DANISH EMISSION INVENTORIES FOR STATIONARY COMBUSTION PLANTS

Inventories until 2011

Scientific Report from DCE – Danish Centre for Environment and Energy No. 102 2014

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Data sheet

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Abstract: Emission inventories for stationary combustion plants are presented and the methodologies and assumptions used for the inventories are described. The pollutants considered are SO_2, NO_x, NMVOC, CH_4, CO, CO_2, N_2O, NH_3, particulate matter, heavy metals, PCDD/F, HCB and PAH. The CO_2 emission in 2011 was 30 % lower than in 1990. However, fluctuations in the emission level are large as a result of electricity import/export. The emission of CH_4 has increased due to increased use of lean-burn gas engines in combined heating and power (CHP) plants. In recent years, the emission has declined. This is due to liberalisation of the Danish electricity market, which means that the fuel consumption in gas engines has decreased. The N_2O emission was higher in 2011 than in 1990 but the fluctuations in the time series are significant. A considerable decrease of the SO_2, NO_x and heavy metal emissions is mainly a result of decreased emissions from large power plants and waste incineration plants. The combustion of wood in residential plants has increased considerably until 2007 resulting in increased emission of PAH and particulate matter. The emission of NMVOC has increased since 1990 as a result of both the increased combustion of wood in residential plants and the increased emission from lean-burn gas engines. The PCDD/F emission decreased since 1990 due to flue gas cleaning on waste incineration plants.

Keywords: Emission, combustion, emission inventory, stationary combustion, power plants, district heating, CHP, co-generation, boiler, engine, incineration, MSW, residential combustion, SO_2, NO_x, NMVOC, CH_4, CO, CO_2, N_2O, particulate matter, NH3, heavy metals, PCDD/F, PAH, HCB, greenhouse gas, uncertainty

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List of abbreviations

As	Arsenic
BAT	Best Available Techniques
BREF	BAT Reference Document
Cd	Cadmium
CH_4	Methane
CHP	Combined Heat and Power
CLRTAP	Convention on Long-Range Transboundary Air Pollution
CO	Carbon Monoxide
CO_2	Carbon Dioxide
CORINAIR	CORe INventory on AIR emissions
Cr	Chromium
CRF	Common Reporting Format applied for greenhouse gas emission reporting
Cu	Copper
DEA	Danish Energy Agency
DEPA	Danish Environmental Protection Agency
EEA	European Environment Agency
EMEP	European Monitoring and Evaluation Programme
EU ETS	EU Emission Trading Scheme
GHG	Greenhouse Gas
HCB	Hexachlorobenzene
Hg	Mercury
HM	Heavy metals
I-Teq	International Toxic Equivalents for dioxins and furans
IIR	Informative Inventory Report
IPCC	Intergovernmental Panel on Climate Change
KCA	Key Category Analysis
LPG	Liquefied Petroleum Gas
LRTAP	Long-Range Transboundary Air Pollution
LULUCF	Land Use, Land-Use Change and Forestry
N_2O	Nitrous Oxide
NCV	Net Calorific Value
NECD	European Commissions National Emissions Ceiling Directive
NFR	Nomenclature for Reporting applied for emission reporting for the LRTAP Convention
NH_3	Ammonia
Ni	Nickel
NIR	National Inventory Report
NMVOC	Non-Methane Volatile Organic Compounds
NO_x	Nitrogen Oxides
PAH	Polycyclic Aromatic Hydrocarbons
Pb	Lead
PCB	Polychlorinated biphenyl
PCDD/-F	Poly Chlorinated Dibenzo Dioxins and Furans
PM	Particulate Matter
PM_{10}	Particulate Matter < 2.5 µm
$PM_{2.5}$	Particulate Matter < 10 µm
POP	Persistent Organic Pollutant
Se	Selenium
SNAP	Selected Nomenclature for Air Pollution
SO_2	Sulphur dioxide
TSP	Total Suspended Particulates
UHC	Unburned hydrocarbons
UNECE	United Nations Economic Commission for Europe
Zn	Zinc

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Preface

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

This report forms part of the documentation for the emission inventories for stationary combustion plants. The report includes both methodology and emission data. The results of inventories up to 2011 are included. The report updates the five reports published in 2004, 2006, 2007, 2009 and 2010.

The sector reports are reviewed by external national experts. The external national reviews forms a vital part of the QA activities for the emission inventories for stationary combustion required in IPCC Guidelines (IPCC 2006). This report has been reviewed by Vibeke Vestergaard Nielsen, DCE.

The 2004, 2006 and 2009 updates of this report were reviewed by Jan Erik Johnsson from the Technical University of Denmark, Bo Sander from Elsam Engineering and Annemette Geertinger from FORCE Technology.

Summary

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

The annual Danish emission inventories are prepared by the DCE - Danish Centre for Environment and Energy, Aarhus University. The inventories include the following pollutants relevant to stationary combustion: carbon dioxide (CO_2), methane (CH_4), nitrous oxide (N_2O), sulphur dioxide (SO_2), nitrogen oxides (NO_x), non-volatile organic compounds (NMVOC), carbon monoxide (CO), particulate matter (PM), ammonia (NH_3), heavy metals (HMs), polyclorinated dibenzodioxins and –furans (PCDD/F), polycyclic aromatic hydrocarbons (PAH) and hexachlorobenzene (HCB). In addition to annual national emissions, the report includes emission data for a number of source categories. Every five years[1] the reporting includes data on the geographical distribution of the emissions, a projection of emissions, data and details of the activity data, e.g. fuel consumption – on which the inventories are based.

The inventories for stationary combustion are based on the Danish energy statistics and on a set of emission factors for various source categories, technologies and fuels. Plant specific emissions for large combustion sources are incorporated into the inventories. This report provides detailed background information on the methodology and references for the input data in the inventory - energy statistics and emission factors.

The emission factors are based on either national references or on international guidebooks (EEA, 2009; IPCC, 1997). The majority of the country-specific emission factors are determined from: Danish legislation, Danish research reports, or calculations based on plant-specific emission data from a considerable number of large point sources. The plant-specific emission factors are provided by plant operators, e.g. in annual environmental reports or in the EU Emission Trading Scheme (ETS).

In the inventory for the year 2011, 76 stationary combustion plants are specified as large point sources. The point sources include large power plants, waste incineration plants, industrial combustion plants and petroleum refining plants. The fuel consumption of these large point sources corresponds to 58 % of the overall fuel consumption of stationary combustion.

In 2011, the total fuel consumption was 4 % lower than in 1990 and the fossil fuel consumption was 23 % lower than in 1990. The use of coal has decreased whereas the use of natural gas and biomass has increased. The fuel

[1] Last reporting was the 2012 that included time series until 2010.

consumption for stationary combustion plants fluctuates due to variation in the import/export of electricity from year to year.

Stationary combustion plants account for more than 50 % of the national emission for the following pollutants: SO_2, CO_2, PM_{10}, $PM_{2.5}$, the heavy metals As, Cd, Hg and Se, HCB, PCDD/F and PAH. Furthermore, the emission from stationary combustion plants accounts for more than 10 % of the national emission for the following pollutants: NO_x, NMVOC, CO, TSP and the heavy metals Cr, Ni, Pb and Zn. Stationary combustion plants account for less than 10 % of the national emission of CH_4, N_2O, NH_3 and the heavy metal Cu.

Public electricity and heat production is the most important stationary combustion emission source for CO_2, N_2O, and NO_x.

Lean-burn gas engines installed in decentralised combined heating and power (CHP) plants and combustion of biomass in residential plants are the two largest emission sources for CH_4.

Residential plants is the most important stationary combustion emission source for CO, NMVOC, particulate matter, PAH and PCDD/F. Wood combustion in residential plants is the predominant emission source.

The main emission sources for SO_2 are industrial plants and public electricity and heat production plants.

Industrial plants, public electricity and heat production plants and residential plants are the main emission sources for the different heavy metals.

CO_2 is the most important greenhouse gas accounting for 98.0 % of the greenhouse gas emission (CO_2 eq.) from stationary combustion. The greenhouse gas (GHG) emission trend follows the CO_2 emission trend closely. Both the CO_2 and the total GHG emission were lower in 2011 than in 1990: CO_2 by 30 % and GHG by 29 %. However, fluctuations in the GHG emission level are large. The fluctuations in the time series are mainly a result of electricity import/export but also of outdoor temperature variations from year to year that results in fluctuations in the consumption for space heating.

The CH_4 emission from stationary combustion has increased by a factor of 2.9 since 1990. This is mainly a result of the considerable number of lean-burn gas engines installed in CHP plants in Denmark during the 1990s. In recent years, the emission has declined. This is due to liberalisation of the Danish electricity market, which means that the fuel consumption in gas engines has decreased. The CH_4 emission from residential plants has increased since 1990 due to increased combustion of wood in residential plants.

The emission of N_2O was 4 % higher in 2011 than in 1990. The fluctuations follow the fluctuations of the fuel consumption, which is a result of import/export of electricity.

SO_2 emission from stationary combustion plants has decreased by 94 % since 1990. The considerable emission decrease is mainly a result of the reduced emission from electricity and heat production due to installation of desulphurisation technology and the use of fuels with lower sulphur content. These improvements are a result of both sulphur tax laws and legislation concerning sulphur content of fuels, emission ceilings for large power plants and emission limits for several plant categories.

The NO_x emission from stationary combustion plants has decreased by 68 % since 1990. The reduced emission is largely a result of the reduced emission from electricity and heat production due to installation of low NO_x burners, selective catalytic reduction (SCR) units and selective non-catalytic reduction (SNCR) units. The installation of the technical improvements was launched by legislation including emission ceilings for large power plants and lower emission limits for several plant categories. The fluctuations in the emission time-series follow fluctuations in electricity import/export.

In 2011, the wood consumption in residential plants was 3.7 times the 1990 level. The consumption of wood in residential plants peaked in 2007. The increased residential wood consumption until 2007 has caused considerable changes in the emission of NMVOC, CO, PM and PAH from stationary combustion due to the fact that residential wood combustion is a major emission source for these pollutants. However, a change of technology (installation of modern stoves) has caused decreasing emission factors.

The CO emission from stationary combustion has increased 5 % since 1990. The increase in CO emission from residential plants is less than the increase in wood consumption because the CO emission factor for wood combustion in residential plants has decreased since 1990. Furthermore, the emission from straw-fired farmhouse boilers has decreased considerably.

The NMVOC emission from stationary combustion plants has increased 14 % since 1990. The increased NMVOC emission is mainly a result of the increasing wood combustion in residential plants and the increased use of lean-burn gas engines. The emission from straw-fired farmhouse boilers has decreased.

The emission of TSP, PM_{10} and $PM_{2.5}$ has increased by 26-30 % since 2000 due to the increase of wood combustion in residential plants. The emission of PAHs has increased by 79-115 % since 1990, also a result of the increased combustion of wood in residential plants.

All the heavy metal emissions have decreased considerably since 1990 – between 76 % and 92 %. This is a result of the installation and improved performance of gas cleaning devices in waste incineration plants and large power plants.

PCDD/F emission has decreased 62 % since 1990 mainly due to installation of dioxin abatement in waste incineration plants that was necessary due to the emission limit included in Danish legislation. However, the emission from residential plants has increased due to the increased wood combustion in the sector.

The uncertainty level of the Danish greenhouse gas (GHG) emission from stationary combustion is estimated to be within a range of ±2.0 % and trend in greenhouse gas emission is -29.1 % ± 1.2 %-age points[2].

[2] Tier 1 approach. A tier 2 approach for uncertainty estimates has also been applied.

Sammendrag

Opgørelser over de samlede danske luftemissioner rapporteres årligt til klimakonventionen (United Nation Framework Convention on Climate Change, UNFCCC) og Kyotoprotokollen samt til UNECE (United Nations Economic Commission for Europe) konventionen om langtransporteret grænseoverskridende luftforurening (UNECE Convention on Long-Range Transboundary Air Pollution, der forkortes LRTAP Convention). Endvidere rapporteres drivhusgasemissionen til EU, fordi EU – såvel som de enkelte medlemslande – har ratificeret klimakonventionen og Kyotoprotokollen. Der udarbejdes også opgørelser til rapportering til Europa-Kommissionens NEC (National Emissions Ceiling) direktiv.

De danske emissioner opgøres og rapporteres af DCE – Nationalt Center for Miljø og Energi ved Aarhus Universitet (AU). Emissionsopgørelserne omfatter følgende stoffer af relevans for stationær forbrænding: CO_2, CH_4, N_2O, SO_2, NO_x, NMVOC, CO, partikler, NH_3, tungmetaller, dioxin, PAH og HCB. Foruden de årlige opgørelser over samlede nationale emissioner, rapporteres også sektoropdelt emission. Hvert femte år[3] rapporteres endvidere en geografisk fordeling af emissionerne, fremskrivning af emissionerne samt de aktivitetsdata – fx brændselsforbrug – der ligger til grund for opgørelserne.

Emissionsopgørelserne for stationære forbrændingsanlæg (ikke mobile kilder) er baseret på den danske energistatistik og på et sæt emissionsfaktorer for forskellige sektorer, teknologier og brændsler. Anlægsspecifikke emissionsdata for store anlæg, som fx kraftværker, indarbejdes i opgørelserne. Denne rapport giver detaljeret baggrundsinformation om den anvendte metode samt referencer for de data der ligger til grund for opgørelsen – energistatistikken og emissionsfaktorerne.

Emissionsfaktorerne stammer enten fra danske referencer eller fra internationale guidebøger (EEA 2009 og IPCC 1997) udarbejdet til brug for denne type emissionsopgørelser. De danske referencer omfatter miljølovgivning, danske rapporter samt middelværdier baseret på anlægsspecifikke emissionsdata fra et betydeligt antal større værker. Anlægsspecifikke emissionsfaktorer oplyses af anlægsejere, bl.a. i grønne regnskaber og i CO_2-kvoteindberetninger.

I emissionsopgørelsen for 2011 er 76 stationære forbrændingsanlæg defineret som punktkilder. Punktkilderne omfatter: kraftværker, decentrale kraftvarmeværker, affaldsforbrændingsanlæg, industrielle forbrændingsanlæg samt raffinaderier. Brændselsforbruget for disse anlæg udgør 58 % af det samlede brændselsforbrug for stationære forbrændingsanlæg.

Variationen i årlig import/eksport af el medvirker til at brændselsforbruget til stationære forbrændingsanlæg varierer. I 2011 var det samlede brændselsforbrug 4 % lavere end i 1990. Forbruget af kul er faldet, mens forbruget af naturgas og af biobrændsler er steget.

For følgende stoffer udgør emissionen fra stationær forbrænding over 50 % af den nationale emission: SO_2, CO_2, PM_{10}, $PM_{2.5}$, tungmetallerne As, Cd, Hg og Se, HCB, dioxin og PAH. Endvidere udgør emissionen over 10 % for

[3] Senest rapporteringen fra 2012 der inkluderer tidsserier til 2010.

NO_x, NMVOC, CO, TSP, Cr, Ni, Pb og Zn. Stationær forbrænding bidrager med mindre end 10 % af den nationale emission af CH_4, N_2O, NH_3 og Cu.

Indenfor stationær forbrænding er kraftværker og decentrale kraftvarmeværker den betydeligste emissionskilde for CO_2, N_2O og NO_x.

Gasmotorer installeret på decentrale kraftvarmeværker er sammen med forbrænding af biomasse i forbindelse med beboelse de største emissionskilder for CH_4.

Emissioner fra kedler, brændeovne mv. i forbindelse med beboelse er den betydeligste emissionskilde for CO, NMVOC, partikler, dioxin og PAH. Det er især forbrænding af træ, som bidrager til disse emissioner.

De største emissionskilder for SO_2 er industrielle anlæg samt kraft- og kraftvarmeværker.

Både industrianlæg, kraftværker/kraftvarmeværker samt villakedler/-brændeovne er væsentlige emissionskilder for de forskellige tungmetaller.

I rapporten vises tidsserier for emissioner fra stationær forbrænding.

Udviklingen i drivhusgasemissionen følger udviklingen i CO_2-emissionen ganske tæt. Både CO_2-emissionen og den samlede drivhusgasemission fra stationær forbrænding er lavere i 2011 end i 1990. CO_2 emissionen er 30 % lavere og drivhusgasemissionen er 29 % lavere. Emissionerne fluktuerer dog betydeligt, primært pga. variationerne i import/eksport af el men også pga. varierende udetemperatur og deraf følgende brændselsforbrug til rumopvarmning.

CH_4-emissionen fra stationær forbrænding er steget med en faktor 2,9 siden 1990. Denne stigning skyldes primært, at der i 1990'erne blev installeret et betydeligt antal gasmotorer på decentrale kraftvarmeværker. De senere år er emissionen dog faldet, som følge af de ændrede afregningsregler i henhold til det frie elmarked. Emissionen fra beboelse er steget væsentligt de senere år pga. den øgede forbrænding af træ i brændeovne og lignende.

Emissionen af N_2O var 4 % højere i 2011 end i 1990. Emissionen af N_2O fluktuerer som følge af variationerne i import/eksport af el.

SO_2-emissionen fra stationær forbrænding er faldet med 94 % siden 1990. Den store reduktion er primært et resultat af installering af afsvovlingsanlæg fra el- og fjernvarmeproducerende anlæg samt brug af brændsler med lavere svovlindhold. Dette er sket på baggrund af en indført svovlafgift, grænseværdier for svovlindhold i brændsler, SO_2-kvoter for centrale kraftværker samt emissionsgrænseværdier.

