006 IPCC Guidelines (IPCC, 2006).

3.2.3 Loading of ships

Fugitive emissions of CH_4 and NMVOC from loading of ships include the transfer of oil from storage tanks or directly from the well into ships. The activity also includes losses during transport. When oil is loaded, hydrocarbon vapour will be displaced by oil, and new vapour will be formed, both leading to emissions. Vapour recovery units might be installed to reduce the emissions, which is reflected in the applied emission factors. The emissions from ships are calculated by equation 3.3.

Equation 3.3

$$E_{loading} = EF_{offshore\ loading} \cdot AD_{offshore\ loading} + EF_{onshore\ loading} \cdot AD_{onshore\ loading}$$

where EF is the emission factor for loading of ships offshore and onshore and AD is the amount of oil loaded.

3.2.4 The oil terminal

The main part of the raw oil produced in the North Sea is transported to the Danish raw oil terminal via pipeline (around 90 %). The remaining part is loaded to ships offshore. The CH_4 and NMVOC emissions from the oil terminal, covering storage and handling of raw oil, are given in annual reports for the raw oil terminal from DONG Oil Pipe A/S until 2017. Data for 2018 and onwards are collected via personal communication, as annual reports are no longer prepared (Kold-Christensen, 2019; Boesen, 2020). An implied emission factor is calculated for use in the reporting template on the basis of the amount of oil transported in pipelines according to equation 3.4.

Equation 3.4

$$IEF_{oil\ terminal} = \frac{E_{oil\ terminal}}{AD_{pipeline\ oil}}$$

where $IEF_{oil\ terminal}$ is the implied emission factor for storage of raw oil in tanks, $E_{oil\ terminal}$ is the emission and $AD_{pipeline\ oil}$ is the amount of oil transported by in the pipeline from the offshore production sites to the oil terminal.

3.2.5 Service stations

NMVOC emissions from service stations are estimated as outlined in equation 3.5.

Equation 3.5

$$E_{service\ stations} = (EF_{reloading} + EF_{refueling}) \cdot AD_{gasoline}$$

where $EF_{reloading}$ is the emission factor for reloading of tankers to storage tanks at the service stations, $EF_{refuelling}$ is the emission factor for refuelling of vehicles, and $AD_{gasoline}$ is the amount of gasoline used for road transport. The emission calculation is dependent on true vapour pressure (TVP), which again dependents on the Reid vapour pressure (RVP) and the temperature (T), according to equation 3.6.

Equation 3.6

$$TVP = \mathrm{RWP} \cdot 10^{AT+B}$$

where $A = 0.000007047 \cdot \mathrm{RVP} + 0.0132$, $B = 0.0002311 \cdot \mathrm{RVP} - 0.5236$, T is the temperature in °C), and RVP is the Reid Vapour Pressure in kPa.

3.2.6 Oil refining

When oil is processed in refineries, part of the volatile organic compounds (VOC) is emitted to the atmosphere. VOC emissions from the oil refinery process include non-combustion emissions from handling and storage of feedstock (raw oil), from the petroleum product processing and from handling and storage of products. VOC emissions are provided by the refineries. Only one of the two refineries has made a split between NMVOC and CH_4. For the other refinery it is assumed that 10 % of the VOC emission is CH_4 (Hjerrild & Rasmussen, 2014).

Both the non-combustion processes including product processing and the sulphur recovery plants emit SO_2. The SO_2 emissions are calculated by the refineries based on oil balance, measured sulphur content in products and fuels, flow measurements in sulphur recovery plants and key figures in environmental approvals.

Emissions from flaring in refineries are included in the category venting and flaring (Chapter 3.4). Emissions related to process furnaces in refineries are included reported in the sector stationary combustion (Nielsen, 2021).

3.3 Fugitive emissions from gas

The emissions from gas derive from offshore activities in gas production, transmission of natural gas, and distribution of natural gas and town gas. Emissions from venting and flaring in gas transmission and distribution, and venting and flaring in gas treatment and storage are included in the category venting and flaring (Chapter 3.4). The total emission can be expressed as:

Equation 3.7

$$E_{gas} = E_{exploration} + E_{extraction} + E_{transmission} + E_{distribution}$$

3.3.1 Exploration of gas

Exploration of oil and gas in the North Sea involves the drilling and preparation of E / A wells, which leads to fugitive emissions. The oil and gas operators provide information to the DEA for each exploration drilling, including volume of oil and gas extracted. All oil and gas from exploration drilling is flared on-site. Oil and gas composition is available for most drillings. As calorific values and densities are not available per drilling, data from a gas test in 1992 are applied.

3.3.2 Extraction of gas

The methodology for calculation of emissions from extraction of gas is based on the amount of produced natural gas multiplied with standard emission factors from the 2006 IPCC Guidelines (IPCC, 2006).

3.3.3 Transmission and distribution of gas

The fugitive emission from transmission, storage and distribution of natural gas is based on information from the gas companies. Gas transmission is handled by one company, natural gas distribution is handled by one company (a fusion in the later years of the four previous distribution companies) and town gas distribution is handled by two companies (in earlier years another two companies handled town gas distribution). All transmission and distribution companies deliver data on the transported amount, and the length and material of the pipeline systems.

The fugitive losses from pipelines are only given for some companies, here among the transmission company. The available distribution data are used for the remaining companies too. Emissions are calculated from the fugitive losses from transmission and distribution pipelines due to the annual average gas quality for natural gas transmitted in Denmark measured by Energinet.dk (Energinet.dk 2020c) according to the calculated weight percent of CH_4 and NMVOC. The same approach is used for town gas, which is natural gas admixed ~ 50 % ambient air. Town gas make only a small contribution to the total gas distribution (around 0.5 % of the total distribution in energy units).

Calculations of emissions from distribution of town gas are based on data from the distribution companies on distribution losses. At present, there are two areas with town gas distribution and corresponding distribution companies. Two other companies in different areas were closed in 2004 and 2006, and it has not been possible to collect data for all years in the time series. The emissions have been calculated for the years with available data and the distribution loss for the first year with data has been applied for the previous years in the time series. Data are missing for the later years (1996-2003) for one of the distribution companies. The distribution amount is assumed to decrease linearly to zero over these years, and the share (distribution loss / distribution amount) is assumed equal to the value for 1995.

3.4 Venting and flaring

Venting and flaring occur in oil and gas production, refining of oil at refineries and in connection with treatment, transmission and distribution of natural gas. Flaring is used for safety reasons on offshore oil and gas production sites, in refineries and at the natural gas treatment plant. Venting occur at the two underground natural gas storage facilities. The total emission can be expressed as:

Equation 3.8

$$E = E_{venting} + E_{flaring\ in\ refinery} + E_{flaring\ in\ oil/gas\ production} + E_{flaring\ in\ gas\ handling\ and\ transport}$$

Emissions from flaring are estimated from the amount of gas flared offshore (7 installations), in gas treatment / storage plants (1 / 2 plants), in refineries (2 plants), and in gas transmission (1 company), storage and distribution (1 / 1 company), combined with corresponding emission factors. From 2006 data on flaring in upstream oil and gas production is given in the reports for the European Union Greenhouse Gas Emission Trading System (EU ETS) and thereby flaring can be split to the individual production units. Before 2006 only the total flared amount is available from DEA. Flaring in refineries and in gas transmission, storage and distribution are given in annual environmental reports from the relevant companies and plants or collected via personal communication with the companies.

3.5 Use of EU-ETS data

Reporting to the EU ETS are available in the annual EU ETS reports for refineries, upstream oil and gas extraction facilities and the natural gas treatment plant, concerning fugitive emissions. EU ETS data are only included in the national emission inventory if higher tier methodologies are applied, which is the case for the EU ETS reports regarding fugitive emission sources. The EU ETS data used are fully in line with the requirements in the IPCC Guidelines and are considered the best data source on CO_2 emission factors due to the legal obligation for the relevant companies to make the accounting following the specified EU decisions. The EU ETS data are thereby a source of consistent data with low uncertainties. Further information on EU ETS are included in Chapter 3.5. Unfortunately, corresponding data do not exist before the commencement of EU ETS in 2006 and therefore it is not possible to set up time series based on EU ETS. In these cases, appropriate methods from the IPCC Guidelines have been selected to ensure time series consistency. This is described in the specific chapters.

3.5.1 EU ETS reports for refineries

Activity data are measured with flow meters and rates are reported with high accuracy using the Tier 4 methodology (uncertainty ±1.5 %) for large sources and Tier 3 (uncertainty ±2.5 %) or Tier 2 (uncertainty ±5 %) for small sources. The oxidation factor is set to 1, corresponding the Tier 1 methodology. CO_2 emission factors are calculated according to the relevant Tier given in the European Commission Implementing Regulation of 19 December 2018 (European Commission, 2018). The Tier 2b methodology based on yearly density and calorific values is applied, while the activity specific Tier 3 methodology is applied for diesel. CO_2 emission factors for flaring are calculated using the Tier 3 methodology based on the measured carbon contents.

3.5.2 EU ETS reports for offshore installations

Activity data are measured with flow meters and rates are reported with high accuracy. For combustion, the Tier 4 methodology (uncertainty ±1.5 %) is used for large sources and Tier 3 (uncertainty ±2.5 %) or Tier 2 (uncertainty ±5 %) for small sources. For flaring, mainly the Tier 3 or the Tier 2 methodology (uncertainty ±7.5 % or ±12.5 %) is used. The oxidation factor is set to 1, corresponding the Tier 1 methodology. CO_2 emission factors are calculated according to the relevant Tier given in the European Commission Implementing Regulation of 19 December 2018 (European Commission, 2018). For combustion of fuel gas the Tier 3 methodology, which is activity specific, is applied, while the country specific Tier 3 methodology is applied for diesel. CO_2 emission factors for flaring are calculated using the Tier 2b methodology.

4 Activity data, emission factors and emissions

The following paragraphs describe the methodology for emission calculation for fugitive sources, including activity data, emission factors and annual emissions. The order follows the IPCC structure (1B1 Solid fuels, 1B2a Oil, 1B2b Natural gas, 1B2c Venting and flaring), with the exception that exploration and production of gas are included in the paragraphs for exploration and production of oil, due to similar methodologies and data providers.

4.1 Fugitive emissions from solid fuels (1B1)

Coal mining is not occurring in Denmark, and emissions from solid fuels only include particulate matter and black carbon from storage of coal in piles.

4.1.1 Activity data

Coal production is not occurring in Denmark. The annual total amount of coal used are included in the import statistics provided by DEA (DEA 2020b). Coal is primarily (>90 %) used in power plants, and the annual fluctuations in the import rates mainly owe to variations in electricity import/export and temperature variations (Figure 4.1). The time series show a decreasing trend due to a shift of fuels in power and heat production from coal and oil to natural gas, waste and biomass.

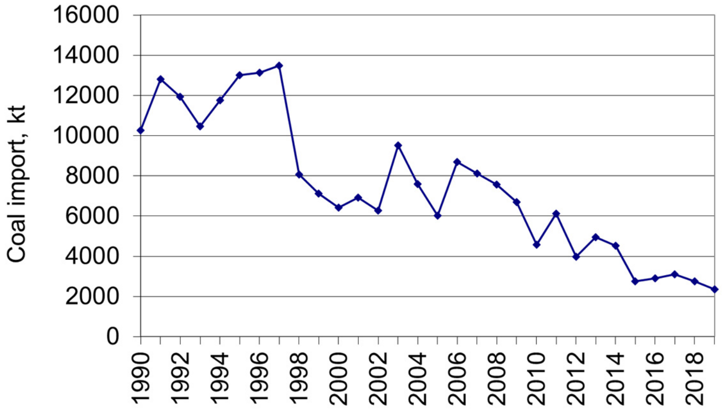


Figure 4.1 Import of coal.

4.1.2 Emission factors

The emission factors are listed in Table 4.1. Emissions of particulate matter (PM) from coal storage are estimated using emission factors from the Coordinated European Particulate Matter Emission Inventory Program, CEPMEIP (Visschedijk et al., 2004). Abatement technologies are used to reduce the dust from coal storage, e.g. wind protection and spraying of water with or without additives. According to the Integrated Pollution Prevention and Control Reference Document on Best Available Techniques on Emissions from Storage July 2006 (European Commission, 2006) the abatement efficiency is 80-95 % for spraying with water without additives and 90-99 % for spraying with water with additives. The US-EPA (1996) include efficiency of using water sprays and chemical stabilizer or wetting agents, respectively, both given as 40 % for $PM_{2.5}$. The abatement efficiencies of 90 % for TSP and 40 % for $PM_{2.5}$ are used in the Danish emission inventory and 78 % is applied for PM_{10} (average of the efficiencies for TSP and $PM_{2.5}$).

Denmark has a long tradition for environmental awareness and regulation. There has been focus on dust from coal storage as early as in the 1980s, because the medium sized coal fired plants typically are located in urban areas. In 1980, the Danish Environmental Protection Agency appointed a steering committee for a project assessing the issues associated with change to coal for the medium sized combustion plants. Due to the fact that most of the large coal piles are located in or near urban areas, where the large harbours and a number of large coal fired plants are located, and because of the early awareness and regulation, the emission reducing due to use of abatement technologies are applied for the years 1990 forward.

The BC emission factor is estimated as a fraction of the TSP emission factor, based on characteristics for other bituminous coal included in the 2006 IPCC Guidelines as outlined in equation 4.1.

Equation 4.1

$$EF_{BC} = EF_{TSP} \cdot C \cdot H \cdot 0.001$$

where EF_{BC} is the emission factor for BC [g/Mg], EF_{TSP} is the emission factor for TSP [g/Mg], C is the carbon content [kg C/GJ], and H is the heating value [GJ/Mg]. The EF_{BC} estimation is based on C = 25.8 kg C/GJ and H = 25.8 GJ/Mg, as given for other bituminous coal in IPCC (2006).

The estimated BC emission factor exceed the $PM_{2.5}$ and the PM_{10} emission factors as coal dust for the major part consist of larger particles. For combustion sources, the BC emission factor does not exceed the $PM_{2.5}$ emission factor. While coal dust is not BC in the traditional sense (from incomplete combustion), it is carbon that is primarily dark black in colour and absorbs across the visible spectrum (Khan et al., 2017). According to the Reporting Guidelines (UNECE 2015), BC is defined as follow: ""Black carbon" (BC), which means carbonaceous particulate matter that absorbs light".

The same abatement efficiency is applied for BC as for TSP, as the BC emission factor is based on the TSP emission factor.

Table 4.1 Emission factors used to estimate particulate emissions from coal storage.

	TSP	PM_{10}	$PM_{2.5}$	BC
Emission factor, unabated [g/Mg]	150	60	6	100
Abatement efficiency [%]	90	78	40	90
Emission factor, abated [g/Mg]	15	13,2	3,6	10

4.1.3 Emissions

Emissions from coal storage (Figure 4.2) are proportional to the import rates. The causes of the variations are described above.

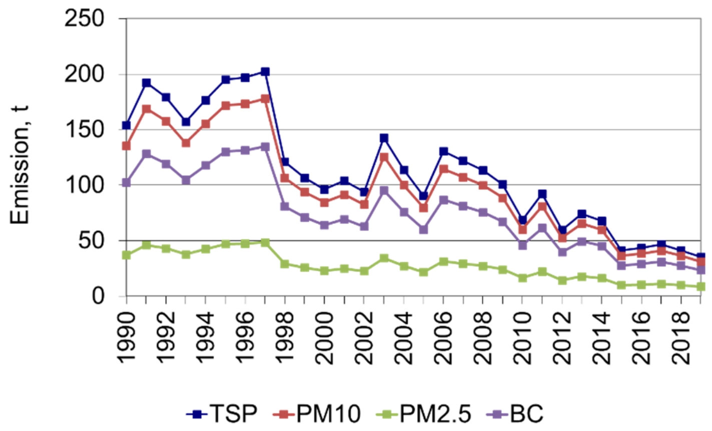


Figure 4.2 Emissions from coal storage.

4.2 Fugitive emissions from oil (1B2a)

The emissions from oil derive from exploration, production, onshore and offshore loading of ships, onshore oil tanks, service stations and refineries. Exploration and production of both oil and gas are described in this paragraph.

4.2.1 Exploration (1B2a1, 1B2b1)

Activity data

Activity data for oil and gas exploration are provided annually by the Danish Energy Agency (Erichsen, 2020). Explorations of oil and gas are given separately for each exploration drilling, and fluctuate significantly over the time series. The largest oil rates are seen for 1990, 2002 and 2005, while relatively large gas rates are seen for more years of the time series. Explored rates are shown in Figure 4.3.

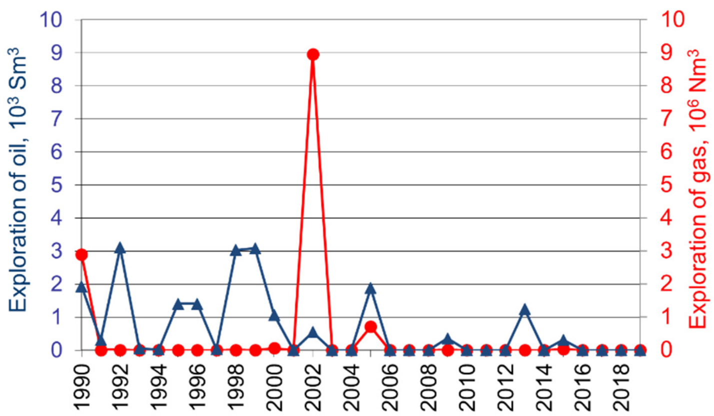


Figure 4.3 Exploration of oil and gas.

Emission factors

Annual CO_2 emission factors are based on composition data, calorific values and densities for explored oil and gas provided by the Danish Energy Agency. Composition data are available for the E/A wells separately, except for a few E/A wells, for which the compositions for the previous E/A well are used for emission calculation. As calorific values and densities are not available per drilling, data from a gas test in 1992 are used. CO_2 emission factors are listed in Table 4.2. The emission factors used to calculate emissions from offshore flaring in upstream oil and gas production are applied for the remaining pollutants (see Chapter 4.4.3).

Table 4.2 Annual CO_2 emission factors for years with exploration of oil and gas.

	1990	1991	1992	1993	1994	1995	1996	1997
EF(CO_2), exploration of oil, kg/Sm3	2433	2437	2439	2441	2437	2449	2449	2449
EF(CO_2), exploration of gas, kg/Nm3	2.85	2.82	2.87	2.93	2.82	2.94	2.94	2.94
continued	1998	1999	2000	2002	2005	2009	2013	2015
EF(CO_2), exploration of oil, kg/Sm3	2445	2449	2449	2441	2444	2449	2449	2449
EF(CO_2), exploration of gas, kg/Nm3	2.94	2.94	2.94	2.88	2.89	2.82	2.82	2.82

Emissions of air pollutants from exploration are calculated from the same emissions that are used for flaring in upstream oil and gas production. Further description on the emission factors, which are based on DEPA (2008) and EMEP/EEA (2019), is included in Chapter 4.4.3, and the emission factors are listed in Table 4.9.

Emissions

Calculated NMVOC and CH_4 emissions from exploration of oil and gas are shown in Figure 4.4. There is no correlation between emissions from oil and gas, as the individual exploration drillings have different ratios between oil and gas rates.

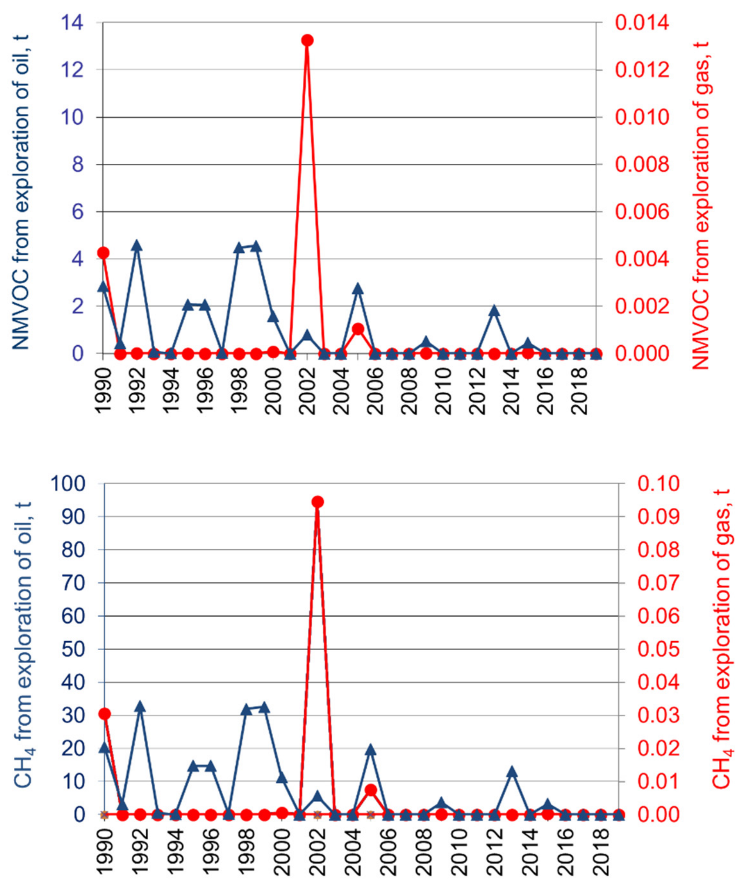


Figure 4.4 NMVOC (a) and CH_4 (b) emissions from exploration of oil and gas.

4.2.2 Production (1B2a2, 1B2b2)

Activity data

Activity data used for oil and gas production are provided by the Danish Energy Agency (DEA 2020a). As seen in Figure 4.5 the production of oil and gas in the North Sea has generally increased in the years 1990-2004, and since 2004 the production has decreased. Commissioning of five major platforms in the period 1997-1999 is the main reason for the great increase in the oil production in the years 1998-2000.

The Tyra platforms are closed in the period between September 2019 and June 2023 due to redevelopment. The Tyra platforms have for 30 years been processing the majority (90 %) of the Danish natural gas production, and the redevelopment ensures continued production from Denmark's largest producing gas field.

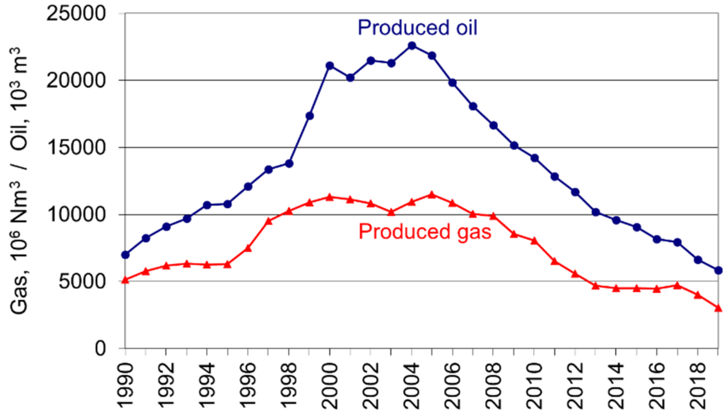


Figure 4.5 Production of oil and gas.

Emission factors

Standard emission factors for production of oil and gas from the 2006 IPCC Guidelines (IPCC 2006) are used to calculate emissions from production of oil and gas (see Table 4.3).

Table 4.3 Emission factors for exploration of oil and gas.

	NMVOC	CO_2	CH_4	Reference
Production of oil, Gg/1000m^3	7.40E-07	4.30E-08	5.90E-07	IPCC, 2006
Production of gas, Gg/Mm3	9.10E-05	1.40E-05	3.80E-04	IPCC, 2006

Emissions

Calculated NMVOC and CH_4 emissions from oil and gas production are shown in Figure 4.6 for selected years. The annual variations follow the production rates.

a)

b)

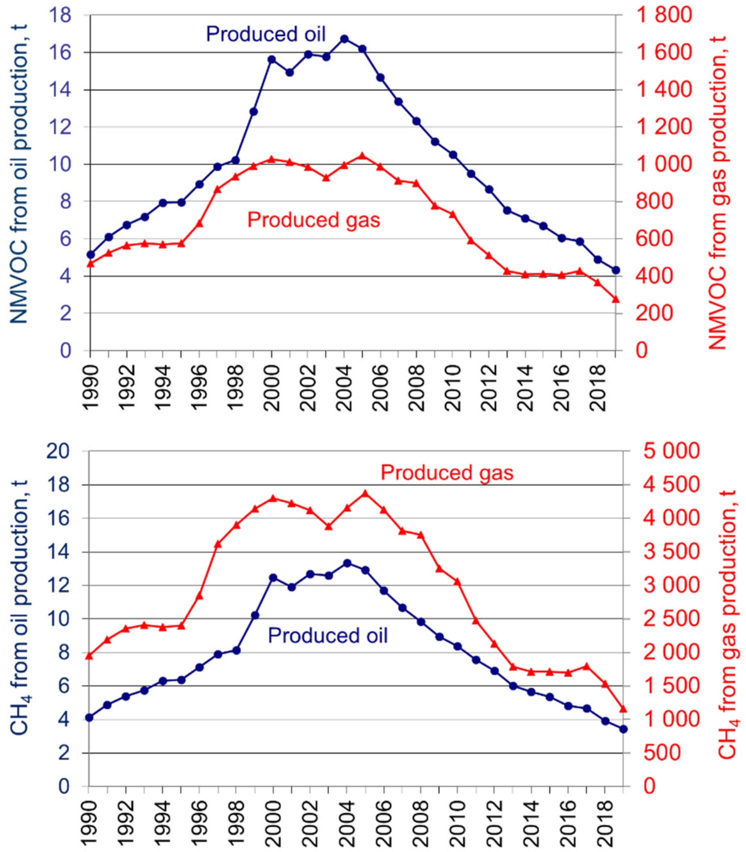


Figure 4.6 NMVOC (a) and CH_4 (b) emissions from production of oil and gas.