NO_x-emissionen fra stationær forbrænding er faldet med 68 % siden 1990. Reduktionen er primært et resultat af, at emissionen fra el- og fjernvarmeproducerende anlæg er faldet som følge af, at der benyttes lav-NO_x-brændere på flere anlæg og at der er idriftsat NO_x-røggasrensning på flere store kraftværker. Baggrunden herfor er emissionskvotebestemmelser for de centrale kraftværker samt skærpede emissionsgrænseværdier for flere anlægstyper. NO_x-emissionen fluktuerer som følge af variationen i import/eksport af el.

Mængden af træ forbrændt i villakedler og brændeovne var i 2011 3,7 gange så højt som i 1990. Den store stigning skete frem til år 2007 hvorefter forbruget er stabiliseret. Dette har stor betydning for emissionstidsserierne for en række emissionskomponenter for hvilke netop træ, anvendt i villakedler/brændeovne, er en væsentlig emissionskilde: NMVOC, CO, partikler og PAH. Emissionen fra nyere brændeovne mv. er lavere end for de ældre, idet forbrændingsteknologien er forbedret, og stigningen i emissioner er således lavere end stigningen i brændselsforbruget.

CO-emissionen fra stationær forbrænding er steget 5 % siden 1990. Emissionen fra brændeovne er steget, men samtidig er emissionen fra halmfyrede gårdanlæg faldet.

Emissionen af NMVOC fra stationær forbrænding er øget med 14 % siden 1990. Stigningen er primært et resultat af det øgede forbrug af træ i forbindelse med beboelse (brændeovne mv.) og idriftsættelsen af gasmotorer på decentrale kraftvarmeværker.

Emissionen af TSP, PM_{10} og $PM_{2.5}$ er steget 26-30 % siden år 2000 - igen på grund af den øgede brug af træ i brændeovne og små villakedler. Emissionen af de forskellige PAH'er er af samme grund steget 79-115 % siden 1990.

Emissionen af dioxin var 62 % lavere i 2011 end i 1990. Dette fald skyldes primært installering af dioxinrensningsanlæg på affaldsforbrændingsanlæg som alle affaldsforbrændingsanlæg iht. forbrændingsbekendtgørelsen[4] skulle idriftsætte senest i 2005. Emissionen fra brændeovne er dog samtidig steget.

Tungmetalemissionerne er faldet betydeligt siden 1990. Emissionen af de enkelte tungmetaller er reduceret mellem 76 % og 92 %. Reduktionen er et resultat af den forbedrede røggasrensning på affaldsforbrændingsanlæg og på kraftværker.

Emissionen af drivhusgasser er bestemt med en usikkerhed på ±2,0 %. Drivhusgasemissionen er siden 1990 faldet 29,1 % ± 1,2 %-point[5].

[4] Bekendtgørelse om anlæg der forbrænder affald, Bekendtgørelse 162 af 11. marts 2003.
[5] Resultater af Tier 1 approach. Der er endvidere beregnet usikkerhed med tier 2 approach.

1 Introduction

1.1 National emission

An overview of the national emission inventories for 2011 including all emission source categories is shown in Table 1-4[6]. The emission inventories reported to the LRTAP Convention and to the Climate Convention are organised in six main source categories and a number of subcategories. The emission source *Energy* includes combustion in stationary and mobile sources as well as fugitive emissions from the energy source category.

Emissions from incineration of waste in power plants or district heating plants are included in the source category *Energy*, rather than in the source category *Waste*.

Links to the latest emission inventories can be found at the AU home page: http://envs.au.dk/videnudveksling/luft/emissioner/emissioninventory/. Surveys of the latest inventories and the updated emission factors are also available on the AU homepage.

Note that according to convention decisions emissions from certain specific sources are not included in the inventory totals. These emissions are reported as memo items and are thus estimated, but not included in the totals. The data for the national emission included in this report does not include memo items.

CO_2 emission from combustion of biomass is not included in national totals, but reported as a memo item. Likewise, emissions from international bunkers and from international aviation are not included in national totals.

Further emission data for stationary combustion plants are provided in Chapter 3 and 4.

Table 1 National greenhouse gas emission for the year 2011 (Nielsen et al., 2013a).

Pollutant	CO_2	CH_4	N_2O	HFCs, PFCs & SF_6
Unit	Gg CO_2 equivalent			
1. Energy	42711	483	360	-
2. Industrial Processes	1011	-	-	843
3. Solvent and Other Product Use	151	-	16	-
4. Agriculture	-	4151	5521	-
5. Land-Use Change and Forestry	-2678	0	13	-
6. Waste	18	859	124	-
National emission excluding LULUCF [1)]	56248			
National emission including LULUCF [2)]	53583			

[1)] Not including Land Use, Land-Use Change and Forestry.

[2)] Including Land Use, Land-Use Change and Forestry.

[6] Emissions from Greenland and the Faroe Islands are not included.

Table 2 National emissions 2011 reported to the LRTAP Convention (Nielsen et al., 2013b).

Pollutant	NO_x Gg	NMVOC Gg	SO_2 Gg	NH_3 Gg	$PM_{2.5}$ Gg	PM_{10} Gg	TSP Gg	CO Gg
1. Energy	125	47	12	2	21	23	25	377
2. Industrial Processes	0	5	1	0	0	0	0	0
3. Solvent and Other Product Use	0	27	0	0	0	0	0	3
4. Agriculture	0	2	0	71	1	6	11	2
5. Land-Use Change and Forestry	-	-	-	-	-	-	-	-
6. Waste	0	0	1	1	0	0	0	1
National emission	126	81	14	74	23	29	38	383

Table 3 National heavy metal (HM) emissions 2011 reported to the LRTAP Convention (Nielsen et al., 2013b).

Pollutant	Pb Mg	Cd Mg	Hg Mg	As Mg	Cr Mg	Cu Mg	Ni Mg	Se Mg	Zn Mg
1. Energy	9.20	0.18	0.38	0.29	0.63	42.41	3.78	1.02	34.15
2. Industrial Processes	0.47	0.01	0.01	0.01	0.05	0.06	0.09	0.19	1.09
3. Solvent and Other Product Use	0.04	0.00	0.00	0.01	0.19	2.10	0.14	0.01	1.36
4. Agriculture	0.03	0.00	0.00	0.00	0.01	0.00	0.01	0.00	0.00
5. Land-Use Change and Forestry	-	-	-	-	-	-	-	-	-
6. Waste	0.11	0.00	0.00	0.00	0.00	0.01	0.00	0.00	0.44
National emission	9.85	0.20	0.39	0.32	0.88	44.58	4.02	1.22	37.04

Table 4 National PAH, dioxins/furans (PCDD/F) and hexachlorobenzene (HCB) emissions 2011 reported to the LRTAP Convention (Nielsen et al., 2013b).

Pollutant	Benzo(a)-pyrene Mg	Benzo(b)-fluoranthene Mg	Benzo(k)-fluoranthene Mg	Indeno (1,2,3-c,d) pyrene Mg	PCDD/F g I-Teq	HCB kg
1. Energy	4.17	4.32	2.44	2.94	17.62	0.57
2. Industrial Processes	0.00	0.00	0.00	0.00	0.05	-
3. Solvent and Other Product Use	0.00	0.00	0.00	0.00	0.09	-
4. Agriculture	0.10	0.10	0.04	0.04	0.02	-
5. Land-Use Change and Forestry	-	-	-	-	-	-
6. Waste	0.05	0.06	0.05	0.07	6.43	0.01
7. Other	-	-	-	-	-	-
National emission	4.33	4.48	2.53	3.06	24.21	0.58

1.2 Definition of stationary combustion and subsectors

Stationary combustion plants are included in the emission source category *Energy, Fuel combustion*:

- 1A1 Energy Industries.
- 1A2 Manufacturing Industries and Construction.
- 1A4 Other Sectors.

However, the emission source categories *1A2 Manufacturing Industries and Construction* and *1A4 Other Sectors* also include emissions from mobile combustion. The emission source *1A2* includes emissions from non-road machinery in the industry that have been reported separately in the reporting formats CRF and NFR. The emission source *1A4* also includes non-road machinery and for greenhouse gases the stationary and mobile emissions have been reported aggregated in the CRF, while the reporting is separate in the NFR.

The subsector 1A1c in the Danish inventory covers emissions from the energy use in connection with the extraction of oil and gas (off shore gas turbines) and the emission from energy use in processing of natural gas onshore.

The emission and fuel consumption data included in tables and figures in this report only include emissions originating from stationary combustion plants of a given CRF/NFR source category. The CRF source category codes have been applied unchanged, but some source category names have been changed to reflect the stationary combustion element of the source.

In the Danish emission database, all activity rates and emissions are defined in SNAP sector categories (Selected Nomenclature for Air Pollution) according the CORINAIR system. The emission inventories are prepared from a complete emission database based on the SNAP source categories. DCE - Danish Centre for Environment and Energy, Aarhus University has modified the SNAP categorisation to enable direct reporting of the disaggregated data for manufacturing industries and construction. Aggregation to the CRF source category codes is based on a correspondence list enclosed in Annex 1. Stationary combustion is defined as combustion activities in the SNAP sectors 01 – 03, not including SNAP 0303.

The CO_2 emission from calcination processes, e.g. in cement and lime production, is not part of the source category *Energy*. This emission is included in the source category *Industrial Processes*.

A list of CRF/NFR subsectors is shown below.

1A1a	Electricity and heat production
1A1b	Petroleum refining
1A1c	Other energy industries
1A2a	Iron and steel
1A2b	Non-ferrous metals
1A2c	Chemicals
1A2d	Pulp, paper and print
1A2e	Food processing, beverages and tobacco
1A2f i	Industry-Other
1A4a i	Commercial/Institutional plants
1A4b i	Residential plants
1A4c i	Agriculture/forestry/fishing, stationary

1.3 Emission share from stationary combustion

Table 5 gives an overview of the emission share from stationary combustion compared to national total. Main emission sources are discussed in Chapter 3 and 4.

Table 5 Emission share from stationary combustion compared to national total, 2011.

Pollutant	Emission share, %
GHG	48
CO_2	60
CH_4	6
N_2O	3
SO_2	65
NO_x	29
NMVOC	20
CO	37
NH_3	0.3
TSP	49
PM_{10}	59
$PM_{2.5}$	73
As	76
Cd	60
Cr	45
Cu	2
Hg	84
Ni	47
Pb	26
Se	75
Zn	16
HCB	98
PCDD/F	71
Benzo(a)pyrene	95
Benzo(b)fluoranthene	94
Benzo(k)fluoranthene	92
Indeno(123cd)pyrene	93

1.4 Key Categories for GHGs

For greenhouse gases, a key category analysis is reported each year. Key category analysis points out main emission sources for which higher tier methodologies are required (IPCC, 2006).

Two key category analysis are included; tier 1 and tier 2. The tier 1 analysis points out the emission source categories that add up to 95 % of the total national emission of greenhouse gases. The tier 2 approach includes uncertainties for each emission source category and points out the main sources of uncertainty in the national emission inventory for greenhouse gases.

Key Category Analysis (KCA) tier 1 and 2 for year 1990, 2011 and trend for Denmark has been carried out in accordance with the IPCC Good Practice Guidance / IPCC Guidelines (2006). The results (for stationary combustion) of the KCA are shown in Table 6. The table is based on the analysis including LULUCF. Detailed key category analysis is shown in Nielsen et al. (2013a)[7].

The CO_2 emissions from stationary combustion are key for all the major fuels. In addition, the CH_4 emission from natural gas fuelled engines and biomass are also key. Finally, due to the relatively high uncertainty for N_2O emission factors, the N_2O emission from all five fuel categories are also key categories in the tier 2 analysis.

[7] Niensen et al. (2013), Chapter 1.5 and Annex 1

Table 6 Result of the key category analysis, stationary combustion.

			Tier 1			Tier 2		
			1990	2011	1990-2011	1990	2011	1990-2011
Energy	Stationary Combustion, Coal	CO_2	Level	Level	Trend	Level	Level	Trend
Energy	Stationary Combustion, brown coal briquettes	CO_2						
Energy	Stationary Combustion, Coke	CO_2						
Energy	Stationary Combustion, Fossil waste	CO_2	Level	Level	Trend		Level	Trend
Energy	Stationary Combustion, Petroleum coke	CO_2	Level	Level	Trend			
Energy	Stationary Combustion, Residual oil	CO_2	Level	Level	Trend			
Energy	Stationary Combustion, Gas oil	CO_2	Level	Level	Trend	Level		Trend
Energy	Stationary Combustion, Kerosene	CO_2	Level		Trend			
Energy	Stationary Combustion, LPG	CO_2						
Energy	Stationary Combustion, Refinery gas	CO_2	Level	Level	Trend			
Energy	Stationary Combustion, Natural gas	CO_2	Level	Level	Trend		Level	Trend
Energy	Stationary Combustion, SOLID	CH_4						
Energy	Stationary Combustion, LIQUID	CH_4						
Energy	Stationary Combustion, GAS	CH_4						
Energy	Natural gas fuelled engines, GAS	CH_4			Trend			
Energy	Stationary Combustion, WASTE	CH_4						
Energy	Stationary Combustion, BIOMASS	CH_4					Level	Trend
Energy	Biogas fuelled engines, BIOMASS	CH_4						
Energy	Stationary Combustion, SOLID	N_2O				Level	Level	Trend
Energy	Stationary Combustion, LIQUID	N_2O				Level	Level	Trend
Energy	Stationary Combustion, GAS	N_2O					Level	Trend
Energy	Stationary Combustion, WASTE	N_2O						Trend
Energy	Stationary Combustion, BIOMASS	N_2O				Level	Level	Trend

2 Fuel consumption data

In 2011, the total fuel consumption for stationary combustion plants was 478 PJ of which 354 PJ was fossil fuels and 124 PJ was biomass.

Fuel consumption distributed according to the stationary combustion subcategories is shown in Figure 1 and Figure 2. The majority - 60 % - of all fuels is combusted in the source category, *Public electricity and heat production.* Other source categories with high fuel consumption are *Residential* and *Industry*.

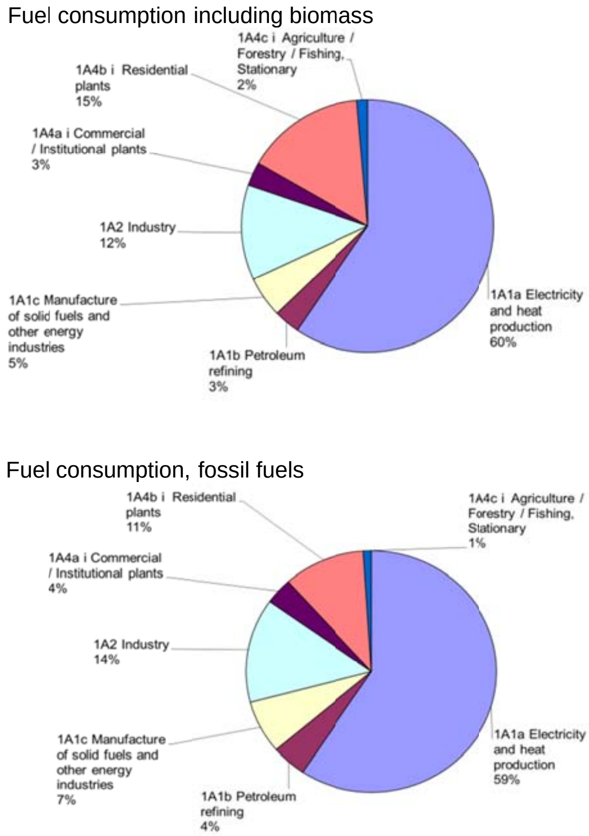


Figure 1 Fuel consumption of stationary combustion source categories, 2011. Based on DEA (2012a).

Coal and natural gas are the most utilised fuels for stationary combustion plants. Coal is mainly used in power plants and natural gas is used in power plants and decentralised combined heat and power (CHP) plants, as well as in industry, district heating, residential plants, and offshore gas turbines (see Figure 2).

Detailed fuel consumption rates are shown in Annex 2.