4.2.3 Transport (1B2a3)

Activity data

Fugitive emissions from oil transport include loading of ships from storage tanks or directly from the wells, and storage and handling at the oil terminal. Activity data for loading offshore and onshore are provided by the Danish Energy Agency (DEA, 2020a) and from the annual self-regulating reports and supporting information from Danish Oil Pipe A/S (Boesen, 2020), respectively. The latter also provides annual emissions from storage and handling at the oil terminal.

The rates of oil loaded on ships roughly follow the trend of the oil production (Figure 4.7). Offshore loading of ships was introduced in 1999. In earlier years, all produced oil was transported to land via pipeline.

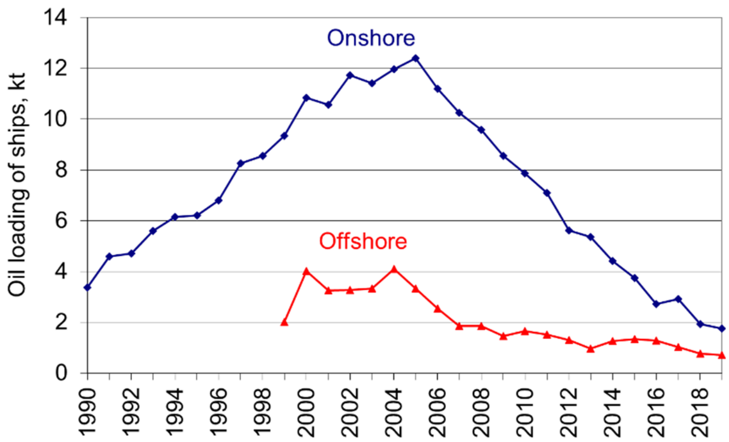


Figure 4.7 Onshore and offshore loading of ships.

Emission factors

Emissions from storage tanks at the oil terminal are provided annually by Danish Oil Pipe A/S. During 2009 new emission reducing technologies (degassing unit) were installed at the crude oil terminal, leading to a significant decrease of the emissions (see Figure 4.8).

The EMEP/EEA Guidebook provides standard emission factors for loading of ships offshore for different countries (EMEP/EEA, 2019). In the Danish inventory, the Norwegian emission factors are used for estimation of fugitive emissions from loading of ships offshore for the years 1990-2009.

Emission factors for onshore loading is based on annual reports from the Shell Harbour Terminal for the years 2012-2019 (A/S Dansk Shell - Havneterminalen, 2013, 2014, 2015, 2016, 2017, 2018, 2019, 2020), which include loaded amounts, standard NMVOC emission factors and emissions of NMVOC (2013-2017) or VOC (2019). The emission factor for 2012 is applied for the earlier years in the time series. The NMVOC emission factor show a significant decrease from 2016-2019 due to installation of a new vapour recovery unit (VRU) during 2017. No emissions were reported for 2018, but has been estimated according to the environmental approval for VRU2 (Danish EPA, 2017) which include a requirement of 85 % emission reduction of the VRU2. For years with only VOC emission data, NMVOC is assumed to make up 80 % of VOC, in accordance with the annual reports for the harbour terminal.

Estimation of CH_4 emission factors are based on the assumption that NMVOC make up 80 % of VOC in accordance with the annual reports for the harbour terminal.

Emission factors for loading of ships offshore and onshore are listed in Table 4.4.

Table 4.4 Emission factors for loading of ships onshore and offshore.

Source	Pollutant	Unit	Emission factor	Reference
Offshore loading of ships	NMVOC	fraction of loaded	0.001	EMEP/EEA, 2019
Ships onshore, 1990-2012	NMVOC	g/tonne	584	A/S Dansk Shell - Havneterminalen, 2013
Ships onshore, 2013	NMVOC	g/tonne	587	A/S Dansk Shell - Havneterminalen, 2014
Ships onshore, 2014-2016	NMVOC	g/tonne	584	A/S Dansk Shell - Havneterminalen, 2015, 2016, 2017
Ships onshore, 2017	NMVOC	g/tonne	334	A/S Dansk Shell - Havneterminalen, 2018
Ships onshore, 2018	NMVOC	g/tonne	88	A/S Dansk Shell - Havneterminalen, 2019 Danish EPA, 2017
Ships onshore, 2019	NMVOC	g/ton	7	A/S Dansk Shell - Havneterminalen, 2020
Offshore loading of ships	CH_4	fraction of loaded	5E-05	EMEP/EEA, 2019
Ships onshore, 1990-2012	CH_4	g/tonne	146	A/S Dansk Shell - Havneterminalen, 2013
Ships onshore, 2013	CH_4	g/tonne	147	A/S Dansk Shell - Havneterminalen, 2014
Ships onshore, 2014-2016	CH_4	g/tonne	146	A/S Dansk Shell - Havneterminalen, 2015, 2016, 2017
Ships onshore, 2017	CH_4	g/tonne	84	A/S Dansk Shell - Havneterminalen, 2018
Ships onshore, 2018	CH_4	g/tonne	22	A/S Dansk Shell - Havneterminalen, 2019 Danish EPA, 2017
Ships onshore, 2019	CH_4	g/tonne	1.8	A/S Dansk Shell - Havneterminalen, 2020
Oil terminal	CO2	kt/1000m^3 oil transported by pipeline	4.9E-07	IPCC, 2006

Emissions

NMVOC and CH_4 emissions from transport of oil are shown in Figure 4.8.

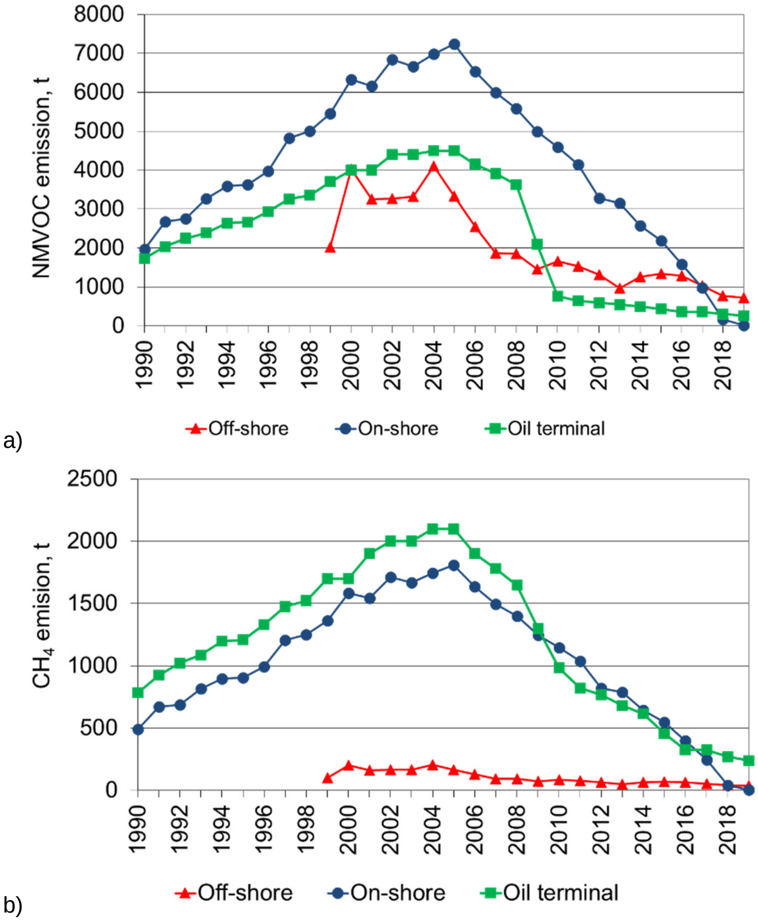


Figure 4.8 NMVOC (a) and CH_4 (b) emissions from the oil terminal and from offshore and onshore loading of ships.

4.2.4 Refining (1B2a4)

Activity data

Emissions from oil refinery processes include non-combustion emissions from handling and storage of feedstock (raw oil), from the petroleum product processing and from handling and storage of products. Emissions from flaring in refineries are included in the Chapter 4.4.2. Emissions related to process furnaces in refineries are included in stationary combustion. The EMEP/EEA Guidebook lists potential emissions from catalytic cracking unit regenerators with partial burn and without a CO boiler and from fluid coking units. In Denmark, these processes are not used. In Denmark, visbreaking (a thermal cracking process) is used at refineries instead of the aforementioned processes. No information on emissions from this process is available from the emissions reported by the Danish refineries, and as no method is included in the 2019 EMEP/EEA Guidebook, this source is not included in the emission inventory.

Rates of crude oil processed in the two Danish refineries are given in their annual environmental report (A/S Dansk Shell, 2020 and Equinor Refining Denmark A/S, 2020). Until 1996 a third refinery was in operation, leading to a decrease in the crude oil rate from 1996 to 1997. Activity date is shown in Figure 4.9.

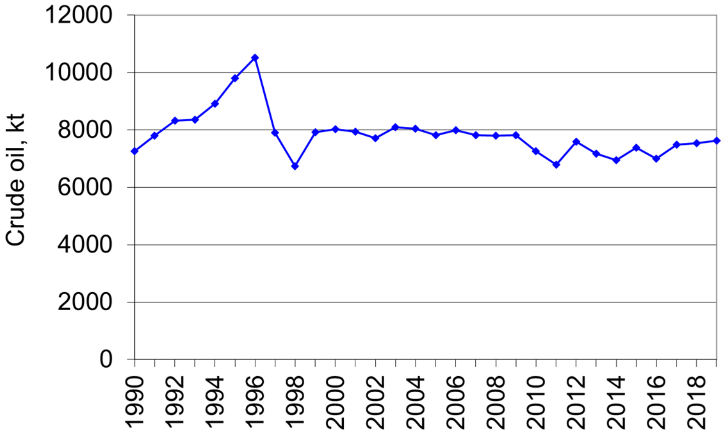


Figure 4.9 Crude oil processed in Danish refineries.

Emission factors

Emissions of SO_2 and VOC are given by the refineries. Only one of the two refineries has made a split between NMVOC and CH_4. For the other refinery, it is assumed that 10 % of the VOC emission is CH_4 and the remaining 90 % is NMVOC (Hjerrild & Rasmussen, 2014).

Both the non-combustion processes including product processing and sulphur recovery plants emit SO_2.

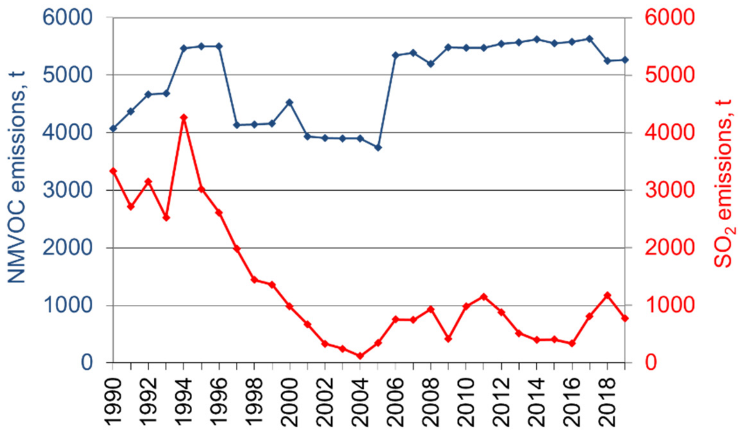
The standard CO_2 emission factor for oil transport from the 2006 IPCC Guidelines (IPCC, 2006) is used to calculate emissions from storage and handling at the oil terminal.

Emissions

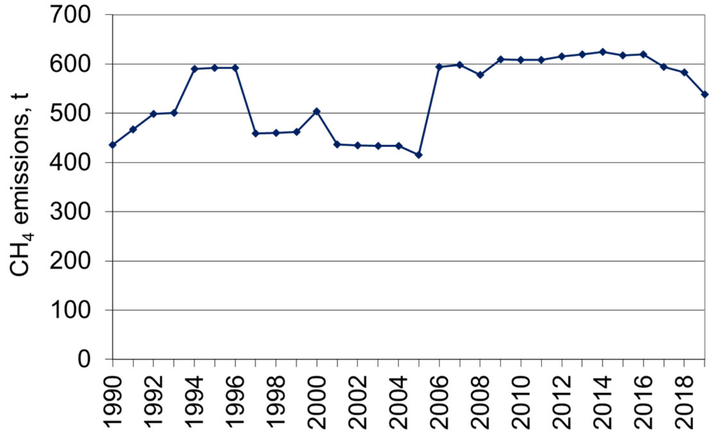
Refineries are a significant source to fugitive emissions of SO_2, the most important activities being sulphur recovery and flaring. In 1990-1993, emissions from petroleum product processing were included in emissions from flaring in refineries (NFR category 1B2c). From 1994 the data delivery format was changed, which made it possible to split the emissions between contributions from flaring and processing, respectively. Emissions from processing are included in NFR category 1B2aiv from 1994 and forward.