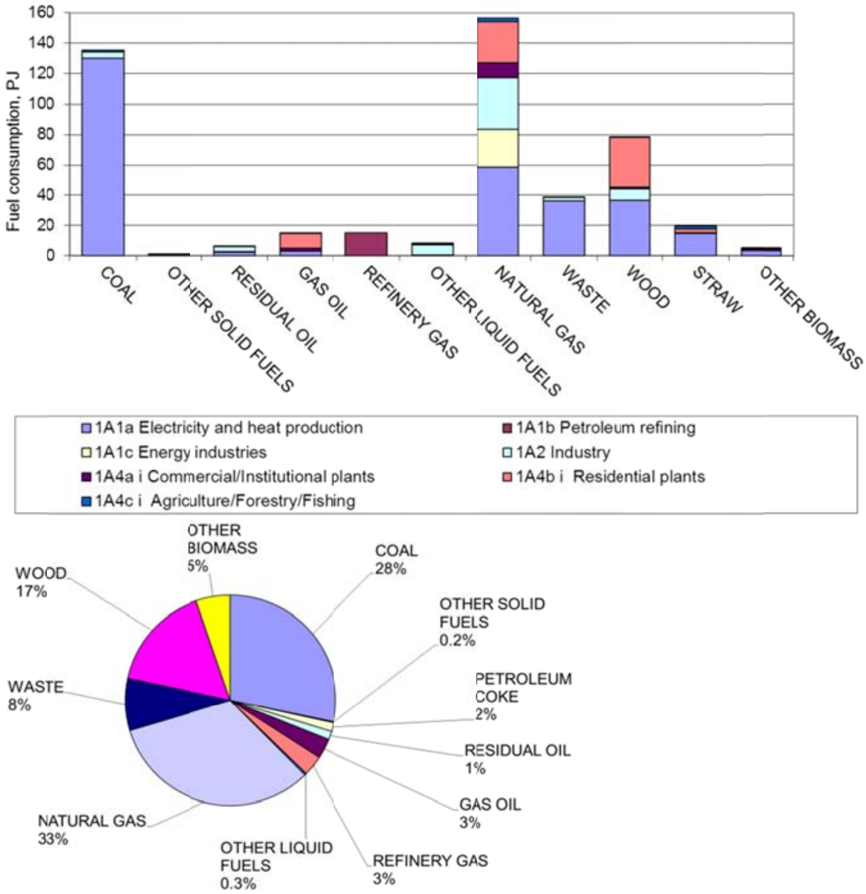


Figure 2 Fuel consumption of stationary combustion 2011, disaggregated to fuel type. Based on DEA (2012a).

Fuel consumption time series for stationary combustion plants are presented in Figure 3. The fuel consumption for stationary combustion was 4 % lower in 2011 than in 1990, while the fossil fuel consumption was 23 % lower and the biomass fuel consumption 3.1 times the level in 1990.

The consumption of natural gas and biomass has increased since 1990 whereas coal consumption has decreased.

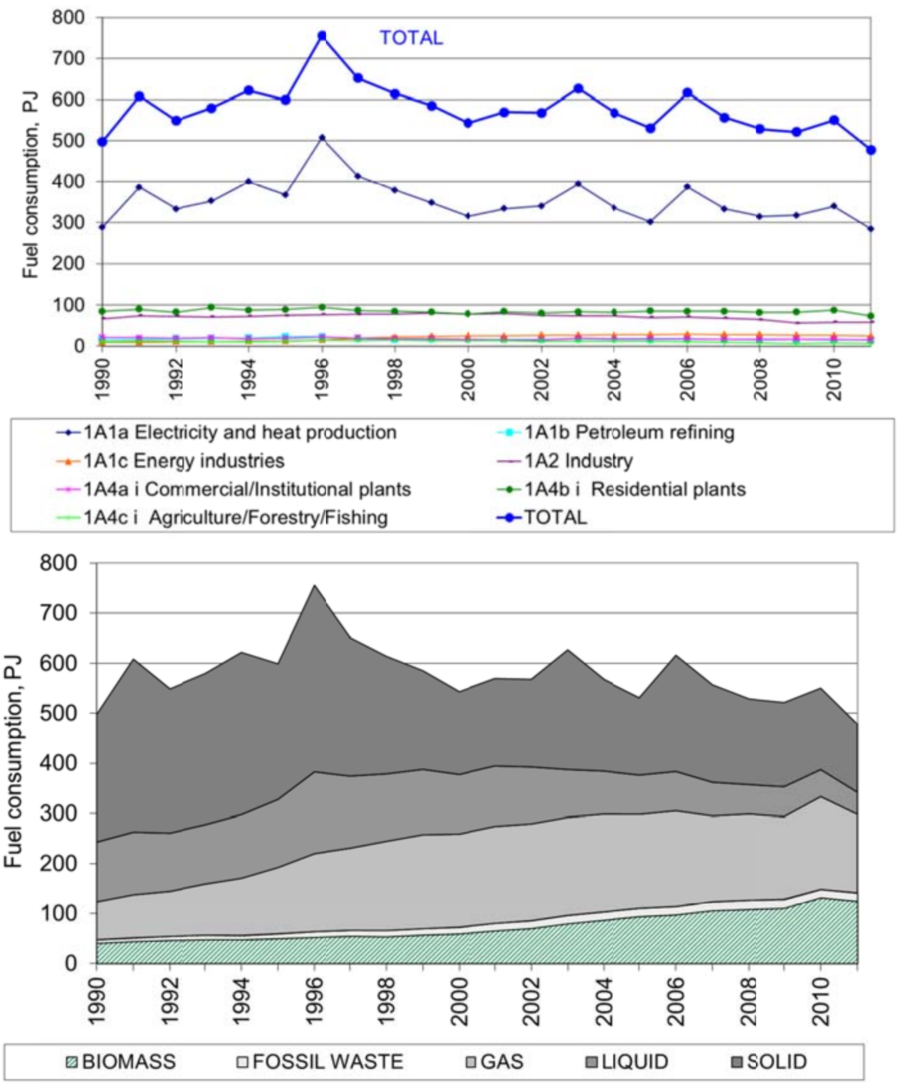


Figure 3 Fuel consumption time series, stationary combustion. Based on DEA (2012a).

The fluctuations in the time series for fuel consumption are mainly a result of electricity import/export, but also of outdoor temperature variations from year to year. This, in turn, leads to fluctuations in emission levels. The fluctuations in electricity trade, fuel consumption, CO_2 and NO_x emission are illustrated and compared in Figure 4. In 1990, the Danish electricity import was large causing relatively low fuel consumption, whereas the fuel consumption was high in 1996 due to a large electricity export. In 2011, the net electricity import was 4.7 PJ, whereas there was a 4.1 PJ electricity export in 2010. The large electricity export that occurs some years is a result of low rainfall in Norway and Sweden causing insufficient hydropower production in both countries.

To be able to follow the national energy consumption as well as for statistical and reporting purposes, the Danish Energy Agency (DEA) produces a correction of the actual fuel consumption and CO_2 emission without variations in electricity imports/exports and in ambient temperature. This fuel consumption trend is also illustrated in Figure 4. The corrections are included here to explain the fluctuations in the time series for fuel rate and emission.

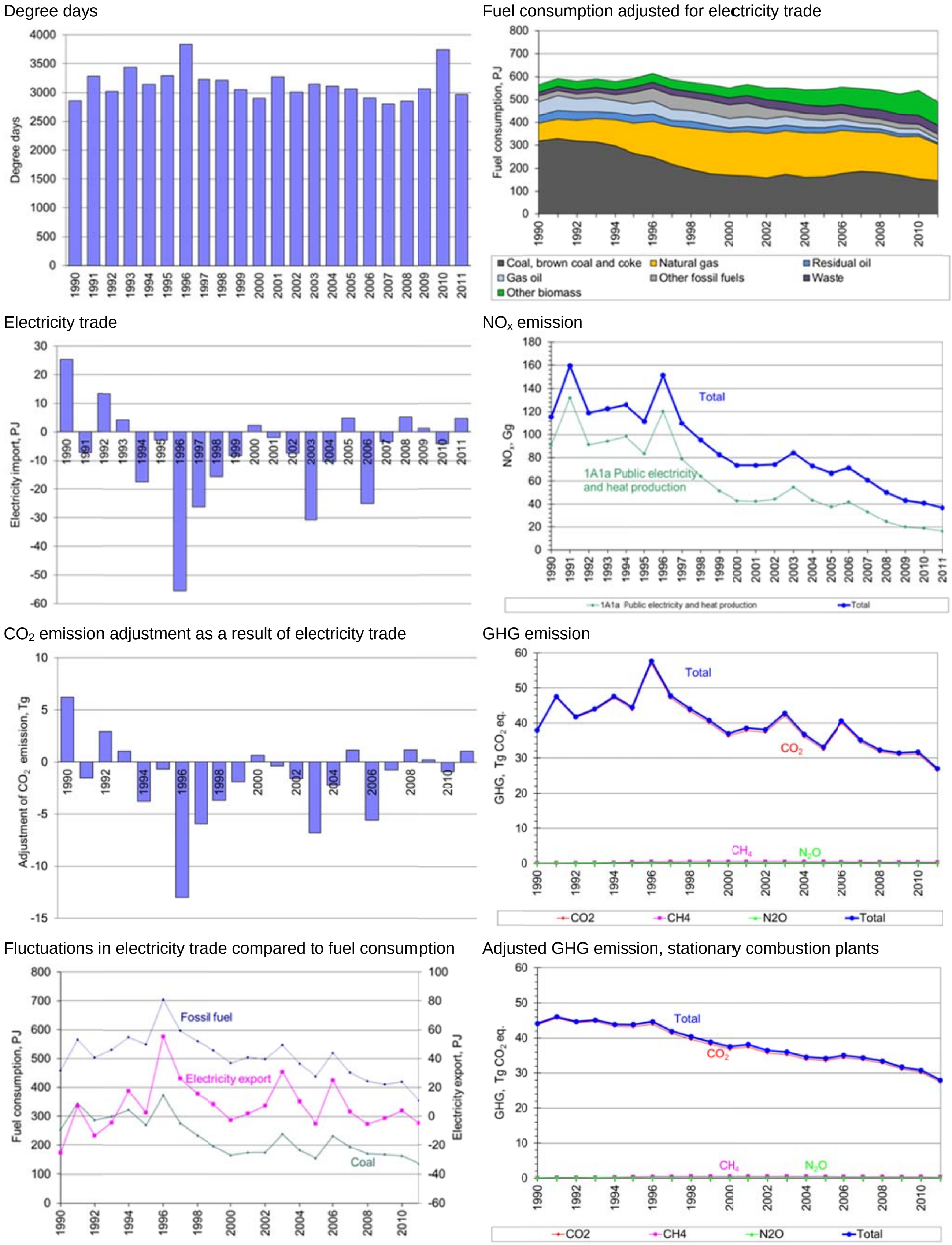


Figure 4 Comparison of time series fluctuations for electricity trade, fuel consumption, CO_2 emission and NO_x emission. Based on DEA (2012a) and DEA (2012d).

Fuel consumption time series for the subcategories to stationary combustion are shown in Figure 5, Figure 6 and Figure 7.

Fuel consumption for *Energy Industries* fluctuates due to electricity trade as discussed above. The fuel consumption in 2011 was 4 % higher than in 1990. The fluctuation in electricity production is based on fossil fuel consumption in the subcategory *Electricity and Heat Production*. The energy consumption in *Other energy industries* is mainly natural gas used in gas turbines in the off-shore industry. The biomass fuel consumption in *Energy Industries* 2011 added up to 75 PJ, which is 4.6 times the level in 1990 and a 5 % decrease since 2010.

The fuel consumption in *Industry* was 13 % lower in 2011 than in 1990 (Figure 6). The fuel consumption in industrial plants decreased considerably from 2007-2009 as a result of the financial crisis. However, the fuel consumption is stabile since 2010. The biomass fuel consumption in *Industry* in 2011 added up to 9 PJ which is a 45 % increase since 1990.

The fuel consumption in *Other Sectors* has decreased by 20% since 1990 and decreased 16 % from 2010 to 2011 (Figure 7). The large decrease from 2010 to 2011 is caused by higher temperature in the winter season of 2011. The biomass fuel consumption in *Other sectors* in 2011 added up to 41 PJ which is 2.2 times the consumption in 1990 and a 9 % decrease since 2010. Wood consumption in residential plants in 2011 was 2.3 times the consumption in year 2000.

Time series for subcategories are shown in Chapter 5.

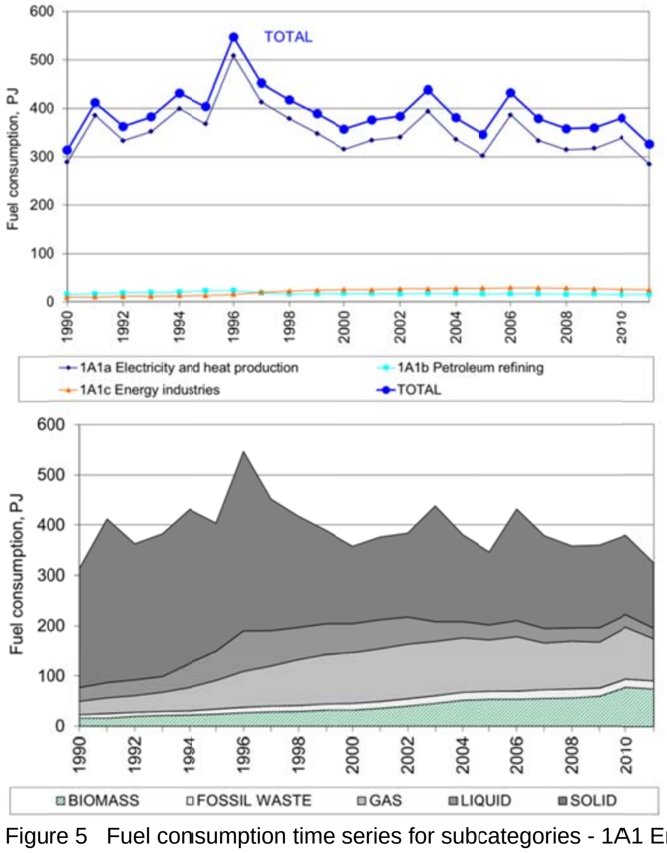


Figure 5 Fuel consumption time series for subcategories - 1A1 Energy Industries.

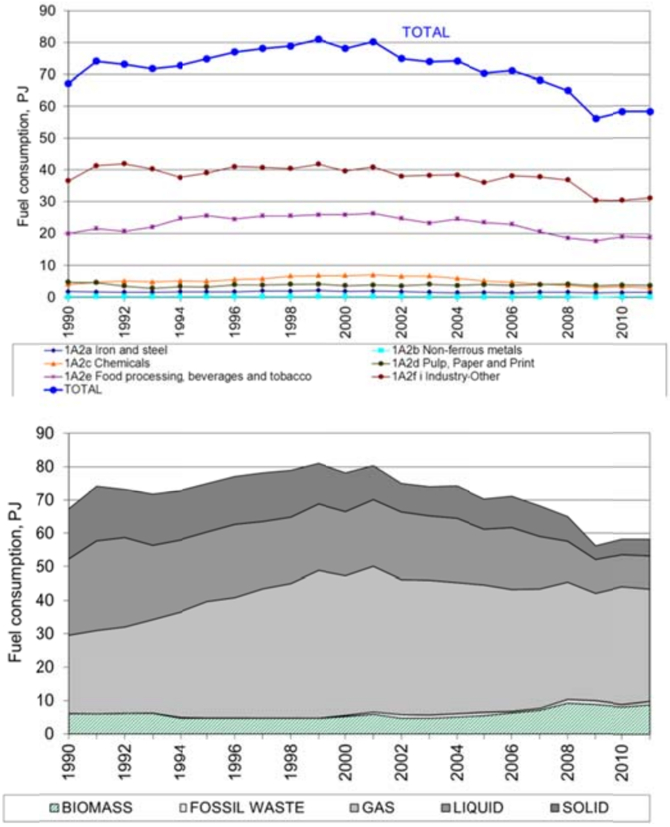


Figure 6 Fuel consumption time series for subcategories - 1A2 Industry.

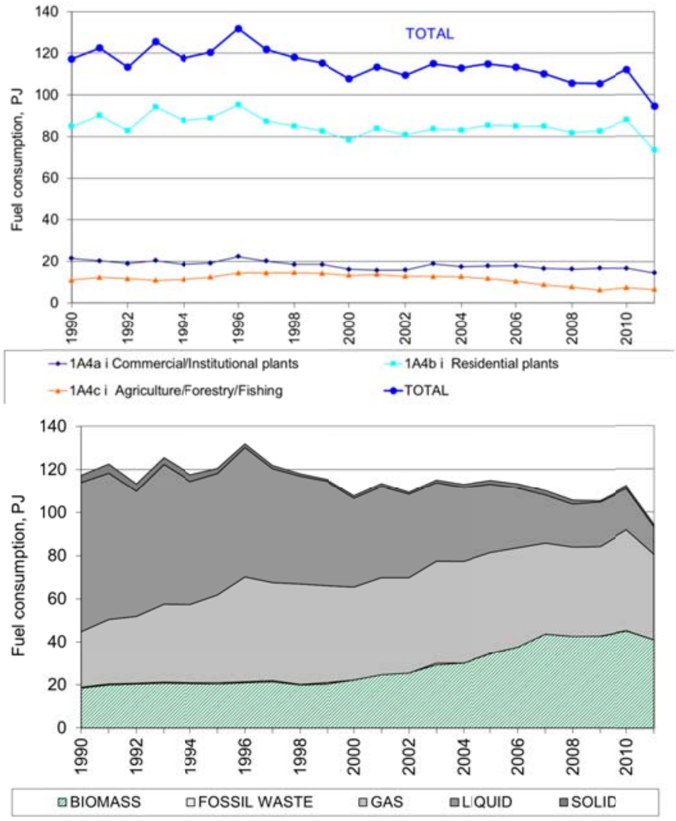


Figure 7 Fuel consumption time series for subcategories - 1A4 Other Sectors.

3 Emission of greenhouse gases

The greenhouse gas emissions from stationary combustion are listed in Table 7. The emission from stationary combustion accounted for 48 % of the national greenhouse gas emission (excluding LULUCF) in 2011.

The CO_2 emission from stationary combustion plants accounts for 60 % of the national CO_2 emission (excluding LULUCF). The CH_4 emission accounts for 6 % of the national CH_4 emission and the N_2O emission for 3 % of the national N_2O emission.

Table 7 Greenhouse gas emission, 2011[1).]