SO_2 and NMVOC emissions are shown in Figure 4.10a. One refinery was shut down in 1996 leading to a decrease of the emissions from 1996 to 1997. Technical improvements of the sulphur recovery system at one of the two Danish refineries lead to a decrease of the SO_2 emissions from 1996-1998. The large emissions from 2005 and onwards owe to shutdowns due to maintenance and accidents. Further, construction and initialisation of new facilities and problems related to the ammonium thiosulphate (ATS) plant at the one refinery has led to increased emissions. In 2007, the capacity of the ATS plant was increased followed by commissioning difficulties.

The increase of NMVOC and CH_4 emissions from 2005 to 2006 owes a new measurement campaign at one refinery, which showed larger emissions than the previous measurement campaign (Figure 4.10). According to the environmental department at the refinery, fugitive emissions from oil processing in refineries does not correlate to any measured parameters, but are expected to follow a more random pattern. The refinery has chosen to report the latest measured emission for the years between measurement campaigns, and as no better methodology are available, the same approach is used in the national emission inventories.



a)



b)

Figure 4.10 SO_2 and NMVOC (a) and CH_4 (b) emissions from crude oil processing including sulphur recovery in Danish refineries.

4.2.5 Service stations (1B2a5)

Activity data

Calculations of emissions from service stations are based on gasoline sales figures from the Danish Energy statistics (DEA, 2020b). The gasoline sales increase from 1990-1998 and a decreasing trend since 1999 as shown in Figure 4.11.

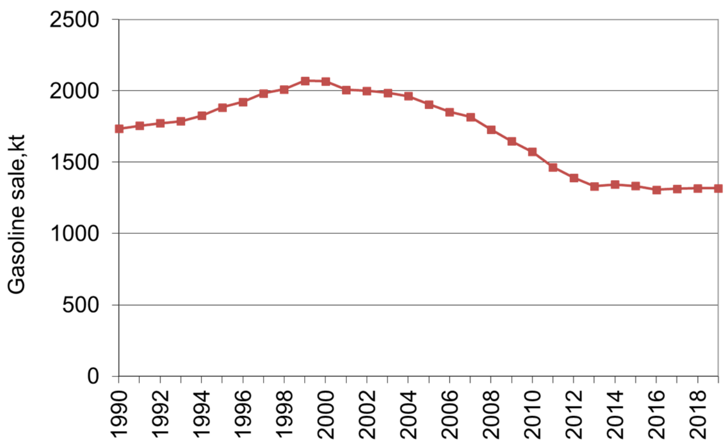


Figure 4.11 Gasoline sales in Denmark.

Emission factors

The NMVOC emission from service stations is calculated by use of different emission factors for the time series as shown in Table 4.5.

In 1994, the emission factors for NMVOC from service stations were investigated by Fenhann and Kilde (1994) for 1990 and 1991, individually. The emission factors reported for reloading for 1990 are used for the years 1985-1990, while the emission factor for 1991 is used for 1991 only. In 1995, Stage I (emissions reduction from storage at terminals and refuelling of storage tanks at service stations) was made obligatory, and the emission factor from the 2019 EMEP/EEA Guidebook (EMEP/EEA, 2019) is applied from 1997 and onwards. Linear interpolation is applied for the years 1995-1996.

Fenhann & Kilde (1994) also include NMVOC emission factors for refuelling for the years 1990, 1991, 1992, and 1993. The same value is given for these years. From 1994, the refuelling emission factor is based on the EMEP/EEA Guidebook (EMEP/EEA, 2019). An abatement rate of Stage II (petrol vapour recovery during refuelling of motor vehicles at service stations) of 85 % is given in the 2019 EMEP/EEA Guidebook, while 60 % were given in the 2006 EMEP/EEA Guidebook (EMEP/EEA, 2006). The Danish requirement is 85 % abatement under optimal conditions, but 70 % in practice (Danish Ministry of the Environment, 1994). Based on this, 70 % abatement is applied in the emission calculations.

Table 4.5 Emission factors used for estimating NMVOC from service stations.

Year	Reloading of tankers, kg NMVOC per tonnes gasoline	Refuelling of vehicles, kg NMVOC per tonnes gasoline	Sum of reloading and refuelling, kg NMVOC per tonnes gasoline	Source - reloading	Source - refuelling
1985-1990	1.28	1.52	2.8	Fenhann & Kilde, 1994	Fenhann & Kilde, 1994
1991	0.64	1.52	2.16	Fenhann & Kilde, 1994	Fenhann & Kilde, 1994
1992	0.519	1.52	2.039	Interpolation	Fenhann & Kilde, 1994
1993	0.397	1.004	1.401	Interpolation	Fenhann & Kilde, 1994
1994	0.276	0.488	0.764	MST, 1994	EMEP/EEA 2019 with 70 % efficiency (national regulation)
1995	0.202	0.488	0.69	Interpolation	EMEP/EEA 2019 with 70 % efficiency (national regulation)
1996	0.127	0.488	0.615	Interpolation	EMEP/EEA 2019 with 70 % efficiency (national regulation)
1997 onwards	0.053	0.488	0.541	EMEP/EEA 2019	EMEP/EEA 2019 with 70 % efficiency (national regulation)

Emissions

Emissions from service stations are shown in Figure 4.12. The decrease from 1990 to 1999 owes to decreasing emission factors due to technological improvements. From 1999 to 2005, the decrease owe to a combination of decreasing gasoline sales and decreasing emission factors. Since 2005, the decreasing trend is less pronounced and only variates with the gasoline sales, which show a slight decreasing trend.

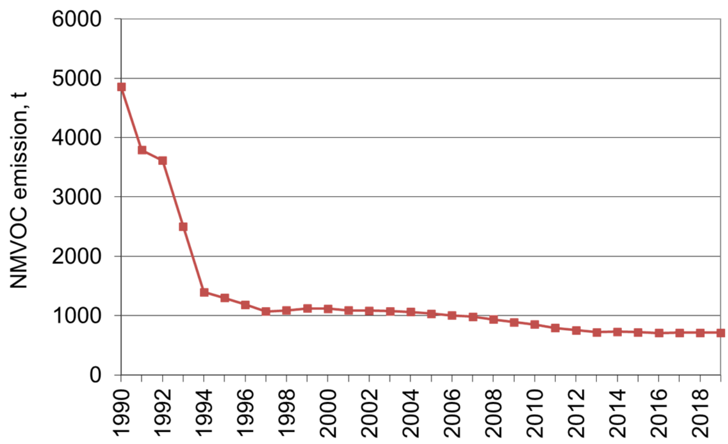


Figure 4.12 NMVOC emissions from service stations.

4.3 Fugitive emissions from natural gas (1B2b)

The emissions from natural gas derive from exploration, transmission, storage and distribution. Descriptions of exploration and production of natural gas are included in Chapter 4.2.1 covering exploration and production of oil and in Chapter 4.2.2.

4.3.1 Exploration (1B2b1)

See Chapter 4.2.1.

4.3.2 Production (1B2b2)

See Chapter 4.2.2.

4.3.3 Transmission and storage (1B2b4)

Activity data

The fugitive emissions from transmission and storage of natural gas are based on information from the gas transmission companies, which provide data on transmission rates, pipeline losses, and length and material of the pipeline systems. The length of the transmission pipelines is approximately 900 km.

The activity data used in the calculation of the emissions from transmission of natural gas are shown in Figure 4.13. Transmission rates for 1990-1998 refer to annual environmental reports of DONG Energy. For 1999-2006, the transmission rates refer to the Danish Gas Technology Centre (Karll 2002, 2003, 2004, 2005; Oertenblad 2006, 2007). From 2008 onwards, transmission rates refer to Energinet.dk (2020b). Transmission losses for 1991-1999 are based on annual environmental report of DONG Energy. The average for 1991-1995 is applied for 1990. From 2005 onwards, transmission losses are given by Energinet.dk. The average for 2005-2010 is applied for the years 2000-2004.

The variation over the time series owes mainly to variations in production, in the winter temperature and to the variations in import/export. The transmission rate is less than the production rate, as part of the produced natural gas is exported through the NOGAT pipeline system.

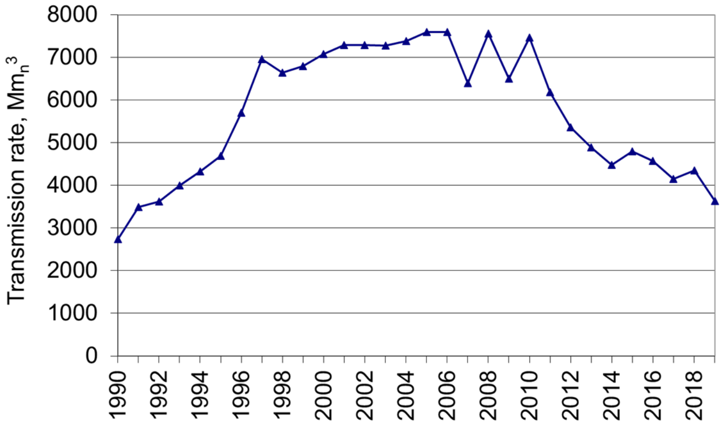


Figure 4.13 Rates for transmission of natural gas.

Emission factors

The fugitive emissions from transmission and storage of natural gas are based on data on gas losses from the companies and on the average annual natural gas composition given by Energinet.dk (2020c). Gas composition data for selected years are listed in Table 4.6.

Table 4.6 Annual gas composition, lower heating value and density for Danish natural gas.

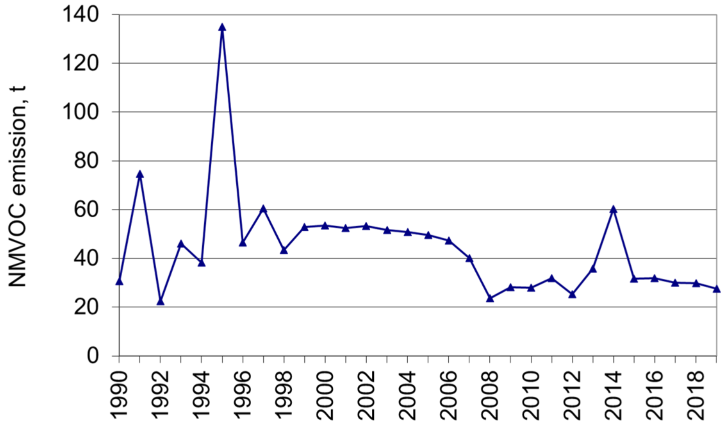
		Unit	1990	2000	2005	2010	2015	2019
Methane	CH_4	molar-%	90.92	86.97	88.97	89.95	88.80	91.2
Ethane	C_2H_6	molar-%	5.08	6.88	6.14	5.71	6.08	5.01
Propane	C_3H_8	molar-%	1.89	3.17	2.50	2.19	2.47	1.75
i-Butane	i-C_4H_{10}	molar-%	0.36	0.43	0.40	0.37	0.39	0.31
n-Butane	n-C_4H_{10}	molar-%	0.50	0.61	0.55	0.54	0.59	0.46
i-Pentane	i-C_5H_{12}	molar-%	0.14	0.11	0.11	0.13	0.13	0.11
n-Pentane	n-C_5H_{12}	molar-%	0.10	0.08	0.08	0.08	0.10	0.07
n-Hexane and heavier hydrocarbons	C^{6+}	molar-%	0.09	0.06	0.05	0.06	0.05	0.05
Nitrogen	N_2	molar-%	0.31	0.34	0.29	0.31	0.32	0.29
Carbon dioxide	CO_2	molar-%	0.60	1.35	0.90	0.66	1.07	0.76
Lower heating value	H_n	MJ/m^3_n	39.176	40.154	39.671	39.461	39.635	38.812
Density	ρ	kg/m^3_n	0.808	0.846	0.825	0.816	0.828	0.803

Emissions

Emissions of NMVOC and CH_4 from transmission of natural gas are shown in Figure 4.14. Emissions of CO_2 from transmission and storage are very limited and not included in the figure.

The gas transmission company reports emissions of CH_4 for the years 1999 and onwards, based on registered loss in the transmission grid and the emission from the natural gas consumption in the pressure regulating stations. For the years 1991-1998, the CH_4 emissions for transmission are estimated based on the registered loss provided by the transmission company and the annual composition of Danish natural gas given by Energinet.dk. Transmission loss is not available for 1990, why the average for 1991-1995 is applied.

As the pipelines in Denmark are relatively new and made of plastic, most emissions are due to leaks during construction and maintenance. This leads to large annual fluctuations in emissions, which are not correlated to the transmission rates. E.g. the large emission in 1995 owe to a large construction work covering four different locations. The increase in 2011 owe to venting for drainage of the pipes in preparation for construction work on a new compressor station, and the increase in 2014 owe to the construction of a new major railway line.