	CO_2	CH_4	N_2O
	Gg CO_2 equivalent		
1A1 Fuel Combustion, Energy industries	19738	196	96
1A2 Fuel Combustion, Manufacturing Industries and Construction[1)]	3350	12	22
1A4 Fuel Combustion, Other sectors [1)]	3304	143	61
Emission from stationary combustion plants	26393	351	179
Emission share for stationary combustion	60%	6%	3%

[1)] Only stationary combustion sources of the category is included.

CO_2 is the most important greenhouse gas accounting for 98.0 % of the greenhouse gas emission (CO_2 eq.) from stationary combustion. CH_4 accounts for 1.3 % and N_2O for 0.7 % of the greenhouse gas emission (CO_2 eq.) from stationary combustion (Figure 8).

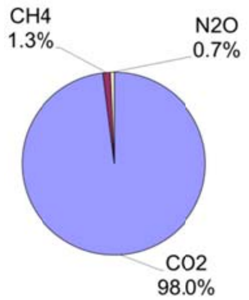


Figure 8 Stationary combustion - Greenhouse gas emission (CO_2 equivalent), contribution from each pollutant.

Figure 9 shows the time series of greenhouse gas emission (CO_2 eq.) from stationary combustion. The total greenhouse gas emission development follows the CO_2 emission development very closely. Both the CO_2 and the total greenhouse gas emission are lower in 2011 than in 1990, CO_2 by 30 % and total greenhouse gases by 29 %. However, fluctuations in the GHG emission level are large.

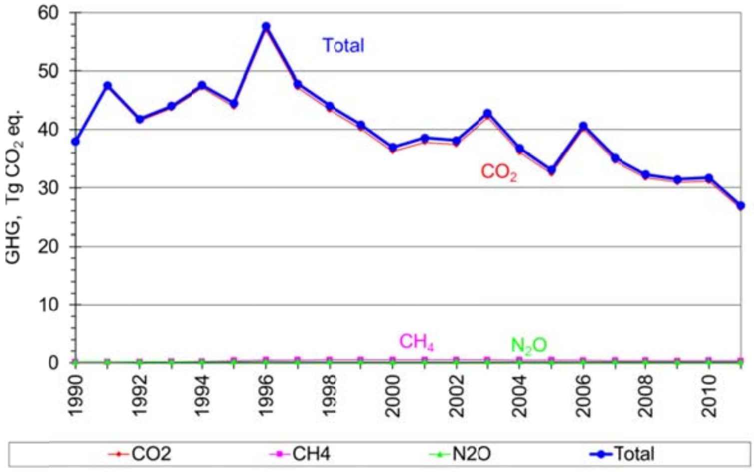


Figure 9 GHG emission time series for stationary combustion.

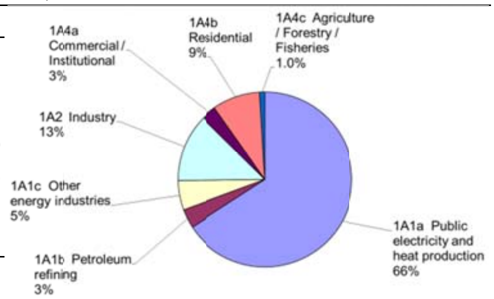
The fluctuations in the time series are largely a result of electricity import/export, but also of outdoor temperature variations from year to year. The fluctuations follow the fluctuations in fuel consumption discussed in Chapter 2. As mentioned in Chapter 2, the Danish Energy Agency estimates a correction of the actual CO_2 emission without variations in electricity imports/exports and in ambient temperature. The total greenhouse gas emission corrected for electricity import/export and ambient temperature has decreased by 36.6 % since 1990, and the CO_2 emission by 37.4 %. These data are included here to explain the fluctuations in the emission time series.

3.1 CO_2 emission

The carbon dioxide (CO_2) emission from stationary combustion plants is one of the most important sources of greenhouse gas emissions. Thus, the CO_2 emission from stationary combustion plants accounts for 60 % of the national CO_2 emission. Table 8 lists the CO_2 emission inventory for stationary combustion plants for 2011. *Electricity and heat production* accounts for 66 % of the CO_2 emission from stationary combustion. This share is somewhat higher than the fossil fuel consumption share for this category, which is 60 % (Figure 1). This is due to a large share of coal in this category. Other relatively large CO_2 emission sources are *Industry* and *Residential* plants. These are the source categories, which also account for a considerable share of fuel consumption.

Table 8 CO_2 emission from stationary combustion plants, 2011[1)].

		CO_2 Gg
1A1a	Public electricity and heat production	17369
1A1b	Petroleum refining	931
1A1c	Other energy industries	1438
1A2	Industry	3350
1A4a	Commercial/Institutional	745
1A4b	Residential	2307
1A4c	Agriculture/forestry/fisheries	252
Total		26393

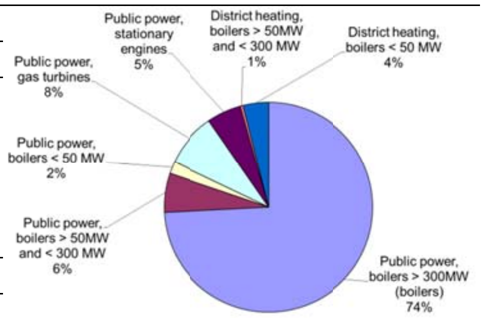


1) Only emission from stationary combustion plants in the categories is included.

In the Danish inventory, the source category *Electricity and heat production* is further disaggregated. The CO_2 emission from each of the subcategories is shown in Table 9. The largest subcategory is power plant boilers >300MW.

Table 9 CO_2 emission from subcategories to 1A1a Electricity and heat production.

SNAP	SNAP name	CO_2, Gg
0101	**Public power**	
010101	Combustion plants ≥ 300MW (boilers)	12886
010102	Combustion plants ≥ 50MW and < 300 MW (boilers)	1052
010103	Combustion plants <50 MW (boilers)	330
010104	Gas turbines	1438
010105	Stationary engines	913
0102	**District heating plants**	
010202	Combustion plants ≥ 50MW and < 300 MW (boilers)	73
010203	Combustion plants <50 MW (boilers)	675



CO_2 emissions from combustion of biomass fuels are not included in the total CO_2 emission data, because biomass fuels are considered CO_2 neutral. The total CO_2 emission from biomass combustion is reported as a memo item in the Climate Convention reporting. In 2011, the CO_2 emission from biomass combustion was 14 085 Gg.

In Figure 10, the fuel consumption share (fossil fuels) is compared to the CO_2 emission share disaggregated to fuel origin. Due to the higher CO_2 emission factor for coal than oil and gas, the CO_2 emission share from coal combustion is higher than the fuel consumption share. Coal accounts for 38 % of the fossil fuel consumption and for 49 % of the CO_2 emission. Natural gas accounts for 44 % of the fossil fuel consumption but only 34 % of the CO_2 emission.

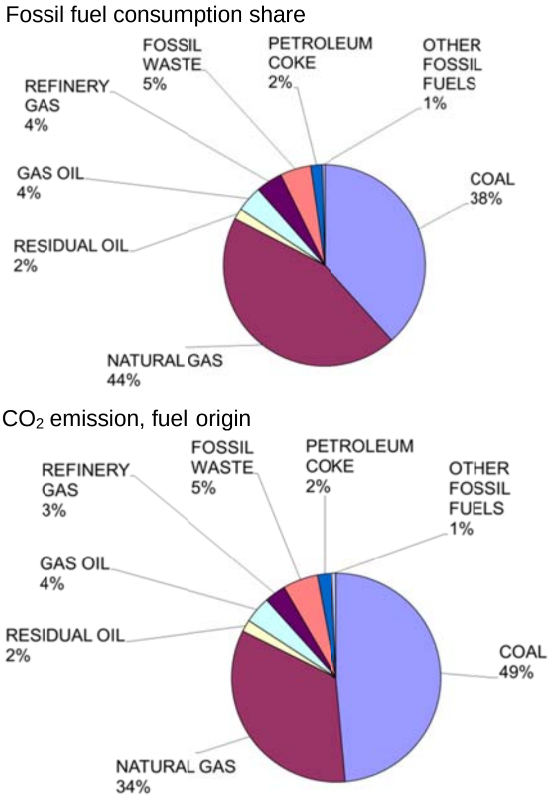


Figure 10 CO_2 emission, fuel origin.

The time series for CO_2 emission is provided in Figure 11. Despite a decrease in fuel consumption of 4 %[8] since 1990, the CO_2 emission from stationary combustion has decreased by 30 % because of the change of fuel type used.

The fluctuations in the total CO_2 emission follow the fluctuations in the CO_2 emission from *Electricity and heat production* (Figure 11) and in coal consumption (Figure 4). The fluctuations are a result of electricity import/export as discussed in Chapter 2.

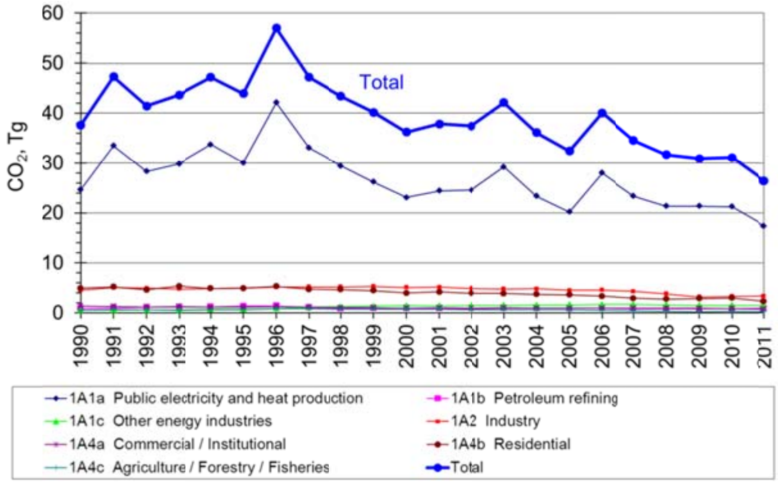


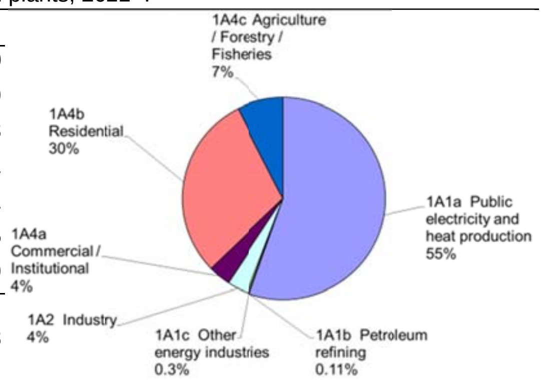
Figure 11 CO_2 emission time series for stationary combustion plants.

3.2 CH_4 emission

The methane (CH_4) emission from stationary combustion plants accounts for 6 % of the national CH_4 emission. The CO_2 equivalence factor for CH_4 is 21. Table 10 lists the CH_4 emission inventory for stationary combustion plants in 2011. *Electricity and heat production* accounts for 55 % of the CH_4 emission from stationary combustion. The emission from residential plants adds up to 30 % of the emission.

Table 10 CH_4 emission from stationary combustion plants, 2011[1)].

	CH_4 Mg
1A1a Public electricity and heat production	9260
1A1b Petroleum refining	19
1A1c Other energy industries	43
1A2 Industry	581
1A4a Commercial/Institutional	591
1A4b Residential	4975
1A4c Agriculture/forestry/fisheries	1249
Total	16718



1) Only emission from stationary combustion plants in the source categories is included.

The CH_4 emission factor for reciprocating gas engines is much higher than for other combustion plants due to the continuous ignition/burn-out of the gas. Lean-burn gas engines have an especially high emission factor. A considerable number of lean-burn gas engines are in operation in Denmark and in 2011, these plants accounted for 62 % of the CH_4 emission from stationary combustion plants (Figure 12). Most engines are installed in CHP plants and

[8] The consumption of fossil fuels has decreased 23 %.

the fuel used is either natural gas or biogas. Residential wood combustion is also a large emission source accounting for 21 % of the emission in 2011.

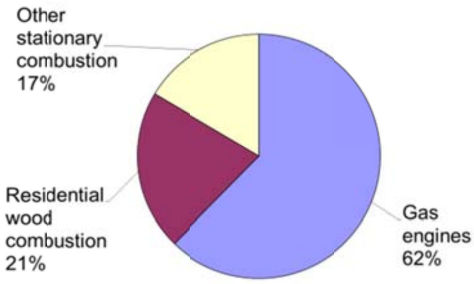


Figure 12 CH_4 emission share for gas engines and residential wood combustion, 2011.

Figure 13 shows the time series for the CH_4 emission. The CH_4 emission from stationary combustion has increased by a factor of 2.9 since 1990. This results from the considerable number of lean-burn gas engines installed in CHP plants in Denmark during the 1990s. Figure 14 provides time series for the fuel consumption rate in gas engines and the corresponding increase of CH_4 emission. The decline in later years is due to liberalisation of the Danish electricity market, which means that the fuel consumption in gas engines has been decreasing.

The CH_4 emission from residential plants has increased since 1990 due to increased combustion of biomass in residential plants. Combustion of wood accounted for 71 % of the CH_4 emission from residential plants in 2011.

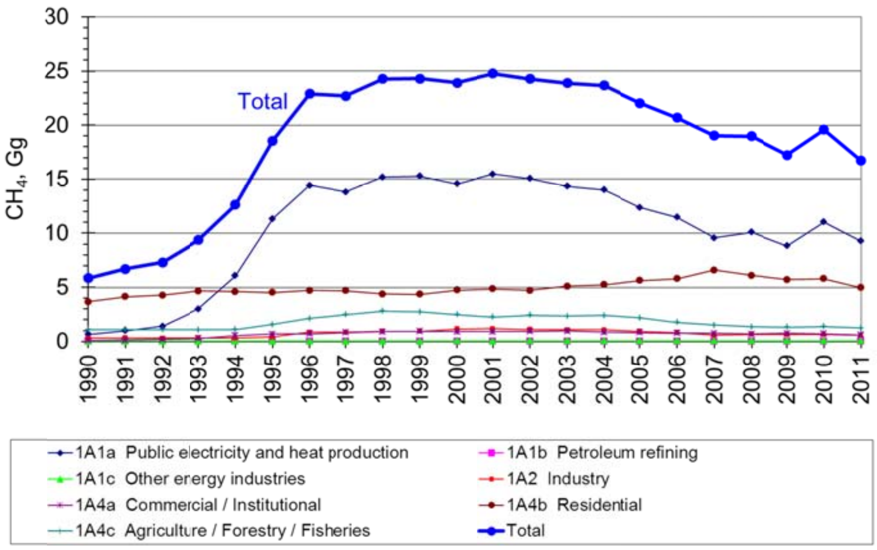


Figure 13 CH_4 emission time series for stationary combustion plants.

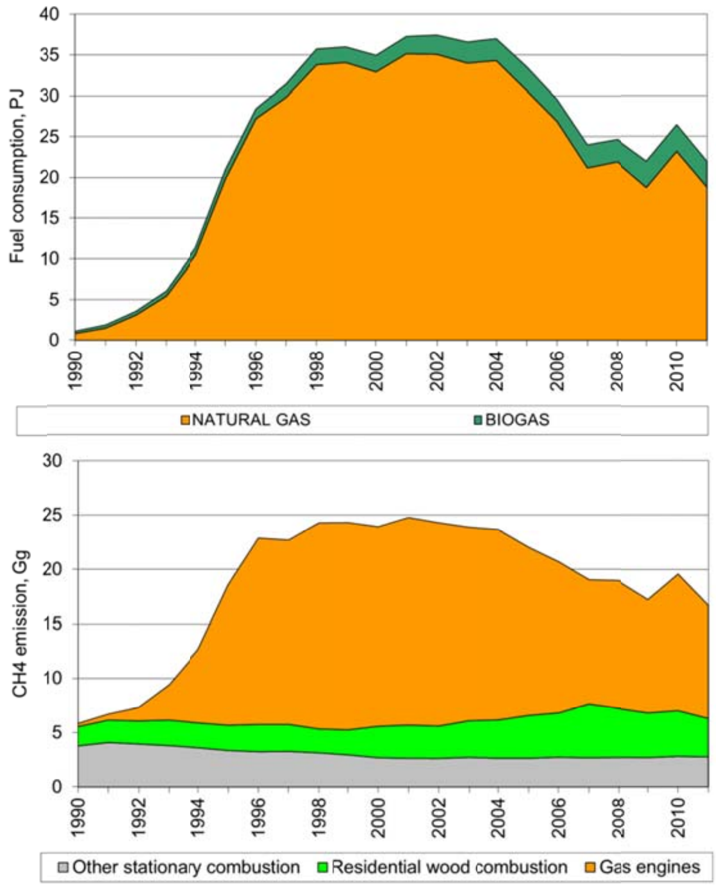


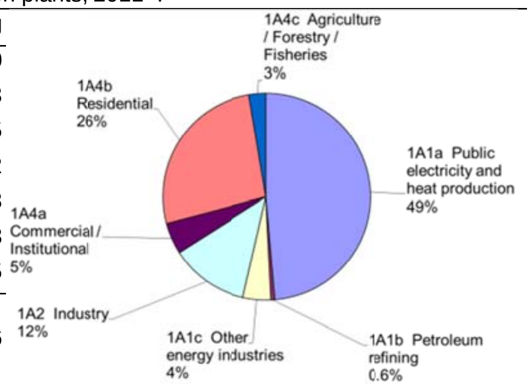
Figure 14 Time series for a) fuel consumption in gas engines and b) CH_4 emission from gas engines, residential wood combustion and other plants.

3.3 N_2O emission

The nitrous oxide (N_2O) emission from stationary combustion plants accounts for 3 % of the national N_2O emission. The CO_2 equivalence factor for N_2O is 310. Table 11 lists the N_2O emission inventory for stationary combustion plants in the year 2011. *Electricity and heat production* accounts for 49 % of the N_2O emission from stationary combustion.

Table 11 N_2O emission from stationary combustion plants, 2011[1)].

	N_2O Mg
1A1a Public electricity and heat production	280
1A1b Petroleum refining	3
1A1c Other energy industries	25
1A2 Industry	72
1A4a Commercial/Institutional	28
1A4b Residential	153
1A4c Agriculture/forestry/fisheries	15
Total	576



1) Only emission from stationary combustion plants in the source categories is included.

Figure 15 shows the time series for the N_2O emission. The N_2O emission from stationary combustion has increased by 4 % from 1990 to 2011, but again fluctuations in the emission level due to electricity import/export are considerable.

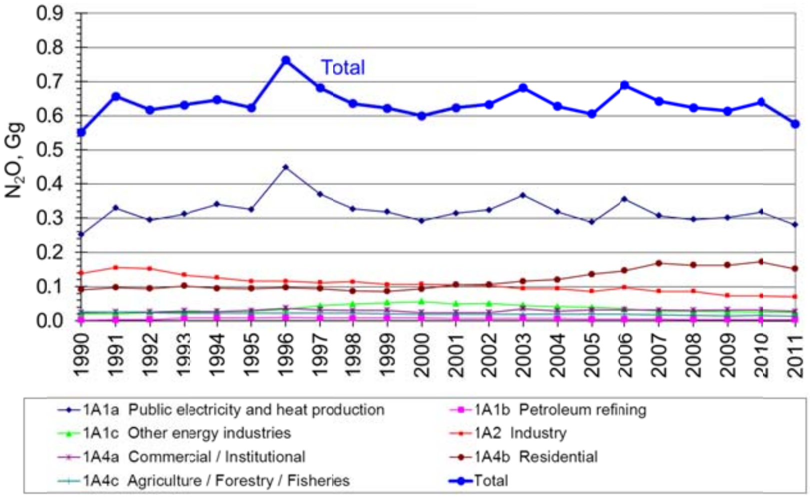


Figure 15 N_2O emission time series for stationary combustion plants.

4 Emission of other pollutants

The emissions of sulphur dioxide (SO_2), nitrogen oxides (NO_x), non-volatile organic compounds (NMVOC) and carbon monoxide (CO) from Danish stationary combustion plants 2011 are presented in Table 12.

SO_2 from stationary combustion plants accounts for 65 % of the national emission. NO_x, CO and NMVOC account for 29 %, 37 % and 20 % of national emissions, respectively.

Table 12 SO_2, NO_x, NMVOC and CO emission, 2011[1)].

Pollutant	NO_x Gg	CO Gg	NMVOC Gg	SO_2 Gg
1A1 Fuel consumption, Energy industries	24.1	10.9	2.1	3.1
1A2 Fuel consumption, Manufacturing Industries and Construction[1)]	5.6	3.8	0.3	3.3
1A4 Fuel consumption, Other sectors[1)]	7.0	125.1	13.6	2.6
Emission from stationary combustion plants	36.7	139.8	15.9	9.0
Emission share for stationary combustion, %	29	37	20	65

1) Only emissions from stationary combustion plants in the source categories are included.

4.1 SO_2

Stationary combustion is the most important emission source for SO_2 accounting for 65 % of the national emission. Table 13 presents the SO_2 emission inventory for the stationary combustion subcategories.

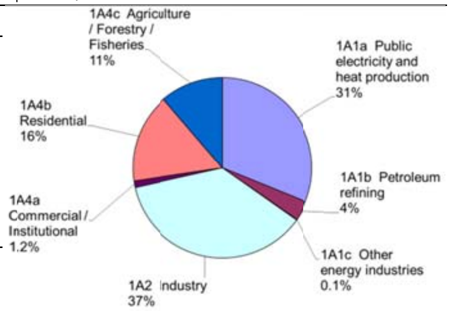
Electricity and heat production is the largest emission source accounting for 31 % of the emission. However, the SO_2 emission share is lower than the fuel consumption share for this source category, which is 60 %. This is a result of effective flue gas desulphurisation equipment installed in power plants combusting coal. In the Danish inventory, the source category *Electricity and heat production* is further disaggregated. Figure 16 shows the SO_2 emission from *Electricity and heat production* on a disaggregated level. Power plants >300MW_{th} are the main emission source, accounting for 45 % of the emission.

The SO_2 emission from combustion in industrial plants accounts for 37 %, a remarkably high emission share compared with the fuel consumption share. The main emission sources in the industrial category are combustion of coal and residual oil without flue gas desulphurisation, but emissions from the cement industry are also a considerable emission source. Some industries are given a basic deduction of the sulphur tax (DMT, 2012). The EU Directive on Industrial Emissions will result in lower emission limits for some industries. Ten years ago SO_2 emissions from the industrial category only accounted for a small part of the emission from stationary combustion, but as a result of reduced emissions from power plants the share has now increased.

The time series for the SO_2 emission from stationary combustion is shown in Figure 17. The SO_2 emission from stationary combustion plants has decreased by 94 % since 1990. The large emission decrease is mainly a result of the reduced emission from *Electricity and heat production*, made possible due to installation of desulphurisation units and due to the use of fuels with lower sulphur content. Despite the considerable reduction in the emission from electricity and heat production plants, these still account for 31 % of the emission from stationary combustion, as mentioned above. The emission from other source categories also decreased considerably since 1990. Time series for subcategories are shown in Chapter 5.

Table 13 SO_2 emission from stationary combustion plants, 2011[1)].

	SO_2, Mg
1A1a Public electricity and heat production	2807
1A1b Petroleum refining	321
1A1c Other energy industries	8
1A2 Industry	3297
1A4a Commercial/Institutional	107
1A4b Residential	1452
1A4c Agriculture/forestry/fisheries	1010
Total	9002



[1)] Only emission from stationary combustion plants in the source categories is included.

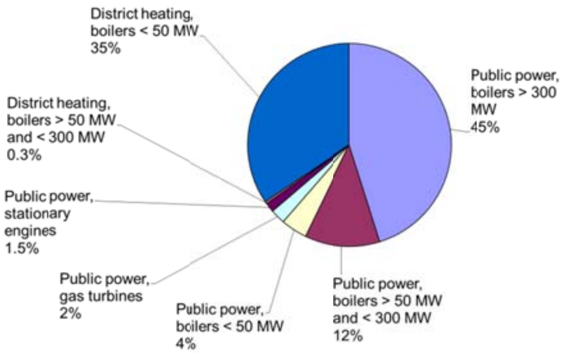


Figure 16 Disaggregated SO_2 emissions from 1A1a Energy and heat production.

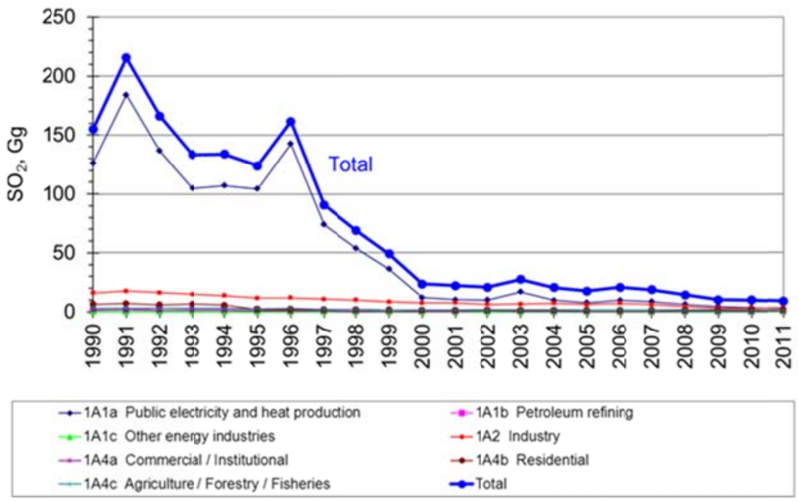


Figure 17 SO_2 emission time series for stationary combustion.

4.2 NO_x

Stationary combustion accounts for 29 % of the national NO_x emission. Table 14 shows the NO_x emission inventory for stationary combustion subcategories.

Electricity and heat production is the largest emission source accounting for 44 % of the emission from stationary combustion plants. The emission from public power boilers > 300 MWth accounts for 29 % of the emission in this subcategory.

Industrial combustion plants are also an important emission source accounting for 15 % of the emission. The main industrial emission source is cement production, which accounts for 35 % of the emission.

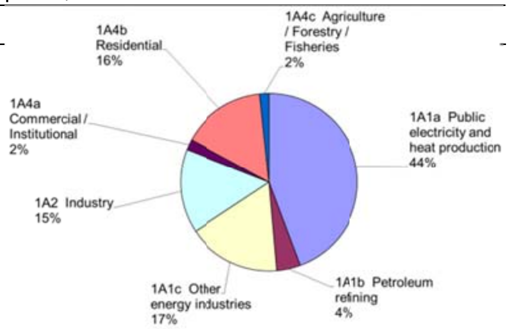
Residential plants account for 16 % of the NO_x emission. The fuel origin of this emission is mainly wood accounting for 70 % of the emission from residential plants.

Other energy industries, which is mainly off-shore gas turbines accounts for 17 % of the NO_x emission.

Time series for NO_x emission from stationary combustion are shown in Figure 18. The NO_x emission from stationary combustion plants has decreased by 68 % since 1990. The reduced emission is largely a result of the reduced emission from electricity and heat production due to installation of low NO_x burners, selective catalytic reduction (SCR) units and selective non-catalytic reduction (SNCR) units. The fluctuations in the time series follow the fluctuations in electricity and heat production, which, in turn, result from electricity trade fluctuations.

Table 14 NO_x emission from stationary combustion plants, 2011[1)].

	NO_x, Mg
1A1a Public electricity and heat production	16295
1A1b Petroleum refining	1571
1A1c Other energy industries	6259
1A2 Industry	5636
1A4a Commercial/Institutional	716
1A4b Residential	5658
1A4c Agriculture/forestry/fisheries	613
Total	36748



1) Only emission from stationary combustion plants in the source categories is included.

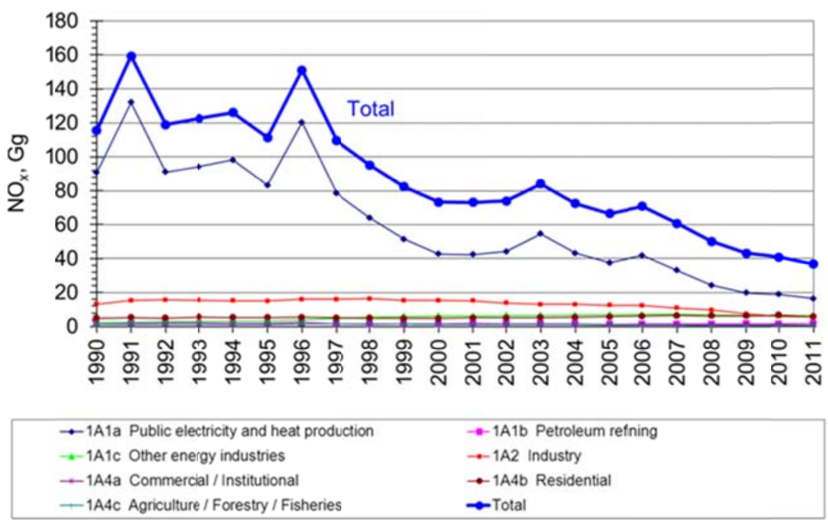


Figure 18 NO_x emission time series for stationary combustion.

4.3 NMVOC

Stationary combustion plants account for 20 % of the national NMVOC emission. Table 15 presents the NMVOC emission inventory for the stationary combustion subcategories.

Residential plants are the largest emission source accounting for 81 % of the emission from stationary combustion plants. For residential plants NMVOC is mainly emitted from wood and straw combustion, see Figure 19.

Electricity and heat production is also a considerable emission source, accounting for 13 % of the emission. Lean-burn gas engines have a relatively high NMVOC emission factor and are the most important emission source in this subcategory (see Figure 19). The gas engines are either natural gas or biogas fuelled.

Time series for NMVOC emission from stationary combustion are shown in Figure 20. The emission has increased by 14 % from 1990. The increased emission is mainly a result of the increasing wood consumption in residential plants and of the increased use of lean-burn gas engines in CHP plants.

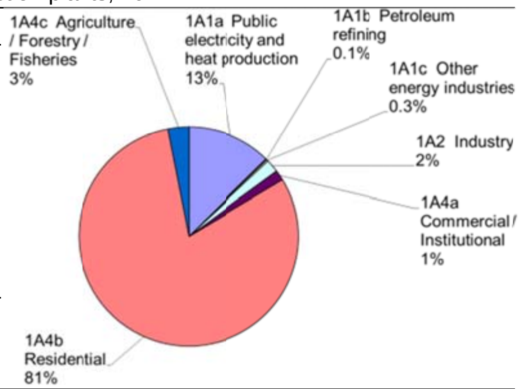
The emission from residential plants increased 12 % since 1990. The NMVOC emission from wood combustion in 2011 was 2.2 times the 1990 level due to increased wood consumption. However, the emission factor has decreased since 1990 due to installation of modern stoves and boilers with improved combustion technology. Further the emission from straw combustion in farmhouse boilers has decreased (75 %) over this period due to both a decreasing emission factor and decrease in straw consumption in this source category.

The use of wood in residential boilers and stoves was relatively low in 1998-99 resulting in a lower emission level.

The consumption of wood in residential plants peaked in 2007. The improved technology that has been implemented in residential wood combustion have led to lower emission factors and thus decreasing NMVOC emission since 2007.

Table 15 NMVOC emission from stationary combustion plants, 2011[1)].

	NMVOC Mg
1A1a Public electricity and heat production	1998
1A1b Petroleum refining	22
1A1c Other energy industries	40
1A2 Industry	305
1A4a Commercial/Institutional	242
1A4b Residential	12830
1A4c Agriculture/forestry/fisheries	491
Total	15930



1) Only emission from stationary combustion plants in the categories is included.

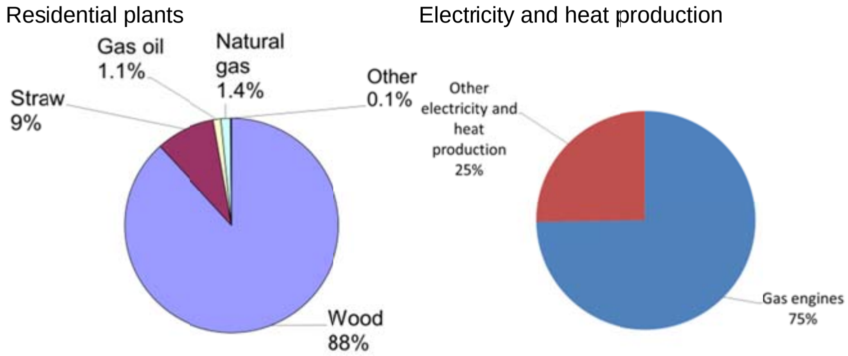


Figure 19 NMVOC emission from Residential plants and from Electricity and heat production, 2011.

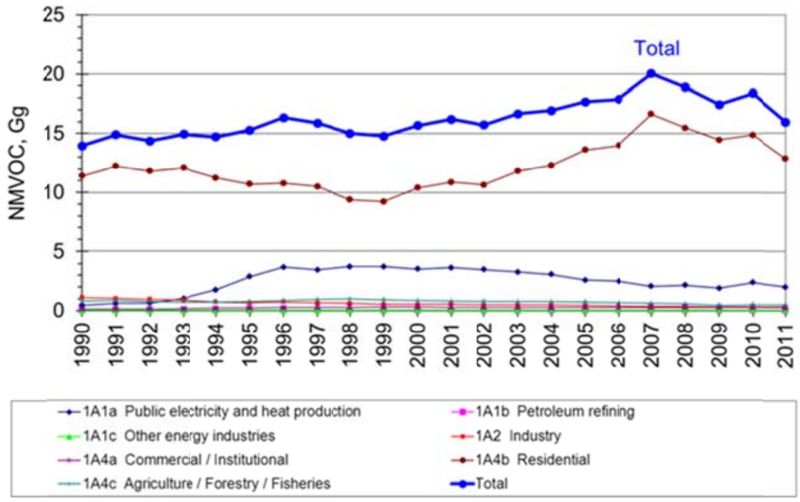


Figure 20 NMVOC emission time series for stationary combustion.

4.4 CO

Stationary combustion accounts for 37 % of the national CO emission. Table 16 presents the CO emission inventory for the stationary combustion subcategories.

Residential plants are the largest emission source, accounting for 82 % of the emission. Wood combustion accounts for 89 % of the emission from residential plants, see Figure 21. This is in spite of the fact that the fuel consumption share is only 45 %. Combustion of straw is also a considerable emission source whereas the emission from other fuels used in residential plants is almost negligible.