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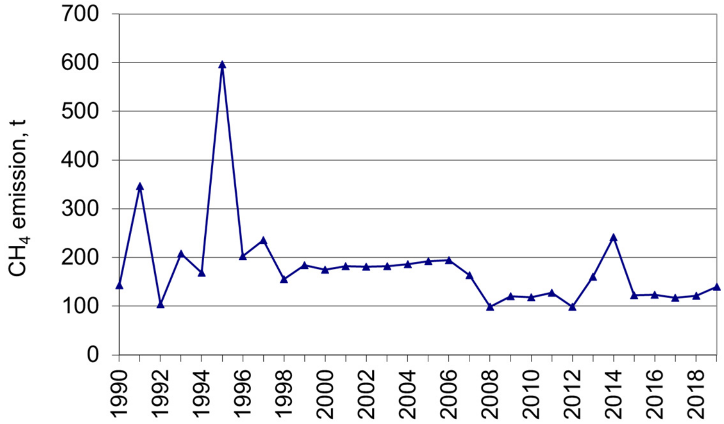

b)

Figure 4.14 NMVOC (a) and CH_4 (b) emissions from transmission of natural gas.

4.3.4 Distribution (1B2b5)

Activity data

Distribution rates for 1990-1998 are estimated from the Danish energy statistics. Distribution rates are assumed to equal total Danish consumption rate minus the consumption rates of sectors that receive the gas at high pressure. The following consumers are assumed to receive high pressure gas: town gas production companies, production platforms and power plants. Distribution rates for 1999-2006 refer to DONG Energy / Danish Gas Technology Centre / Danish gas distribution companies (Karll 2002, 2003, 2004, 2005; Oertenblad 2006, 2007). Since 2007, the distribution rates are given by the companies. The fugitive losses from distribution of natural gas are only given for some companies. The average of the available “loss / distribution” ratios is used for the remaining companies.

Activity data for distribution of town gas are rather scarce, and calculations are based on the available data from the town gas distribution companies on losses from the pipelines. At present, there are two areas with town gas distribution and correspondingly two distribution companies. Two other companies in other areas were closed in 2004 and 2006, and it has not been possible to collect data for all years in the time series. The emissions have been calculated for the years with available data and the distribution loss for the first year with data has been applied for the previous years in the time series. Data are missing for the later years (1996-2003) for one of the distribution companies. The distribution rate is assumed to decrease linearly to cero over these years, and the share “distribution loss / distribution rate” is assumed equal to the value for 1995.

Data on the distribution network are given by Energinet.dk, Danish Gas Technology Centre and the distribution companies concerning length and material. The length of the distribution network is around 20 000 km. Because the distribution network in Denmark is relatively new, most of the pipelines are made of plastic (approximately 90 %). For this reason, the fugitive emission is negligible under normal operating conditions, as the distribution system is basically tight with no fugitive losses. However, the plastic pipes are vulnerable and therefore most of the fugitive emissions from the pipes are caused by losses due to excavation damages, and construction and maintenance activities performed by the gas companies. These losses are either measured or estimated by calculation in each case by the gas companies. About 5 % of the distribution network is used for town gas. This part of the network is older and the fugitive losses are larger. The fugitive losses from this network are associated with more uncertainty, as it is estimated as a percentage (15 %) of the meter differential. This assumption is based on expert judgement from one of the town gas companies (Jensen, 2008). Distribution rates are shown in Figure 4.15.

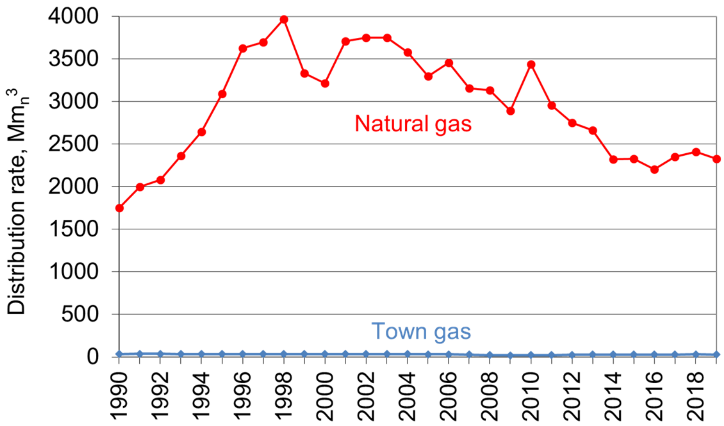

Figure 4.15 Distribution rates of natural gas and town gas.

Emission factors

Emissions from natural gas distribution are calculated from the fugitive losses from pipelines and the gas quality measured by Energinet.dk (see Table 4.6). The same approach is used for town gas, which is natural gas admixed ~ 50 % ambient air. From 2014, one town gas distribution company has started to admix biogas. In 2019, the share of biogas is 34 %, which is expected to increase in the coming years. The admixed biogas has not been upgraded as tests of different appliances have shown, that up to 40 % un-upgraded biogas can be added to the town gas without causing problems with the appliances’ combustion. The gas composition of biogas is given in Table 4.7.

Table 4.7 Composition of biogas admixed to town gas (Jeppesen, 2014; Ea Energianalyse, 2014).

Methane	molar-%	60.98
Nitrogen	molar-%	0.001
Carbon dioxide	molar-%	39.02
Lower heating value	MJ/m^3_n	21.53
Density	kg/m^3_n	0.808

The distribution companies provide emissions of CH_4 for 1997 and onwards. For 1995-1996, emissions are calculated from the registered loss from distribution and the annual composition of Danish natural gas given by Energinet.dk. As distribution losses are not available for the years 1990-1994, the percentage loss for 1995 is used.

Emissions

Emissions of NMVOC and CH_4 from distribution of natural gas and town gas are shown in Figure 4.16. The decreasing trend for town gas owe to phase-out of town gas distribution in two areas. Further relining of old pipelines has reduced the gas loss from town gas distribution. The NMVOC emissions are reduced from 2014 onwards due to admix of biogas, which does not contain NMVOC (see Table 4.7).

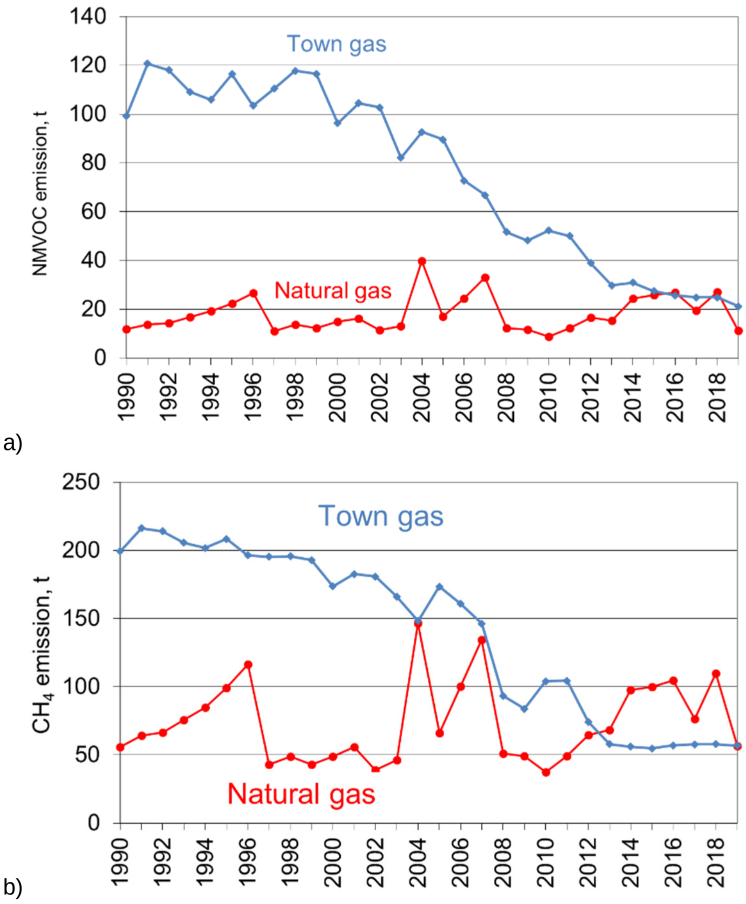

Figure 4.16 NMVOC (a) and CH_4 (b) emissions from transmission of natural gas.

4.4 Fugitive emissions from venting and flaring (1B2c)

Venting occur in the two Danish natural gas storage facilities. Flaring occurs in refineries, in oil and gas production, in gas treatment and storage facilities, and in gas transmission and distribution.

4.4.1 Venting (1B2c1)

Activity data

The natural gas storage facilities make environmental reports on annual basis, including data on venting. Venting of gas is assumed not to be occurring in extraction and in refineries, as controlled venting enters the gas flare system. Venting rates in gas storage facilities are shown in Figure 4.17. Data are not available for the years 1990-1994 for the one gas storage facility that was in operation over the entire time series, and the average for 1995-1998 is applied. The second gas storage facility was opened in 1994, leading to increasing venting rates.

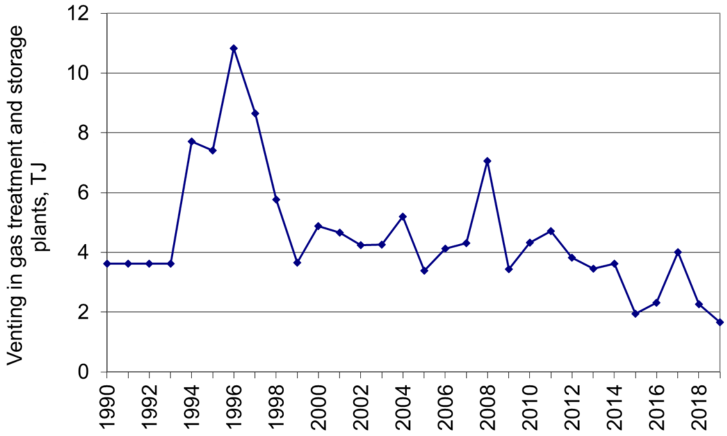

Figure 4.17 Venting rates in gas storage facilities.

Emission factors

Emissions of CH_4 and NMVOC from venting are given in the environmental reports for the gas storage facilities (Energinet.dk, 2020a). CO_2 emissions from venting are calculated from country specific emission factors based on annual natural gas composition published by Energinet.dk (Table 4.6).

Emissions

Venting is limited to the gas storage facilities and the emissions are of minor importance to the total fugitive emissions. Venting emissions are included in Figure 4.21.

4.4.2 Flaring in refineries (1B2c2i)

Activity data

Flaring rates for the two Danish refineries are given in their environmental reports and in additional data provided by the refineries directly to DCE. From 2006, flaring rates are given in the EU ETS reporting. Data are not available for the years 1990-1993, why the flaring rate for 1994 has been adopted for the previous years. Flaring rates are shown in Figure 4.18.

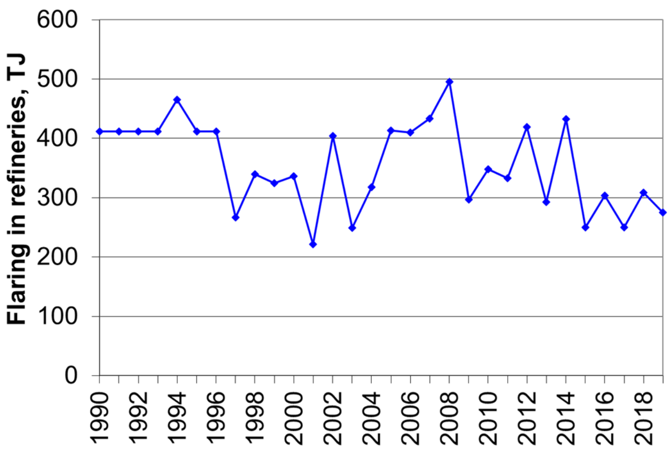

Figure 4.18 Flaring rates in refineries.

Emission factors

SO_2 emissions are provided annually by the refineries, and NO_x emissions are provided annually by only one refinery. The composition of refinery gas is given for 2008 by one of the two refineries. As the composition for refinery gas is very different from the composition of natural gas, the 2008 refinery gas composition is used in calculations for both Danish refineries. The NMVOC and CH_4 emission factor based on the 2008 refinery gas composition are applied for both refineries for the entire time series. The CO_2 emission factor is based on the refineries reporting to the EU ETS from the years 2006 and onwards. Before 2006, corresponding data are not available, and the average of CO_2 emission factors for 2007-2011 for each refinery is applied. The emission factor applied for N_2O is based on OLF (1993) for flaring in oil and gas extraction, as no value are given for flaring in refineries in the 2006 IPCC Guidelines. Emissions of the remaining pollutants are based on standard emission factors from the 2019 EMEP/EEA Guidebook. Emission factors for selected pollutants are listed in Table 4.8.