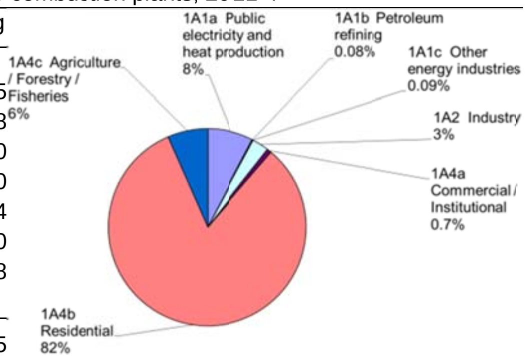
Time series for CO emission from stationary combustion are shown in Figure 22. The emission has increased by 5 % from 1990. The time series for CO from stationary combustion plants follows the time series for CO emission from residential plants.

The increase of wood consumption in residential plants in 1999-2007 is reflected in the time series for CO emission. The consumption of wood in residential plants in 2011 was 3.7 times the 1990 level. The decrease in the emission from 2007 to 2011 is a result of implementation of improved residential wood combustion technologies and the fact that the rapid increase of wood consumption until 2007 have stopped.

Both straw consumption and CO emission factor for residential plants have decreased since 1990.

Table 16 CO emission from stationary combustion plants, 2011[1)].

	CO, Mg
1A1a Public electricity and heat production	10635
1A1b Petroleum refining	118
1A1c Other energy industries	120
1A2 Industry	3810
1A4a Commercial/Institutional	1024
1A4b Residential	114920
1A4c Agriculture/forestry/fisheries	9168
Total	139795



[1)] Only emission from stationary combustion plants in the source categories is included.

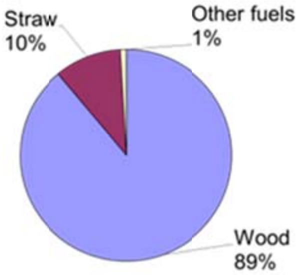


Figure 21 CO emission sources, residential plants, 2011.

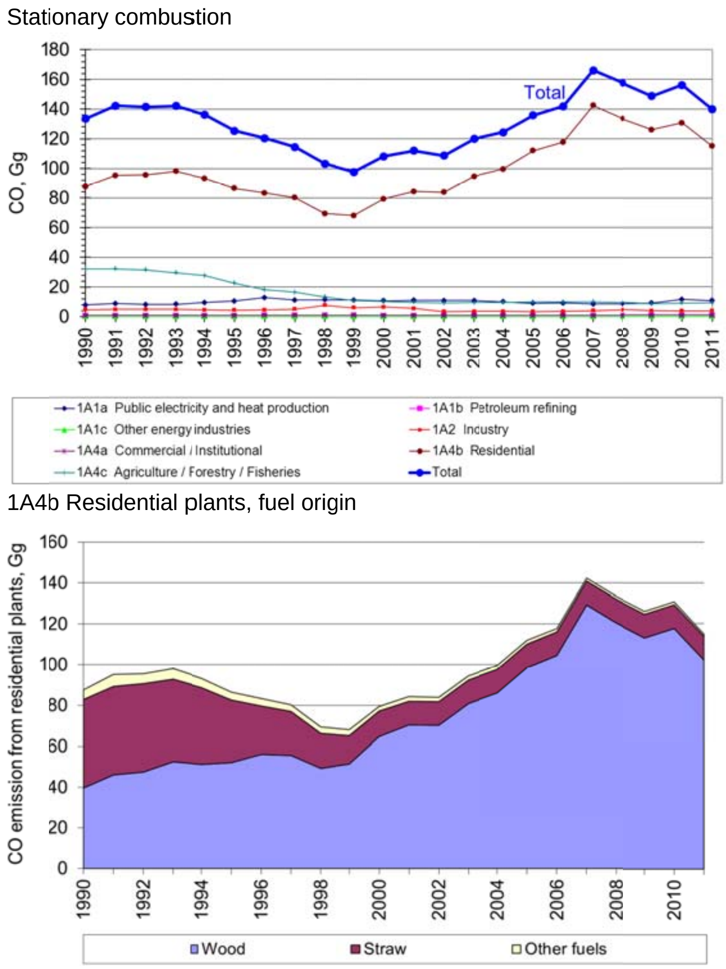


Figure 22 CO emission time series for stationary combustion.

4.5 NH_3

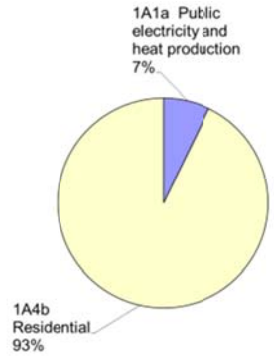
Stationary combustion plants accounted for only 0.3 % of the national ammonia (NH_3) emission in 2011. The emission inventory for stationary combustion does not include all possible sources due to lack of emission factors for a large number of fuels and sectors.

Table 17 shows the NH_3 emission inventory for the stationary combustion subcategories. Residential plants account for 93 % of the emission. Wood combustion accounts for 94 % of the emission from residential plants. For public electricity and heat production the emission comes from waste incineration plants using NH_3 to reduce emissions of NO_x.

The time series for the NH_3 emission is presented in Figure 23. The NH_3 emission has increased to 2.8 times the 1990 level.

Table 17 NH_3 emission from stationary combustion plants, 2011[1)].

NH_3, Mg	
1A1a Public electricity and heat production	14
1A1b Petroleum refining	-
1A1c Other energy industries	-
1A2 Industry	-
1A4a Commercial/Institutional	-
1A4b Residential	176
1A4c Agriculture/forestry/fisheries	-
Total	190



1) Only the emission from stationary combustion plants in the source categories is included.

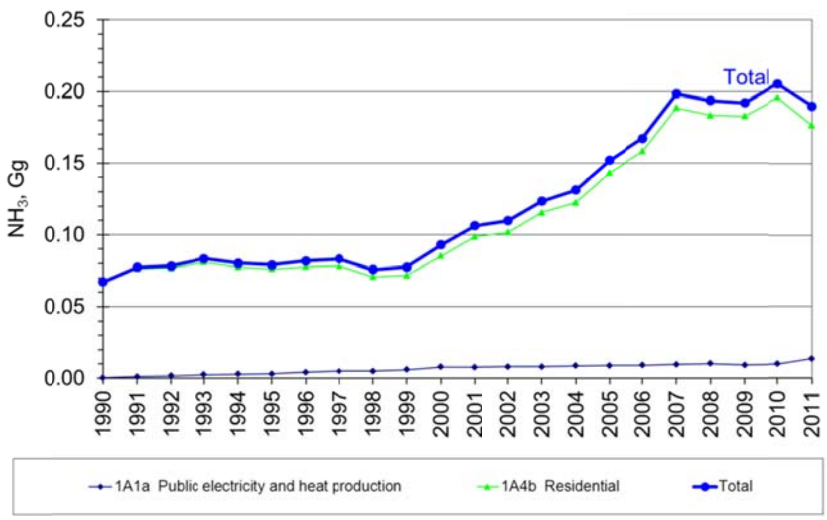


Figure 23 NH_3 emission time series, stationary combustion plants.

4.6 Particulate matter (PM)

Total Suspended Particulates (TSP) from stationary combustion accounts for 49 % of the national emission. The emission shares for Particulate Matter < 10 µm (PM_{10}) and Particulate Matter < 2.5 µm ($PM_{2.5}$) are 59 % and 73 %, respectively.

Table 18 and Figure 24 show the PM emission inventory for the stationary combustion subcategories. Residential plants are the largest emission source accounting for 92 % of the $PM_{2.5}$ emission from stationary combustion plants.

The primary sources of PM emissions are:

- Residential boilers, stoves and fireplaces combusting wood
- Farmhouse boilers combusting straw
- Power plants primarily combusting coal
- Coal and residual oil combusted in industrial plants

The PM emission from wood combusted in residential plants is the predominant source. Thus, 88 % of the $PM_{2.5}$ emission from stationary combustion is emitted from residential wood combustion. This corresponds to 64 % of the national emission. A literature review (Nielsen et al. 2003b) and a Nordic project (Sternhufvud et al., 2004) has demonstrated that the emission factor uncertainty for residential combustion of wood in stoves and boilers is notably high.

Figure 25 shows the fuel consumption and the $PM_{2.5}$ emission of residential plants. Wood combustion accounts for 96 % of the $PM_{2.5}$ emission from residential plants in spite of a wood consumption share of 45 %.

Emission inventories for PM have been reported for the years 2000-2011. The time series for PM emission from stationary combustion is shown in Figure 26. The emission of TSP, PM_{10} and $PM_{2.5}$ has increased 26 %, 27 % and 30 %, respectively, since year 2000. The increase is caused by the increased wood combustion in residential plants. However, the PM emission factors have decreased for this emission source category due to installation of modern stoves and boilers. The stabilisation of wood consumption in residential plants in 2007-2011 has resulted in a decrease of PM emission from stationary combustion in recent years.

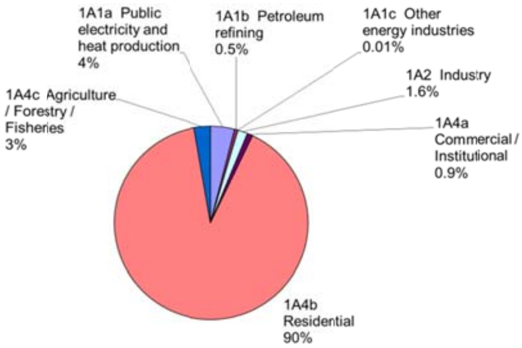
The time series for PM emission from stationary combustion plants follows the time series for PM emission from residential plants.

Table 18 PM emission from stationary combustion plants, 2011[1)].

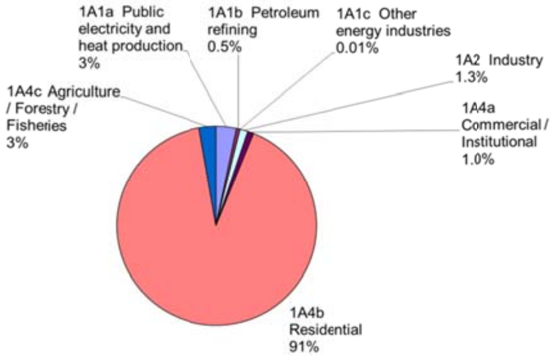
		TSP, Mg	PM_{10}, Mg	$PM_{2.5}$, Mg
1A1a	Public electricity and heat production	734	571	455
1A1b	Petroleum refining	100	95	93
1A1c	Other energy industries	3	2	1
1A2	Industry	300	222	156
1A4a	Commercial/Institutional	168	166	157
1A4b	Residential	16596	15802	15572
1A4c	Agriculture/forestry/fisheries	502	471	441
Total		18404	17328	16875

1) Only emission from stationary combustion plants in the source categories is included.

TSP



PM_{10}



$PM_{2.5}$

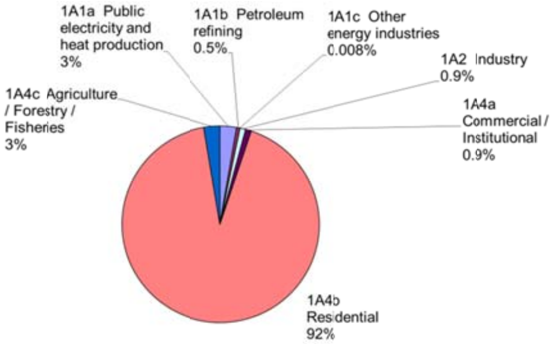
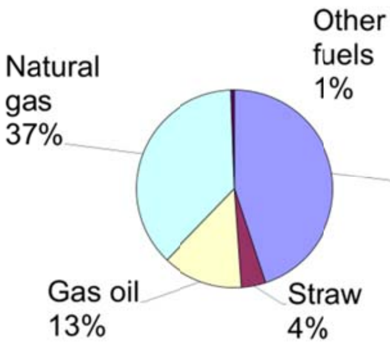


Figure 24 PM emission sources, stationary combustion plants, 2011.

Fuel consumption



$PM_{2.5}$ emission

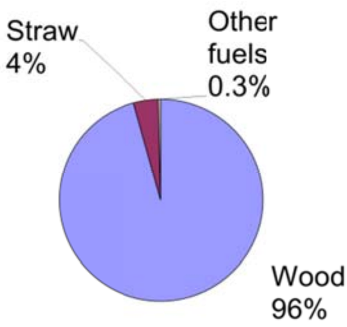


Figure 25 Fuel consumption and $PM_{2.5}$ emission from residential plants.

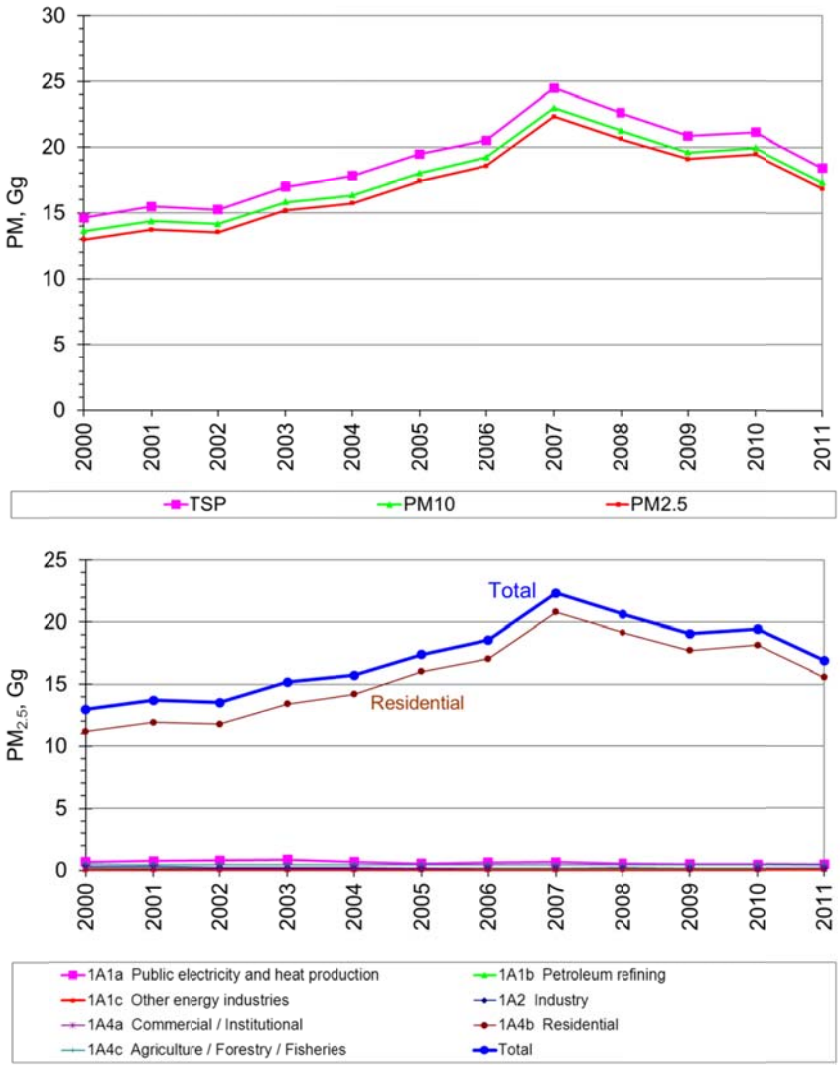


Figure 26 PM emission time series for stationary combustion.

4.7 Heavy metals (HM)

Stationary combustion plants are among the most important emission sources for heavy metals (HM). The emission share for stationary combustion compared to the national total is shown for each metal in Table 19.

Table 19 and Figure 27 present the heavy metal emission inventory for the stationary combustion subcategories. The source categories *Public electricity and heat production, Residential* and *Industry* are the main emission sources. The emission share for waste incineration plants, that formerly was a major emission source, is now below 25 % for all heavy metals. The emission share for waste incineration plants has decreased considerably since the year 2000 due to installation of new improved flue gas cleaning technology that was initiated based on lower emission limit values in Danish legislation (DEPA 2003a).

Table 19 Heavy metal emission from stationary combustion plants, 2011[1)2)].

	As, kg	Cd, kg	Cr, kg	Cu, kg	Hg, kg	Ni, kg	Pb, kg	Se, kg	Zn, kg
1A1a Public electricity and heat production	103	30	185	230	226	299	364	671	502
1A1b Petroleum refining	29	22	22	43	21	204	64	103	75
1A1c Other energy industries	3	0	0	0	3	0	0	0	0
1A2 Industry	74	24	83	106	51	1188	449	92	972
1A4a Commercial/Institutional	3	0	3	4	2	3	6	1	17
1A4b Residential	23	37	77	291	19	79	1439	18	3689
1A4c Agriculture/forestry/fisheries	8	5	22	39	11	98	235	31	511
Total	243	118	393	712	332	1871	2558	916	5765
Emission share from stationary combustion	76%	60%	45%	2%	84%	47%	26%	75%	16%

1. Only emission from stationary combustion plants in the source categories is included.
2. Emission < 0.5 kg is denoted "0". No emission is denoted "-"

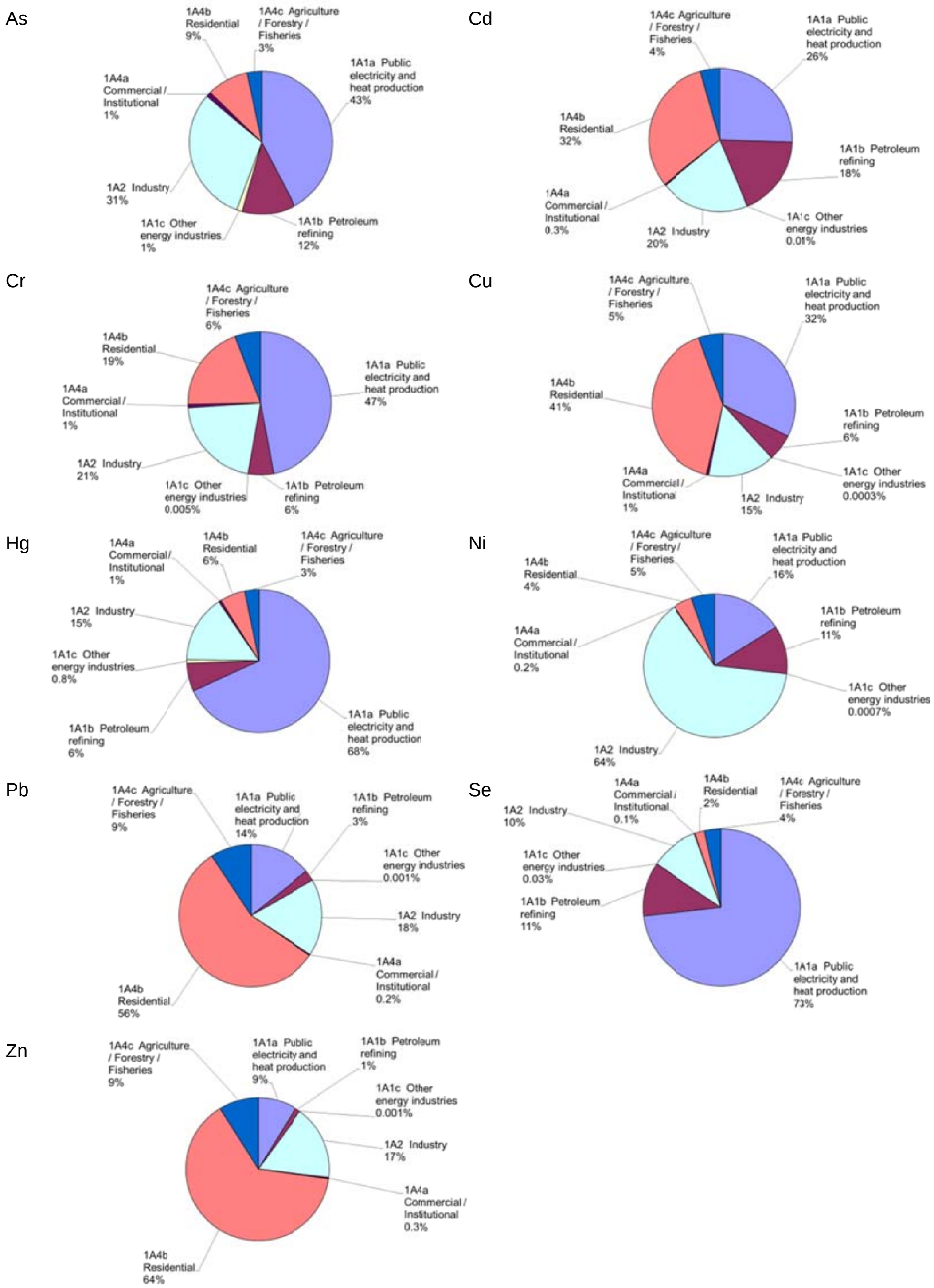


Figure 27 Heavy metal emission sources, stationary combustion plants, 2011.

The time series for heavy metal emissions are provided in Figure 28. Emissions of all heavy metals have decreased considerably (76 % - 92 %) since 1990, see Table 20. Emissions have decreased despite increased incineration of waste. This has been made possible due to installation and improved performance of gas cleaning devices in waste incineration plants and also in large power plants, the latter being a further important emission source.

The decrease of As emission in 1995 and the increase in 1996 is a result of a relatively low consumption of coal in 1995 and a high consumption of coal in 1996 (se Figure 41 on page 59). The high consumption of coal in 1996 is also reflected in other heavy metal time series.

The high Ni emission in 1994 is related to plant specific data for power plants. Power plant owners apply an emission model called EMOK that includes emission measurements for particulate matter, fixed input data for heavy metal content of fuels, and reduction efficiency for each metal compared to reduction efficiency for particulate matter. The input data for heavy metals applied in the EMOK model was improved in 1996. The inconsistent time series reflects this improved input data for the EMOK model. The plant specific data have not been recalculated with the improved model data.

Table 20 Decrease in heavy metal emission 1990-2011.

Pollutant	Decrease since 1990, %
As	79
Cd	86
Cr	92
Cu	80
Hg	88
Ni	89
Pb	83
Se	77
Zn	76

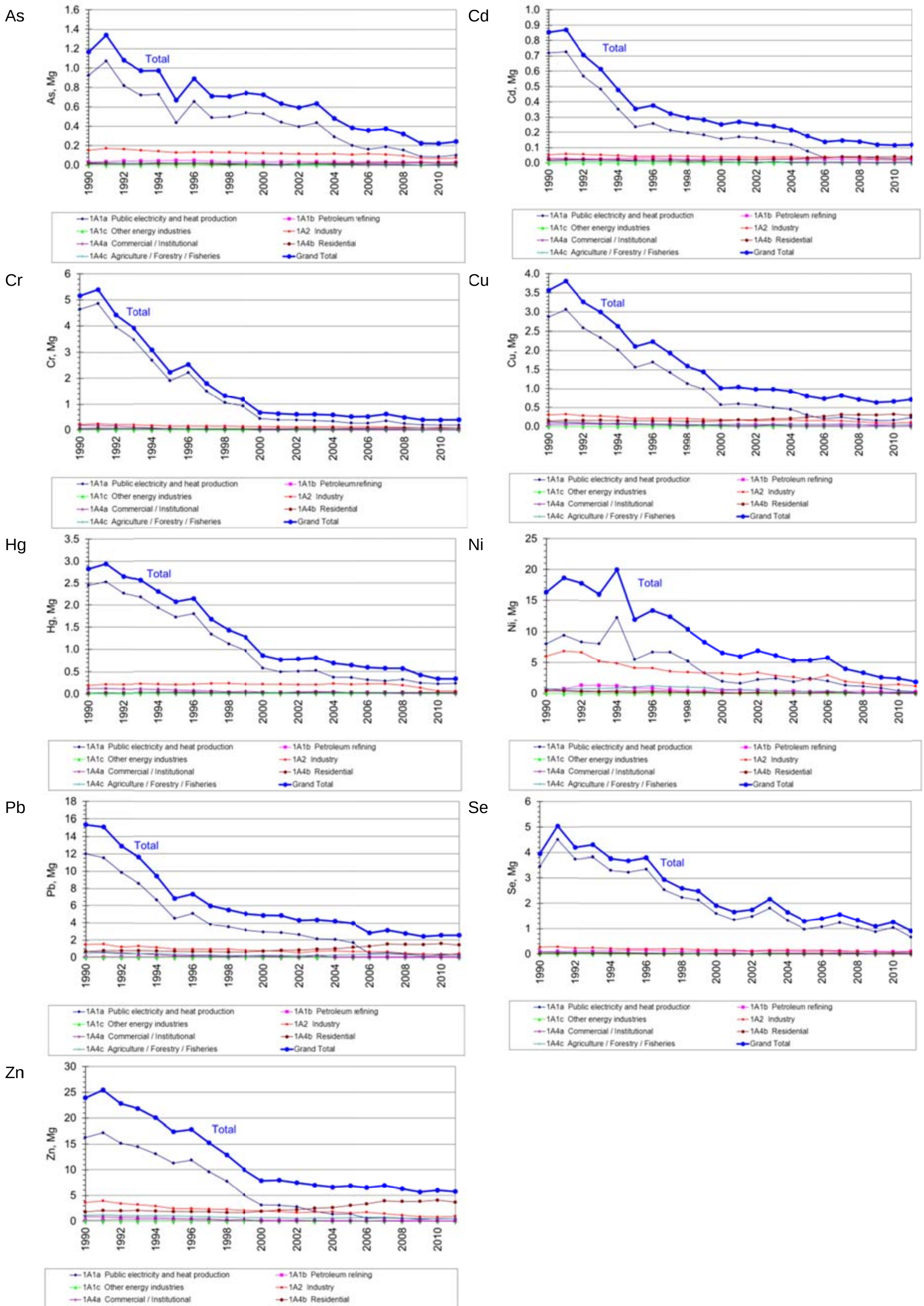


Figure 28 Heavy metal emission time series, stationary combustion plants.

4.8 Polycyclic aromatic hydrocarbons (PAH)

The four polycyclic aromatic hydrocarbons (PAH) reported to the CLRTAP are benzo(a)pyrene, benzo(b)fluoranthene, benzo(k)fluoranthene, indeno(1,2,3-c,d)pyrene. Stationary combustion plants accounted for more than 92 % of the PAH emission in 2011.

Table 21 and Figure 29 present the PAH emission inventories for the stationary combustion subcategories. Residential combustion is the largest emission source accounting for more than 89 % of the emission. Combustion of wood is the predominant source, accounting for more than 98 % of the PAH emission from residential plants, see Figure 30.

The time series for PAH emissions for the four compounds are presented in Figure 31. The increasing (79 % - 115 %) emission trend for PAH is a result of the increased combustion of wood in residential plants. The time series for wood combustion in residential plants is also provided in Figure 31. The stabilisation of the consumption of wood in residential plants since 2007 is reflected in the PAH emission time series.

Table 21 PAH emission from stationary combustion plants, 2011[1)2)].

		Benzo(a)-pyrene, kg	Benzo(b)-fluoranthene, kg	Benzo(k)-fluoranthene, kg	Indeno(1,2,3-c,d)-pyrene, kg
1A1a	Public electricity and heat production	8	33	21	6
1A1b	Petroleum refining	0	0	0	0
1A1c	Other energy industries	0	0	0	0
1A2	Industry	21	76	14	4
1A4a	Commercial/Institutional	166	218	73	118
1A4b	Residential	3781	3754	2196	2560
1A4c	Agriculture/forestry/fisheries	122	135	28	166
Total		4098	4216	2331	2853
Emission share from stationary combustion		95%	94%	92%	93%

1) Only emission from stationary combustion plants in the source categories is included.
2) Emission < 0.5 kg is denoted “0”. No emission is denoted “-“.

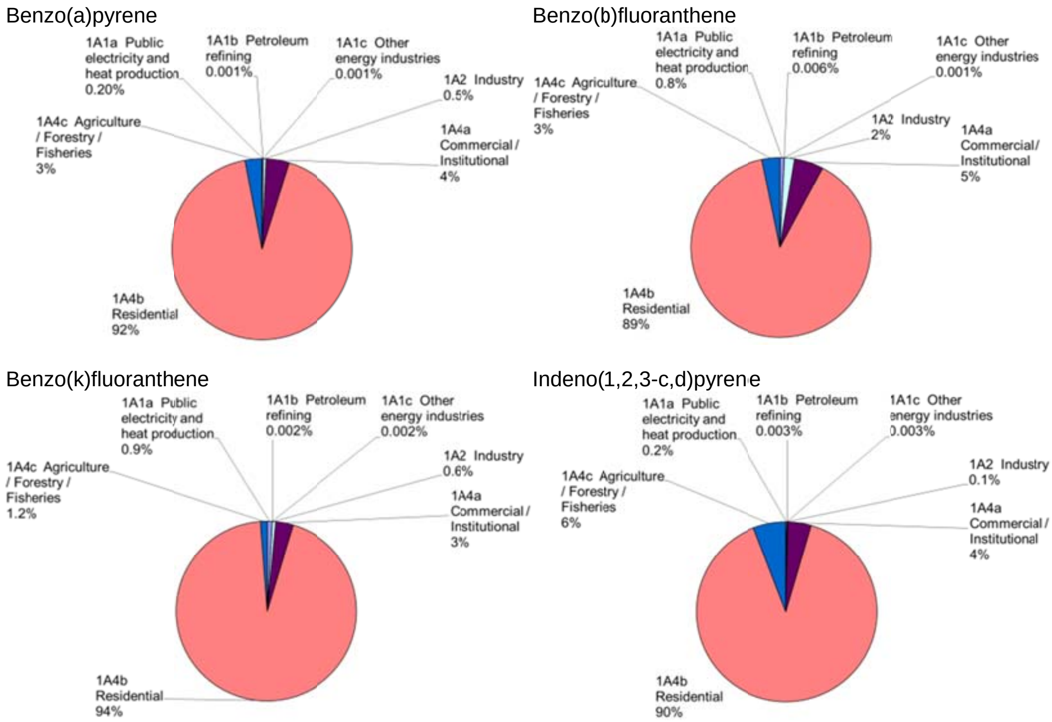


Figure 29 PAH emission sources, stationary combustion plants, 2011.

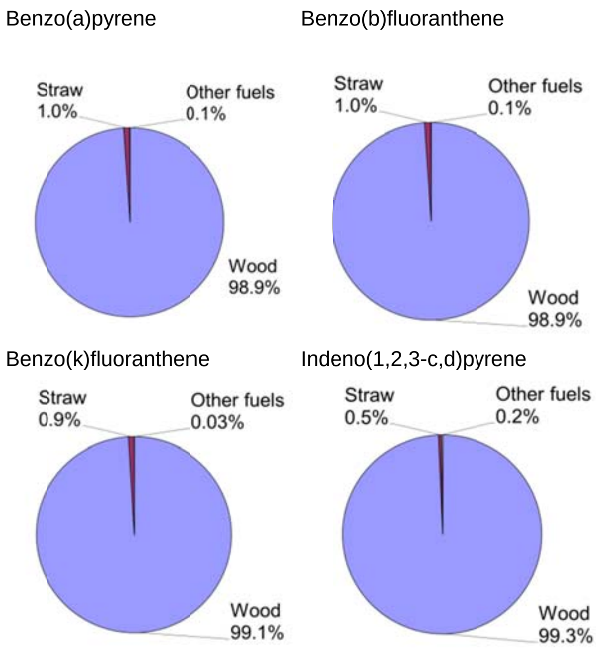


Figure 30 PAH emission from residential combustion plants (stationary), fuel origin.

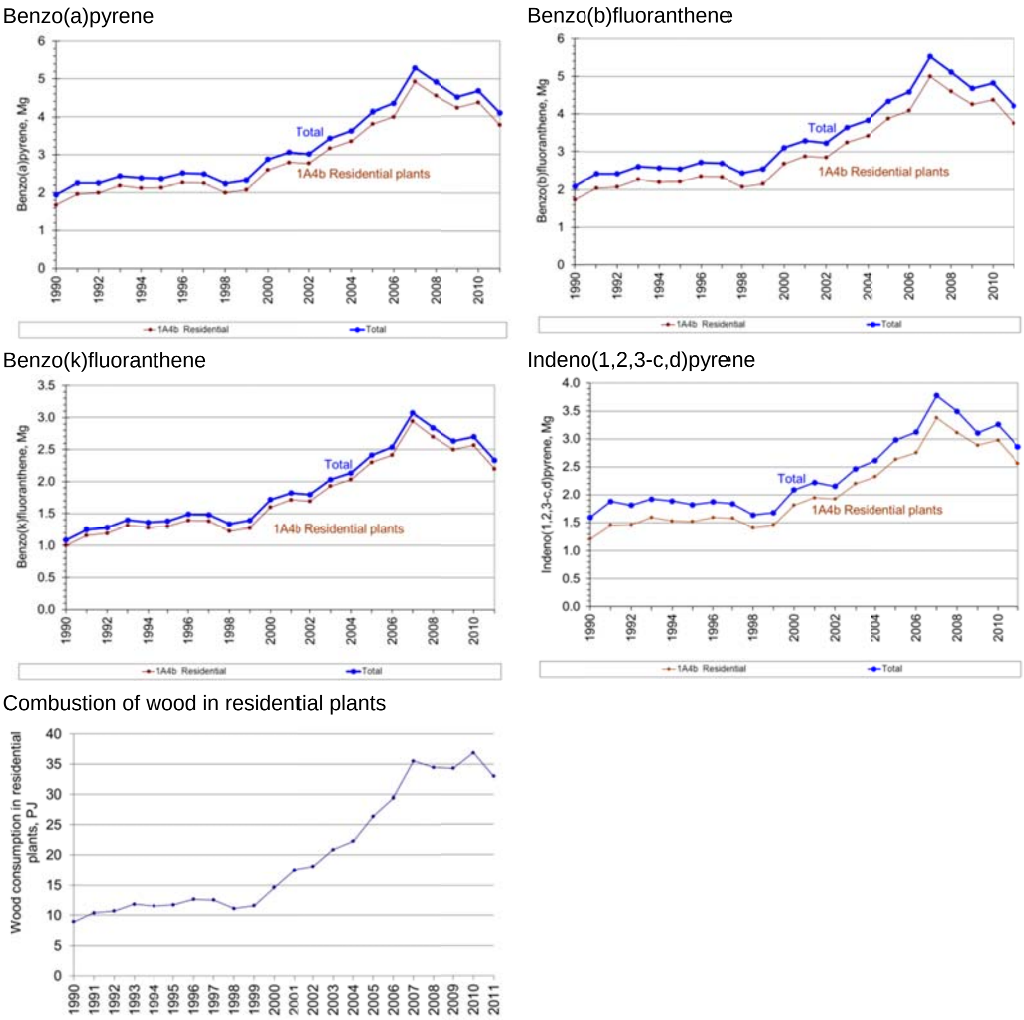


Figure 31 PAH emission time series, stationary combustion plants. Comparison with wood consumption in residential plants.