Table 4.8 Emission factors for flaring in refineries.

Pollutant	Emission factor	Unit
NO_x	29.2	g/GJ
NMVOC	76.45	g/GJ
CO	133	g/GJ
TSP	0.89	g/GJ
PM_{10}	0.89	g/GJ
$PM_{2.5}$	0.89	g/GJ
BC	0.21	g/GJ
CH_4	18.1	g/GJ
CO_2 *	58.16 / 57.20	kg/GJ
N_2O	0.47	g/GJ

** The CO_2 emission factors are plant specific and based on the refineries' reports for EU ETS.

Emissions

Emissions of NMVOC, SO_2, CH_4 and CO_2 are shown in figure 4.19. The variation over the time series mainly reflects the annual variation in the activity rate for flaring, with small variations for CO_2 from 2006 onwards, when annual plant specific CO_2 emission factors became available via the EU ETS reporting. SO_2 in the early years of the time series are very uncertain, as one refinery is closed, and as only very scarce information are available. It has not been possible to get further verification of the data for 1990-1994.

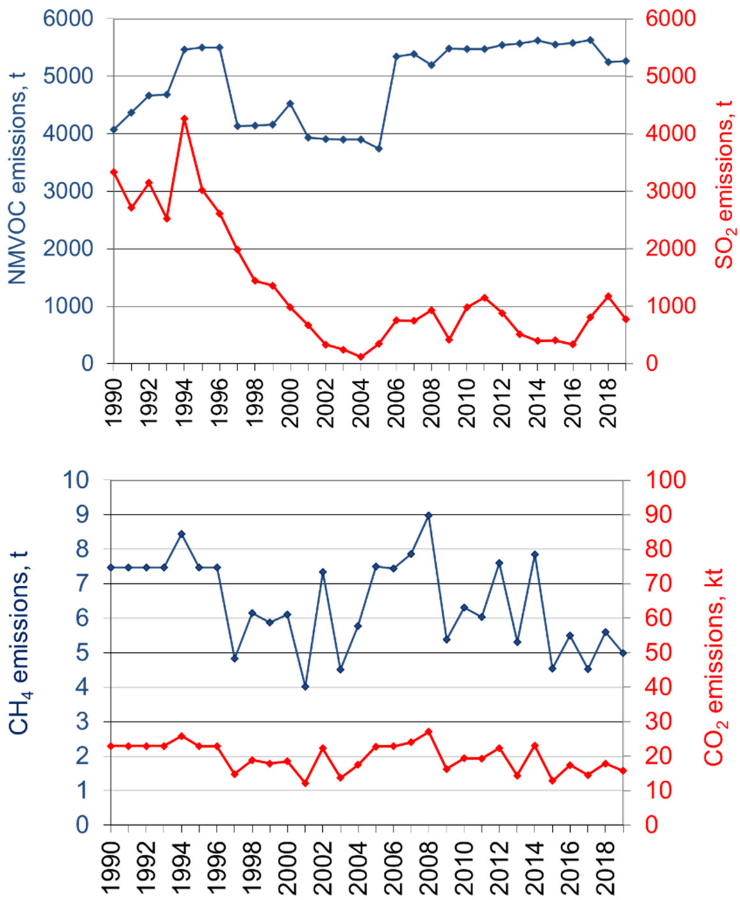

Figure 4.19 Emissions of (a) NMVOC and SO_2 and (b) CH_4 and CO_2 emissions from flaring in refineries.

4.4.3 Flaring in upstream oil and gas production (1B2c2iii)

Activity data

From 2006, data on flaring in upstream oil and gas production is given in the reports submitted under the EU ETS and thereby emission calculation can be made for the individual production units. Before 2006, only the total flared amount is available in the annual report "Denmark's oil and gas production" (Danish Energy Agency, 2020a). Flaring rates are shown in Figure 4.20. Flaring rates in upstream oil and gas production have been decreasing over the last 10 years period in accordance with the decrease in production as seen in Figure 4.5. Further, for environmental reasons there is focus on reduction of the amount being flared.

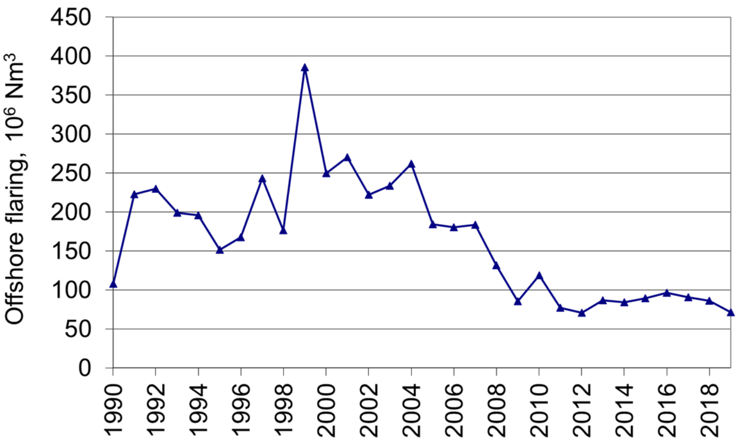

Figure 4.20 Flaring rates in upstream oil and gas production.

Emission factors

The emission factors for flaring in upstream oil and gas production are shown in Table 4.9. The NO_x emission factor is based on the conclusion in a Danish study of NO_x emissions from offshore flaring carried out by the Danish Environmental Protection Agency (DEPA, 2008). The recommended NO_x emission factor (31 008 g per GJ or 0.0015 tonnes NO_x per tonnes gas) corresponded well with the emission factors used to estimate NO_x emission in other countries with oil production in the North Sea (Netherlands: approximately 0.0014 tonnes NO_x per tonnes gas and United Kingdom: approximately 0.0013 tonnes NO_x per tonnes gas). Since 2006, the CO_2 emission factors are calculated according to the reporting for EU ETS. As corresponding data are not available for earlier years, the average CO_2 EF for the years 2008-2012 is applied for the years 1990-2007. The emission factor for CH_4 is estimated from flare gas quality data for one offshore production platform, assuming a flare efficiency of 98 % in agreement with IPCC (2006) and API (2009). Emission factors for N_2O are based on IPCC (2006). Emission factors for all other pollutants are based on standard Tier 1 emission factors for stationary combustion of gaseous fuels in energy industries from the 2019 EMEP/EEA Guidebook (EMEP/EEA, 2019).

Table 4.9 Emission factors for flaring in upstream oil and gas production.

Pollutant	Emission factor,	Unit
SO_2	0.013	g/Nm^3
NO_x	1.23	g/Nm^3
NMVOC	1.48	g/Nm^3
CO	1.85	g/Nm^3
TSP	0.042	g/Nm^3
PM_{10}	0.042	g/Nm^3
PM2.5	0.042	g/Nm3
BC	0.0075	g/Nm3
CH_4	10.56	g per Nm3
CO_2	2.48	kg per Nm3
N_2O	1.6	g per Nm3

Emissions

The time series for the emission of CO_2 from flaring in upstream oil and gas production fluctuates due to the fluctuations in the flaring rate and to a minor degree due to the CO_2 emission factor. Emissions of other pollutants from flaring in upstream oil and gas production are estimated from the same emission factors for all years in the time series, and the variations reflect only the variations in the flared amounts.

As shown in Figure 4.21, there was a marked increase in the rate of flaring in upstream oil and gas production in 1997 and especially in 1999. The increase in 1997 was due to the new Dan field and the commissioning of the Harald field. The increase in 1999 was due to the opening of the three new fields Halfdan, Siri and Syd Arne.

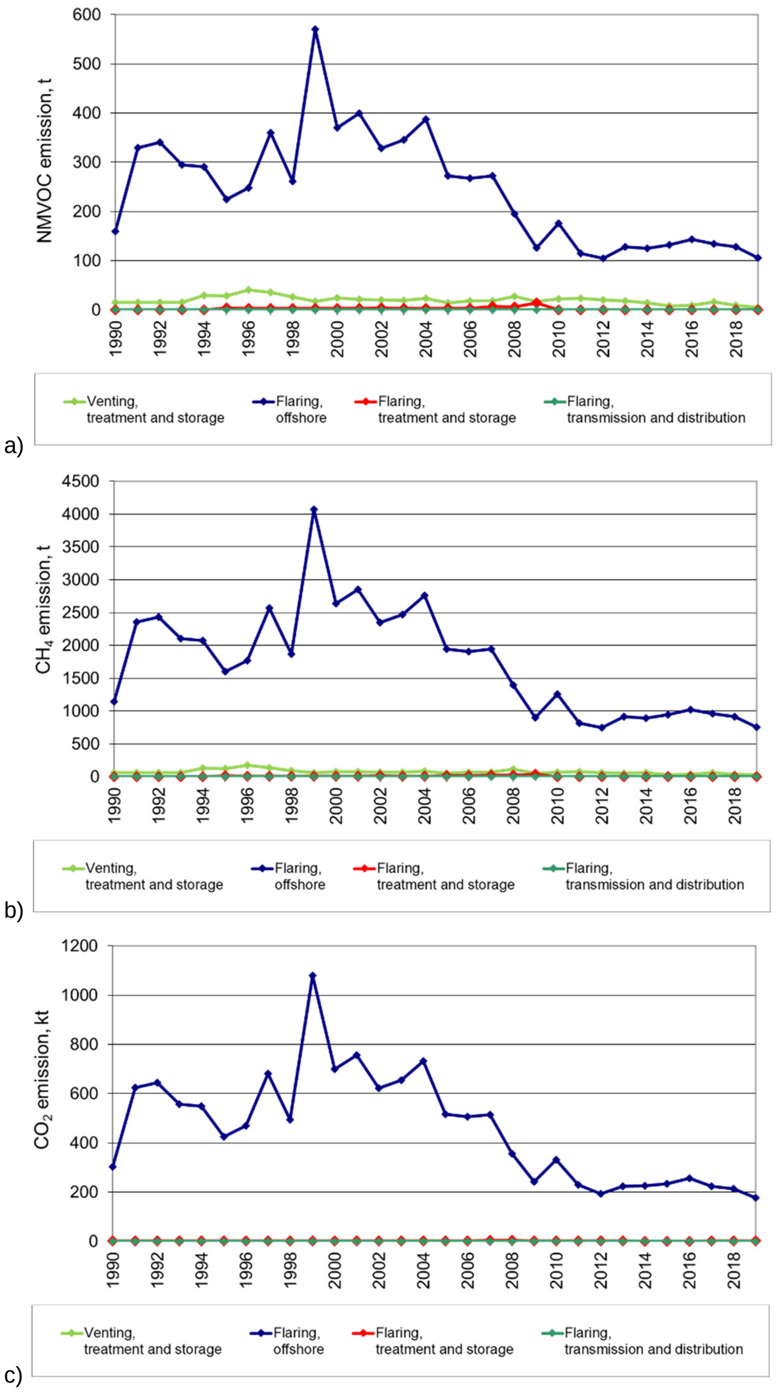

Figure 4.21 NMVOC (a), CH_4 (b) and CO_2 (c) emissions from flaring in upstream oil and gas production.

4.4.4 Flaring in treatment and storage facilities (1B2c2ii)

Activity data

Activity data for flaring in gas treatment and storage facilities are given in environmental reports (Dong Energy, 2020; Energinet.dk, 2020a). Flaring rates in gas treatment and gas storage facilities are not available before 1994. The mean value for 1994-1998 has been adopted as basis for the emission calculation for the years 1990-1993 (Figure 4.22). Note that one of the two gas storage facilities was not opened before 1994. The large amount of gas flared in 2007 owe to a larger maintenance work at the gas treatment plant. The increase in 2017 owe to increased flaring amount at the gas treatment plant.

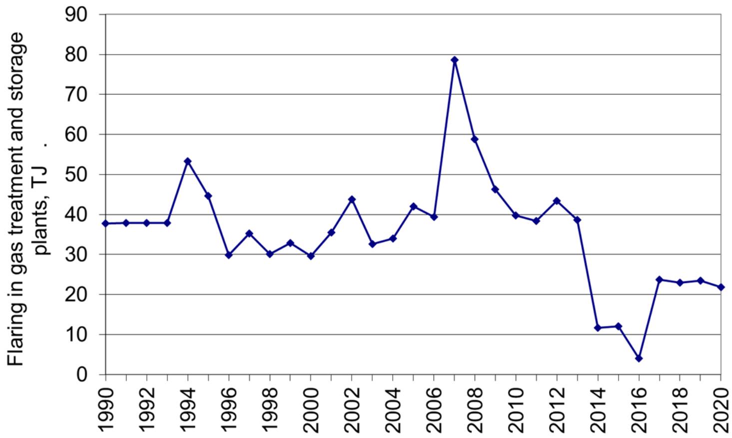

Figure 4.22 Flaring in gas treatment and storage facilities.

Emission factors

NMVOC emissions from flaring in gas treatment and storage facilities are provided for the relevant treatment and storage facilities. Emissions of other pollutants are calculated from the same emission factors, which are used for flaring in upstream oil and gas production (Table 4.9), except for CO_2. The natural gas flared in the treatment and storage facilities are natural gas with the same composition as natural gas distributed in Denmark, and the CO_2 emission factors are based on the gas composition given by Energinet.dk (Table 4.6).

Emissions

Emissions from flaring in gas treatment and storage facilities are of minor importance to the total fugitive emissions. The emissions have decreased from 2009 to 2010 due to a change from continuous to regulating power operation of the power producing gas turbine at the gas storage plant. The increase in 2017 owe to increased flaring amount at the gas treatment plant. Emissions are included in Figure 4.21.

4.4.5 Flaring in gas transmission and distribution

Activity data

The Danish gas transmission company acquired a mobile flare, which have been used during large maintenance work since 2013. Also, flaring have occurred in gas distribution. Flaring rates are provided by the relevant companies.

Emission factors

Emissions from flaring in gas transmission and distribution are calculated from the same emission factors, which are used for flaring in upstream oil and gas production (Table 4.9).

Emissions

Emissions from flaring in gas transmission and distribution are of minor importance to the total fugitive emissions. Emissions are included in Figure 4.21.

5 Uncertainties and time series consistency

5.1 Air pollutants

The applied methodology for uncertainty estimates refers to Pulles & Aardenne (2004). The Danish uncertainty estimates are based on the simple approach 1, as described in the 2006 IPCC Guidelines (IPCC, 2006).

5.1.1 Input data

The uncertainty estimates are based on the calculated emissions for the base year and for the latest inventory year, and on the uncertainty rates for both activity data and emission factors. Data are aggregated for the NFR category 1B - Fugitive Emissions from Fuels. Base year refers to 1990 for all pollutants. Emission data, activity data and emission factors are described in Chapter 4.

For each pollutant the primary emission source/sources are the determinant for the overall uncertainty level. Uncertainty levels are based on the IPCC Guidelines, the EMEP/EEA Guidebook, reports under the EU ETS and DCE assumptions. Uncertainty levels for activity data and emission factors are listed in Table 5.1.

Table 5.1 Uncertainty levels for activity rates and emission factors for NFR category 1B - Fugitive Emissions from Fuels.

Pollutant	Activity data uncertainty level, %	Emission factor uncertainty level, %
SO_2	10	25
NO_x	7.5	125
NMVOC	2	125
CO	7.5	125
TSP	2	50
PM_{10}	2	50
$PM_{2.5}$	2	50
BC	2	100
As	7.5	500
Cd	7.5	500
Cr	7.5	500
Cu	7.5	500
Hg	7.5	500
Ni	7.5	500
Pb	7.5	500
Se	7.5	500
Zn	7.5	500
PCDD/F	7.5	500
Benzo(b)fluoranthene	7.5	500
Benzo(k)fluoranthene	7.5	500
Benzo(a)pyrene	7.5	500
Indeno(1,2,3-cd)pyrene	7.5	500

5.1.2 Results

The uncertainty model estimates uncertainties for both the emission level and the trend. The uncertainty on the emission levels for SO_2, NO_x, NMVOC and CO are 27 %, 125 %, 125 % and 125 %, respectively.

For PM the uncertainty is 50 %, for BC the uncertainty is 100 % and for HM and PAHs the uncertainty is 500 %. The individual uncertainty estimates for the fugitive emission inventory are shown in Table 5.2. The trend refers to the years 1990 onwards for all pollutants.

Table 5.2 Estimated uncertainty levels for emissions and trends for fugitive emissions.

Pollutant	Emission level uncertainty	Trend uncertainty
	%	%
SO_2	27	3
NO_x	125	7
NMVOC	125	2
CO	125	7
TSP	50	1
PM_{10}	50	1
$PM_{2.5}$	50	1
BC	100	1
As	500	7
Cd	500	7
Cr	500	7
Cu	500	3
Hg	500	7
Ni	500	7
Pb	500	7
Se	500	7
Zn	500	7
PCDD/F	500	7
Benzo(b)fluoranthene	500	7
Benzo(k)fluoranthene	500	7
Benzo(a)pyrene	500	7
Indeno (1,2,3-cd) pyrene	500	7

5.2 Greenhouse gases

The uncertainty models follow the methodology in the 2006 IPCC Guidelines (IPCC, 2006). Approach 1 is based on the simplified uncertainty analysis (error propagation method) and Approach 2 is based on Monte Carlo simulations. From the 2017 submission, the Approach 2 uncertainty estimation has not been carried out due to a lack of resources.

Uncertainty estimates are made for total emissions in the latest inventory year and for the emission trends for the corresponding time series. Uncertainty estimates are made for the CO_2, CH_4 and N_2O separately and summarized.

5.2.1 Input data

The Approach 1 uncertainty model is based on emission data, uncertainty levels for activity data and uncertainty levels for emission factors for base year and latest inventory year. Emission data, activity data and emission factors are described in Chapter 4.

The uncertainty levels used in the uncertainty models are based on different sources, e.g. the 2006 IPCC Guidelines, EMEP/EEA Guidebook and reports under the EU ETS. Further, a number of the uncertainty levels are given as DCE assumptions. DCE assumptions are based on source and/or plant specific uncertainty levels for part of the SNAP category and assumptions for the remaining sources and/or plants in the category.

Input data are aggregated on SNAP level. Estimates are made for the greenhouse gases CO_2, CH_4 and N_2O both separately and summarized (GHG). Uncertainty levels for activity data and emission factors are listed in Table 5.3.

Table 5.3 Uncertainty levels for activity rates and emission factors.

Pollutant	CRF category	Source	Activity data uncertainty level, %		Emission factor uncertainty level, %	
CO_2	1.B.2.a.1	Exploration	2	A	10	A
CO_2	1.B.2.a.2	Production	2	A	100	I
CO_2	1.B.2.a.4	Refining/storage	2	A	40	S
CO_2	1.B.2.b.1	Exploration	2	A	10	A
CO_2	1.B.2.b.2	Production	2	A	100	I
CO_2	1.B.2.b.4	Transmission and storage	15	G	2	Q
CO_2	1.B.2.b.5	Distribution	25	G, A	10	Q, A
CO_2	1.B.2.c.1.ii	Venting	15	G, A	2	Q
CO_2	1.B.2.c.2.i	Flaring, oil	11	E	2	E
CO_2	1.B.2.c.2.ii	Flaring, gas	7.5	E	2	E
CO_2	1.B.2.c.2.iii	Flaring, combined	7.5	E	2	E
CH_4	1.B.2.a.1	Exploration	2	A	125	A
CH_4	1.B.2.a.2	Production	2	A	100	I
CH_4	1.B.2.a.3	Transport	2	A	100	I
CH_4	1.B.2.a.4	Refining/storage	1	E, A	200	A
CH_4	1.B.2.b.1	Exploration	2	A	125	A
CH_4	1.B.2.b.2	Production	2	A	100	I
CH_4	1.B.2.b.4	Transmission and storage	15	G	2	Q
CH_4	1.B.2.b.5	Distribution	25	G, A	10	Q, A
CH_4	1.B.2.c.1.ii	Venting	15	G, A	2	Q
CH_4	1.B.2.c.2.i	Flaring, oil	11	E	15	H, A
CH_4	1.B.2.c.2.ii	Flaring, gas	7.5	E	2	A
CH_4	1.B.2.c.2.iii	Flaring, combined	7.5	E	125	I
N_2O	1.B.2.a.1	Exploration, oil	2	A	1000	A
N_2O	1.B.2.c.2.i	Flaring, oil	11	E	1000	I
N_2O	1.B.2.c.2.ii	Flaring, gas	7.5	E	1000	I
N_2O	1.B.2.c.2.iii	Flaring, combined	7.5	E	1000	I

A: DCE assumption.
I: IPCC 2006 Guidelines (default value).
S: Statistisk Sentralbyrå, Statistics Norway, 2008.
E: EU Emission Trading Scheme (EU ETS).
H: Holst, 2009 and Statoil A/S, 2010.
Q: Annual gas quality, Energinet.dk.

The CO_2 emission factors for flaring in upstream oil and gas production and in refineries and the CO_2 and CH_4 emission factors for natural gas transmission, distribution and venting, are the most accurate as they are calculated on basis of gas composition measurements. Emissions factors for flare gas are available in the EU ETS reporting while emissions factors for natural gas are published by Energinet.dk.

The calculations of CO_2 emissions from exploration of oil and gas are based on information on oil and gas quality for most of the E/A wells. As the uncertainty levels of the measurements are not available, the double of the uncertainty for flaring in oil and gas extraction (before EU ETS standards) has been used.

The CO_2 emission factor for extraction of oil and gas is based on standard emission factors from IPCC (2006) and the corresponding uncertainties of 100 % are applied in the uncertainty analysis.

The uncertainty level for the emission factor for fugitive CH_4 emissions from refineries is dominated by a large uncertainty for one refinery. Further, measurements of fugitive emissions from the refineries are only available for one and two years, respectively, and these measurements indicate larger emissions than earlier estimates. As more measurements become available, the uncertainty level is expected to decrease.

The emission factors for loading of ships are given as quality C in EMEP/EEA (2019), corresponding an uncertainty level of 50-200 %. The lower level is assumed the most plausible for Danish conditions.

For onshore activities, the emission factor uncertainty corresponds to the uncertainty for onshore loading by Statistics Norway (2008), and the same uncertainty level is assumed for the CH_4 emission factor for onshore activities.

According to IPCC (2006) the emission factor for N_2O is the least reliable, and the uncertainty interval for the N_2O emission factors given for flaring in oil and gas production is -10 % to +1 000 %. An uncertainty level of 1 000 % is adopted in the Danish uncertainty model for all fugitive sources in the Danish inventory (exploration and flaring of oil and gas).

5.2.2 Results

The results of the Approach 1 uncertainty model for 2019 are shown in Table 5.4. N_2O has the largest uncertainty for both the total emission and the trend followed by CH_4 and CO_2. The estimated uncertainty for the total GHG emission is 114 % and the GHG emission trend is -42 % ±9 %-point.

Table 5.4 Uncertainty estimates for total emissions and emission trends from the Approach 1 uncertainty model.

	1990 emission, kt CO_2 eqv.	2019 emission, kt CO_2 eqv.	Uncertainty, % lower and upper (±)	Trend 1990-2019, %	Uncertainty, % lower and upper (±)
CO_2	341	195	7	-43	6
CH_4	133	76	72	-43	7
N_2O	53	34	999	-35	25
GHG	527	305	114	-42	9

6 Source specific QA/QC and verification

6.1 Source specific QA/QC and verification

The elaboration of a formal QA / QC plan started in 2004 and was updated in 2013 (Nielsen et al., 2013) and latest in 2020 (Nielsen et al., 2020). The plan describes the concepts of quality work and definitions of sufficient quality, Critical Control Points (CCP) and a list of Points of Measuring (PM) (Figure 6.1). Further information are available in Nielsen et al. (2021a).

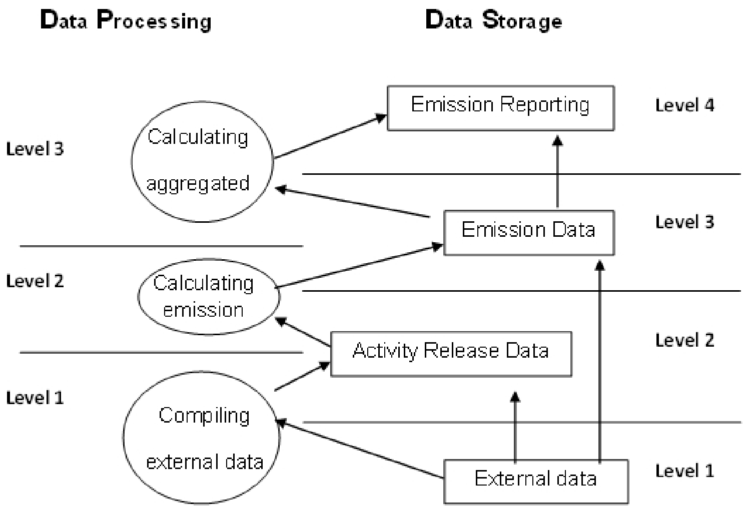

Figure 6.1 The general data structure for the Danish emission inventory (Nielsen et al., 2020).

Data storage level 1

Data storage level 1 refers to the data collected by DCE before any processing or preparing. Table 6.1 lists the external data deliveries used for the inventory of fugitive emissions. Further, the table holds information on the contacts at the data delivery companies.

Table 6.1 List of external data sources.

Category	Data description	Activity data, emission factors or emissions	Reference	Contact(s)	Data agreement /comment
Exploration of oil and gas	Dataset for exploration of oil and gas, including rates and composition	Activity data	The Danish Energy Agency	Kirsten Lundt Erichsen	Data agreement
Production of oil and gas	Gas and oil production. Dataset, including rates of offshore loading of ships	Activity data	The Danish Energy Agency	Kirsten Lundt Erichsen	Not necessary due to obligation by law
Offshore flaring	Flaring in upstream oil and gas production (EU ETS data)	Activity data	The Danish Energy Agency	Dorte Maimann	Data agreement
Service stations	Data on gasoline sales from the Danish energy statistics	Activity data	The Danish Energy Agency	Jane Rusbjerg	Data agreement
Gas transmission	Natural gas transmission rates from the transmission company, sales and losses	Activity data	Energinet.dk	Signe Sonne	Not necessary due to obligation by law
Onshore activities	Rates of oil transport in pipeline and onshore loading to ships. Emissions from storage of raw oil in the terminal	Activity data and emission data	Ørsted	Søren Boesen	No formal data agreement
Gas distribution	Natural gas and town gas distribution rates from the distribution company, sales and losses (meter differences)	Activity data	Dong Energy / Dansk gasdistribution	Malene Hadrup	No formal data agreement
Emissions from refinery	Fuel consumption and emission data	Activity data and emission data	Equinor Refining Denmark A/S, A/S Danish Shell	Anette Holst, Trine Bjerre Kristiansen	No formal data agreement
Treatment and storage of gas	Environmental reports from plants defined as large point sources (Lille Torup, Stenlille, Nybro)	Activity data	Energinet.dk (Lille Torup, Stenlille) Nybro	Christian Guldager Corydon Per Korshøj	No formal data agreement
CO_2 emission factors for different sources	Reports according to the CO_2 emission trading scheme (EU ETS)	Activity data	Various plants		Not necessary due to obligation by law
Emission factors	Emission factors origin from a large number of sources	Emission factors	See Chapter 4 regarding emission factors		

The following section lists the CCPs and the PMs in the Danish QA / QC plan, relevant for the emission inventory for the fugitive sector.

Level	CCP	PM	Description
Data Storage level 1	1. Accuracy	DS.1.1.1	General level of uncertainty for every dataset including the reasoning for the specific values

The uncertainty for every dataset included in the inventory of fugitive emissions are evaluated and included in the Tier 1 / Approach 1 uncertainty calculations with short descriptions of the reasoning behind the specific values. The general levels of uncertainty are relatively low. The largest uncertainties are expected for emissions from refineries and distribution of town gas, the latter being of minor importance to the total fugitive emissions. For further comments regarding uncertainties, see Chapter 5.

Level	CCP	PM	Description
Data Storage level 1	2.Comparability	DS.1.2.1	Comparability of the emission factors/calculation parameters with data from international guidelines, and evaluation of major discrepancies

Systematic inter-country comparison has only been made on Data Storage Level 4. Further information are available in Nielsen et al. (2021a).

Level	CCP	PM	Description
Data Storage level 1	3.Completeness	DS.1.3.1	Ensuring that the best possible national data for all sources are included, by setting down the reasoning behind the selection of datasets

External data include energy statistics from the Danish Energy Agency, EU ETS reports and annual environmental reports from a number of plants and companies. Further, supplementary information are gathered annually from a number of companies. For most of the fugitive sources only one national data set is found, and all data sets are expected to be complete and include all activities / emissions form the sources. Data on flaring in upstream oil and gas production, in refineries and in gas treatment and storage facilities are available both in annual environmental reports and in EU ETS reports. Data are compared and if any differences occur, these are checked with the data suppliers. Minor differences may owe to the allocation of fuels, e.g. if pilot gas are included in the flare gas or the fuel gas rate.

Energy statistics

The Danish Energy Agency reports fuel consumption statistics on the SNAP level based on a correspondence table developed in co-operation with DCE. Both traded and non-traded fuels are included in the Danish energy statistics. Data on production and flaring in upstream oil and gas production, coal imports and gasoline sales are used for estimation of fugitive emissions.

Annual reports

A large number of plants publish environmental reports annually with information on e.g. fuel consumption and emissions. DCE compares data with those from previous years, discrepancies are checked, and large fluctuations are verified. In other cases, the self-regulation reports, annual reports and / or supplementary information are used. All information is compared with data for previous years.

Reports for the European Union Greenhouse Gas Emission Trading System (EU ETS)

CO_2 emission factors for offshore in upstream oil and gas production and in refineries are gathered from the EU ETS reports since 2006, when the EU ETS reports became available. EU ETS reports are available individually for the Danish oil / gas production fields and refineries.

Emission factors from a wide range of sources

For specific references, see Chapter 4.

Level	CCP	PM	Description
Data Storage level 1	4.Consistency	DS.1.4.1	The original external data has to be archived with proper reference

All external data are stored in the inventory file system and are accessible for all inventory staff members. Data processing is carried out in separate spread sheets to ensure that the external data are always available in the original form. Data sources are referenced in the spread sheets. Further information are available in Nielsen et al. (2021a).

Level	CCP	PM	Description
Data Storage level 1	6.Robustness	DS.1.6.1	Explicit agreements between the external institution holding the data and DCE about the conditions of delivery

Formal agreements are made with the Danish Energy Agency. Annual environmental reports are available due to legal requirements. The remaining data are published or delivered by the companies on voluntary basis (Table 6.1).

Level	CCP	PM	Description
Data Storage level 1	7.Transparency	DS.1.7.1	Listing of all archived datasets and external contacts

See DS 1.3.1 and Table 6.1.

Data Processing Level 1

Level	CCP	PM	Description
Data Processing level 1	1. Accuracy	DP.1.1.1	Uncertainty assessment for every data source not part of DS.1.1.1 as input to Data Storage level 2 in relation to type and scale of variability

Further information are available in Nielsen et al. (2021a).

Level	CCP	PM	Description
Data Processing level 1	2.Comparability	DP.1.2.1	The methodologies have to follow the international guidelines suggested by UNFCCC and IPCC

The methodologies in the inventory follow the principles in international guidelines by the UNFCCC and the IPCC.

Level	CCP	PM	Description
Data Processing level 1	3.Completeness	DP.1.3.1	Identification of data gaps with regard to data sources that could improve quantitative knowledge

Data gaps are found for distribution of town gas, as more companies are closed before this source was included in the Danish inventory. Emissions, which account for only a limited part of the total fugitive emissions, are calculated on a scarce data foundation. Also further information regarding volatile organic compounds (VOC) emissions from refineries would be preferred, but are not available. DCE continue the collaboration with the refineries and update the methodology and emission estimates if new information becomes available.

Level	CCP	PM	Description
Data Processing level 1	4.Consistency	DP.1.4.1	Documentation and reasoning of methodological changes during the time series and the qualitative assessment of the impact on time series consistency

Since 2006, the EU ETS data have been available for a number of sources. In all cases, the new data replace use of data assumed to be less accurate. Therefore, the CO_2 emission factors have been updated for all years, and no methodological change occur in the time series. Changes of the calculating procedures would entail elaboration of an updated description in Chapter 4.

Level	CCP	PM	Description
Data Processing level 1	5.Correctness	DP.1.5.2	Verification of calculation results using time series

Time series for activity data, emission factors and emissions on source and / or SNAP level are used to identify possible errors in the calculation procedure.

Level	CCP	PM	Description
Data Processing level 1	5.Correctness	DP.1.5.3	Verification of calculation results using other measures

For fugitive sources, only one data set is available for calculation, and no verification using other measures are possible. For sources where activity data is available in more data sources (e.g. in both EU ETS and annual reports), data are compared and the reasons for any differences are clarified.

Level	CCP	PM	Description
Data Processing level 1	7.Transparency	DP.1.7.1	The calculation principle, the equations used and the assumptions made must be described

Descriptions are included in Chapter 4.

Level	CCP	PM	Description
Data Processing level 1	7.Transparency	DP.1.7.2	Clear reference to dataset at Data Storage level 1

Notes on data sources are included in the calculation files for all input data.

Level	CCP	PM	Description
Data Processing level 1	7.Transparency	DP.1.7.3	A manual log to collect information about recalculations

Information on recalculations are included in the spread sheets in the fugitive model. Further, recalculations are described in the annual documentation reports; Denmark's National Inventory Report submitted under the United Nations Framework Convention on Climate Change and the Kyoto Protocol (the NIR) and the Annual Danish Informative Inventory Report to UNECE (the IIR).

Data storage level 2

Level	CCP	PM	Description
Data Storage level 2	5.Correctness	DS.2.5.1	Check if a correct data import to level 2 has been made

To ensure a correct connection between data on level 2 to data on level 1, different controls are in place, e.g. control of sums and random tests.

Data storage level 4

Level	CCP	PM	Description
Data Storage level 4	4.Consistency	DS.4.4.3	The IEFs from the CRF are checked both regarding level and trend The level is compared to relevant emission factors to ensure correctness Large dips/jumps in the time series are explained

Time series for IEFs are checked to identify large fluctuations, which are afterwards investigated and explained. The level of the IEFs are compared to other relevant EFs, e.g. the standard EFs in international guidebooks and guidelines.

Other QC procedures

A list of QA / QC tasks are performed directly in relation to the fugitive emission part of the Danish emission inventories. The following procedures are carried out to ensure the data quality:

- The emissions from the large point sources (refineries, gas treatment and gas storage facilities) are compared with the emissions reported in the previous year
- Annual environmental reports are kept for subsequent control of plant-specific emission data
- Checks of data transfers are incorporated in the fugitive emission models, e.g. sum checks
- Verification of activity data from external data when data are available through more data sources (production and flaring rates in upstream oil and gas production)
- Data sources are incorporated in the fugitive emission models
- Descriptions of recalculations are incorporated in the fugitive emission models
- Comparison with the inventory of the previous year. Any major changes are verified
- Total emission, when aggregated to reporting tables, is compared with totals based on SNAP source categories (control of data transfer)
- Checking of time series in the CRF and SNAP source categories. Significant dips and jumps are controlled and explained.

6.2 International inventory review

The Danish emission inventories for greenhouse gases reported to the EU Effort Sharing Decision (EU ESD) and the UNFCCC and for air pollution reported to the CLRTAP and the National Emission reduction Commitments Directive (NECD) are reviewed regularly. The reviews are conducted by teams of international experts and they include automatic checks, initial assessment, desk reviews and in-country reviews.

The latest review of the Danish greenhouse gas inventory were conducted in the 2020 under the EU ESD review and in 2018 under the UNFCCC individual review. The review reports are published by the European Commission (2020) and by the UNFCCC (2019).

The latest review of the air pollution inventory were conducted in 2021. The review report is not yet completed, but the 2020 review report is published by the European Commission (2020). The NECD review include periodically review of projections, emissions from large point sources (LPS) and gridded emissions.

Observations and recommendations from the international experts following the international reviews are a vital part of the QA and improvement work for the emission inventory.

6.3 External sectoral review

The first documentation report for the sector “Fugitive emissions form fuels” were published in 2009 (Plejdrup et al., 2009). The 2009 report was reviewed by an external expert not involved in the preparation of the inventory to allow for an independent peer review as part of the QA activities. The expert was Anette Holst from Statoil Refinery, Kalundborg, Denmark.

In 2015, an updated documentation report for the sector “Fugitive emissions from fuels” was published, including detailed information on the methodology used in the emission inventories for greenhouse gases and air pollution (Plejdrup et al., 2015). The report was reviewed by the external expert Glen Thistlethwaite from Ricardo Energy & Environment, Oxfordshire, UK.

The present documentation report has been reviewed by Jesper Werner Løhndorf Christensen, the Danish Energy Agency, Centre for Subsoil Resources and Risk Preparedness.

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THE DANISH EMISSION INVENTORY FOR FUGITIVE EMISSIONS FROM FUELS

This report presents the methodology and data used in the Danish inventory of fugitive emissions from fuels for years until 2019. The inventory of fugitive emissions includes the air pollutants SO_2, NO_x, NMVOC, CO, particulate matter (PM), black carbon (BC), heavy metals (HM), dioxin and PAHs, and the greenhouse gases CO_2, CH_4 and N_2O. Refining of oil products is the major source of fugitive emissions of SO_2, while NO_x, and CO mainly come from flaring at refineries and at oil and gas production facilities. The fugitive emissions of NMVOC originate predominantly from refining of oil products, production of oil and natural gas, service stations and oil loading of ships. The major source of PM emissions in the fugitive sector is storage of solid fuels, due to dust from stockpiles of coal for use in power and heating plants. Fugitive emissions from fuels account for approximately 1 % of the total Danish greenhouse gas emissions excluding Land use, Land use change and forestry (LULUCF) in 2019. The major part of the fugitive greenhouse gas emissions are emitted as CO_2. Flaring, the largest contribution being flaring offshore in upstream oil and gas production, is by far the major source of CO_2 in the fugitive sector. The major sources of fugitive emissions of CH_4 are extraction of oil and gas, refining of oil, transport of oil in pipelines, loading of oil onto ships, and flaring.

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