4.9 Polychlorinated dibenzodioxins and -furans (PCDD/F)

Stationary combustion plants accounted for 71 % of the national emission of polyclorinated dibenzodioxins and –furans (PCDD/F) in 2011.

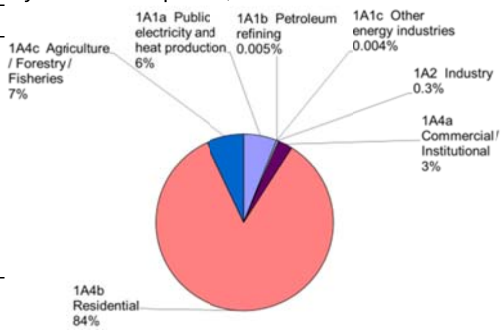
presents the PCDD/F emission inventories for the stationary combustion subcategories. In 2011, the emission from residential plants accounts for 84 % of the emission. Combustion of wood is the predominant source accounting for 89 % of the emission from residential plants (Figure 32).

The time series for PCDD/F emission is presented in Figure 33. The PCDD/F emission has decreased 62 % since 1990 mainly because dioxin abatement was put into operation in waste incineration plants. The relatively high emission in 1997 is a result of inconsistent emission factors for some waste incineration plants. This will be corrected in the next inventory.

The emission from residential plants has increased due to increased wood consumption in this source category.

Table 22 PCDD/F emission from stationary combustion plants, 2011[1].

	PCDD/F, g I-Teq
1A1a Public electricity and heat production	1.0
1A1b Petroleum refining	0.0
1A1c Other energy industries	0.0
1A2 Industry	0.1
1A4a Commercial/Institutional	0.5
1A4b Residential	14.5
1A4c Agriculture/forestry/fisheries	1.2
Total	17.3



1) Only emission from stationary combustion plants in the source categories is included.
2) Emission < 0.05 g I-Teq is denoted “0.0”. No emission is denoted “-“.

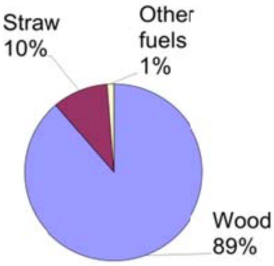


Figure 32 PCDD/F emission from residential plants, fuel origin.

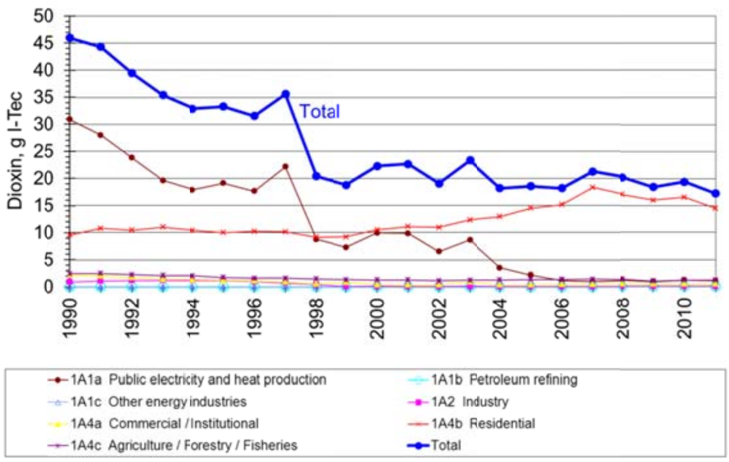


Figure 33 PCDD/F emission time series, stationary combustion plants.

4.10 HCB

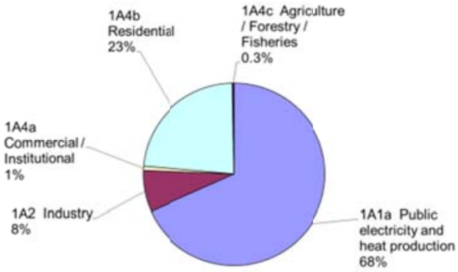
The emission of hexachlorobenzene (HCB) has been estimated only for stationary combustion plants and cremation. Stationary plants accounted for more than 98 % of the estimated national HCB emission in 2011. The emission inventory for stationary combustion does not include all possible sources due to lack of emission factors for a large number of fuels and sectors, see Chapter 12. An improved emission inventory for HCB will be included in the emission inventory reported in 2014.

Table 23 shows the HCB emission inventory for the stationary combustion subcategories. *Public electricity and heat production* account for 68 % of the emission. Residential plants account for 23 % of the emission.

The time series for HCB emission is presented in Figure 34. The HCB emission has decreased 82 % since 1990 mainly due to improved flue gas cleaning in waste incineration plants. The emission from residential plants has increased due to increased wood consumption in this source category.

Table 23 HCB emission from stationary combustion plants, 2011[1)2)].

	HCB, kg
1A1a Public electricity and heat production	0.387
1A1b Petroleum refining	-
1A1c Other energy industries	-
1A2 Industry	0.042
1A4a Commercial/Institutional	0.004
1A4b Residential	0.132
1A4c Agriculture/forestry/fisheries	0.002
Total	0.567



1) Only the emission from stationary combustion plants in the source categories is included.

2) Emission < 0.0005 kg is denoted "0.000". No emission is denoted "-"

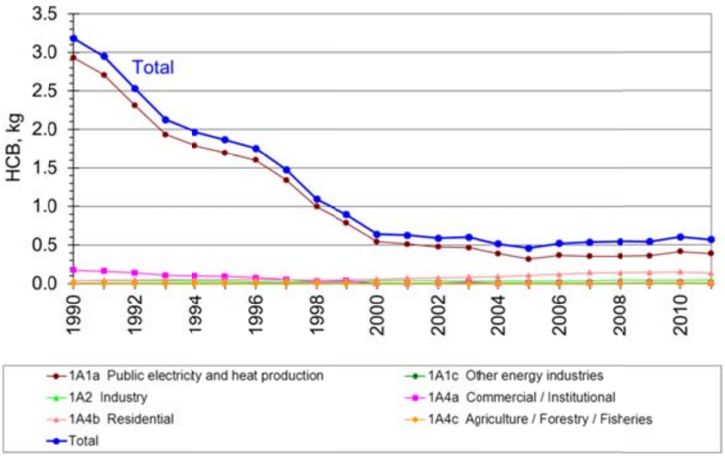


Figure 34 HCB emission time series, stationary combustion plants.

5 Trend for subsectors

In addition to the data for stationary combustion, this chapter presents and discusses data for each of the subcategories in which stationary combustion is included. Time series are presented for fuel consumption and emissions.

5.1 1A1 Energy industries

The emission source category *1A1 Energy Industries* consists of the subcategories:

- 1A1a Public electricity and heat production.
- 1A1b Petroleum refining.
- 1A1c Other energy industries.

Figure 35 – Figure 40 present time series for the *Energy Industries*. *Public electricity and heat production* is the largest subcategory accounting for the main part of all emissions. Time series are discussed below for each subcategory.

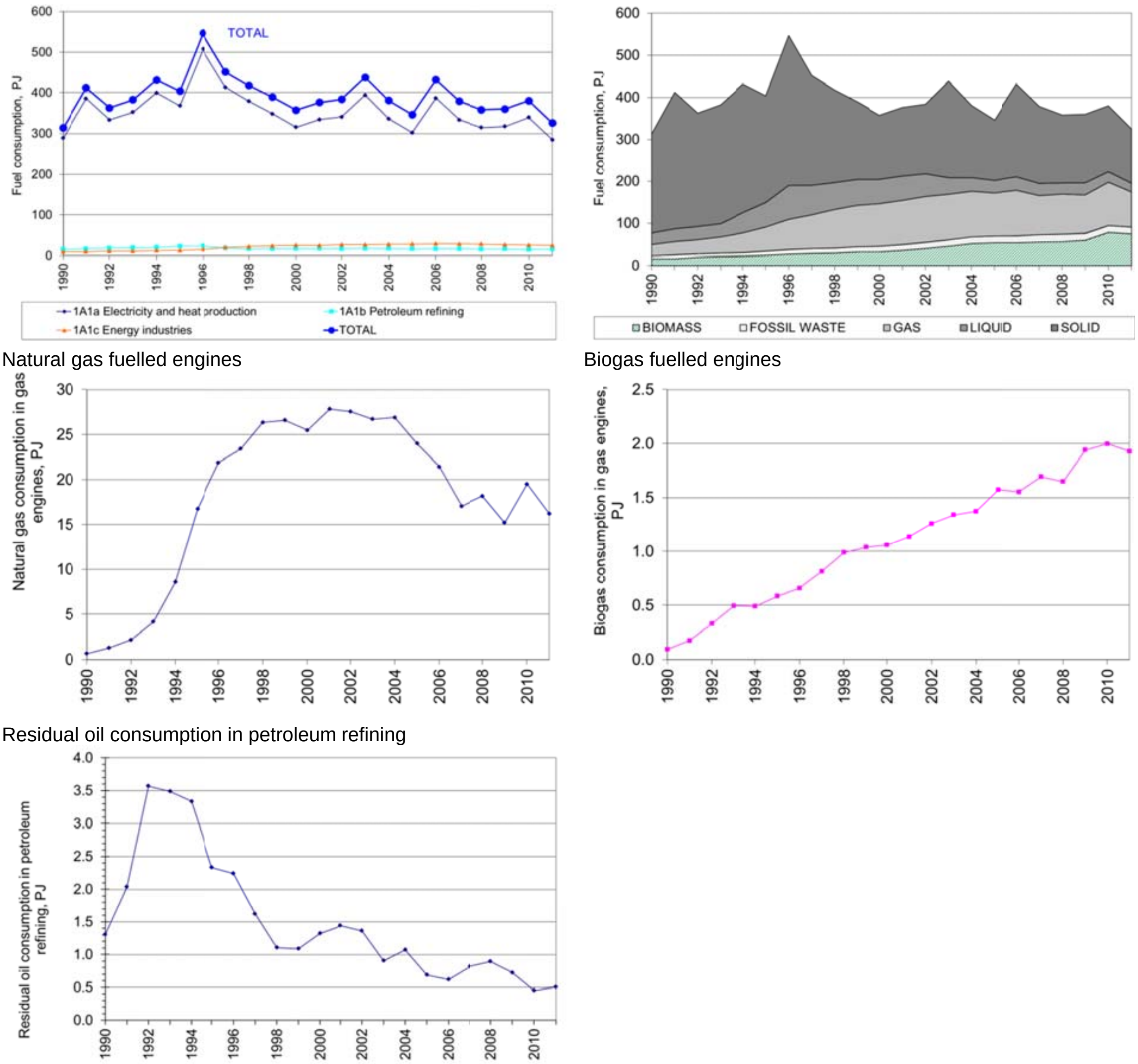


Figure 35 Time series for fuel consumption, 1A1 Energy industries.

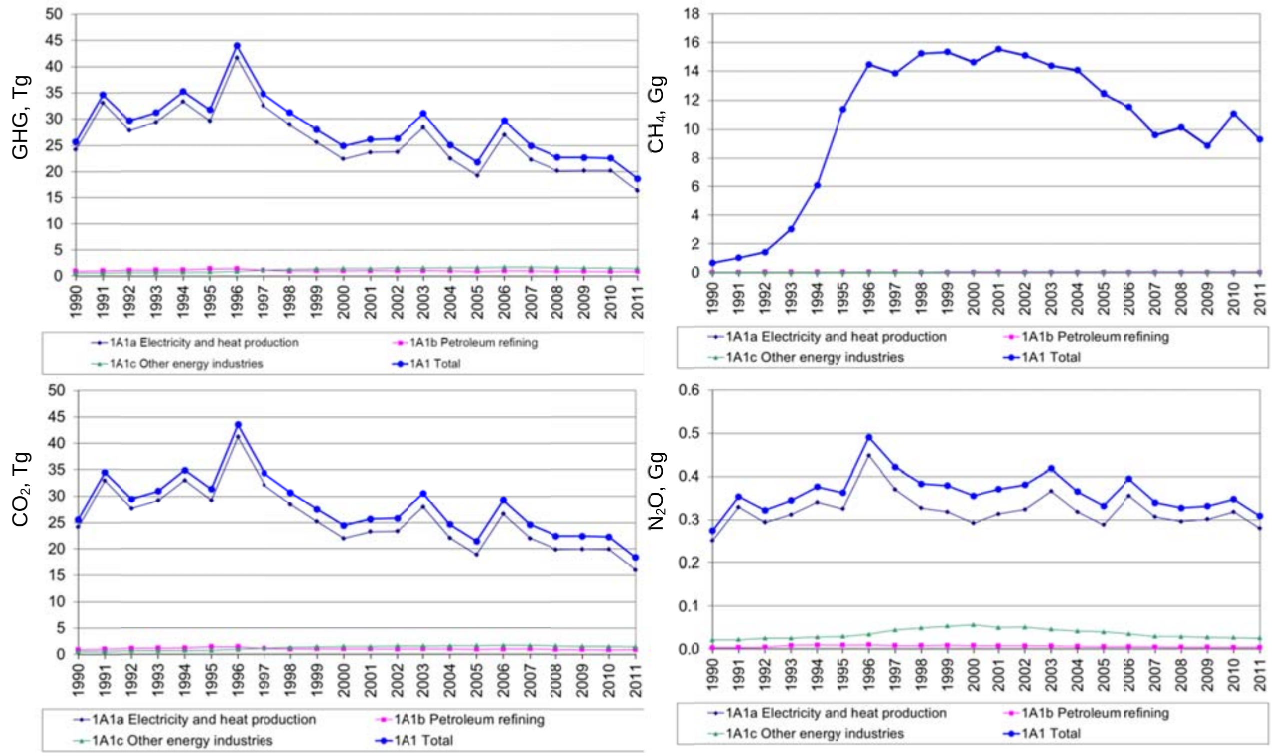


Figure 36 Time series for greenhouse gas emission, 1A1 Energy industries.

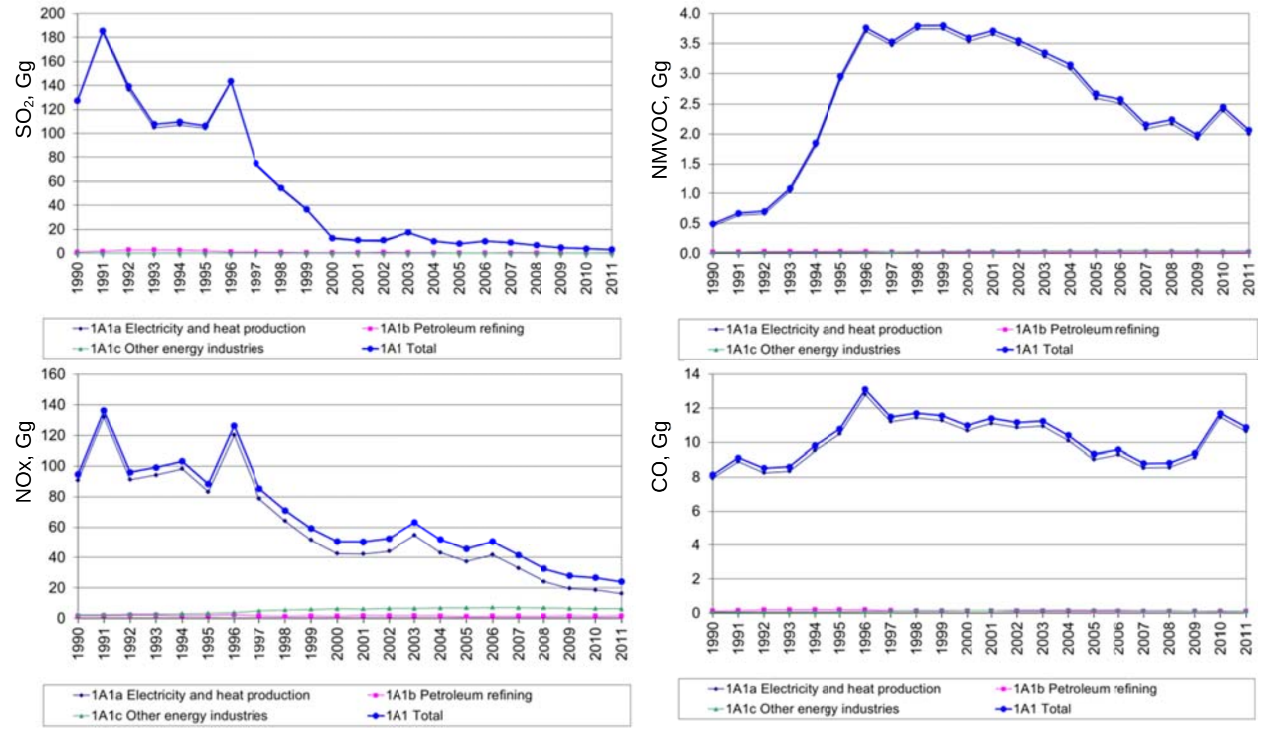


Figure 37 Time series for SO_2, NO_x, NMVOC and CO emission, 1A1 Energy industries.

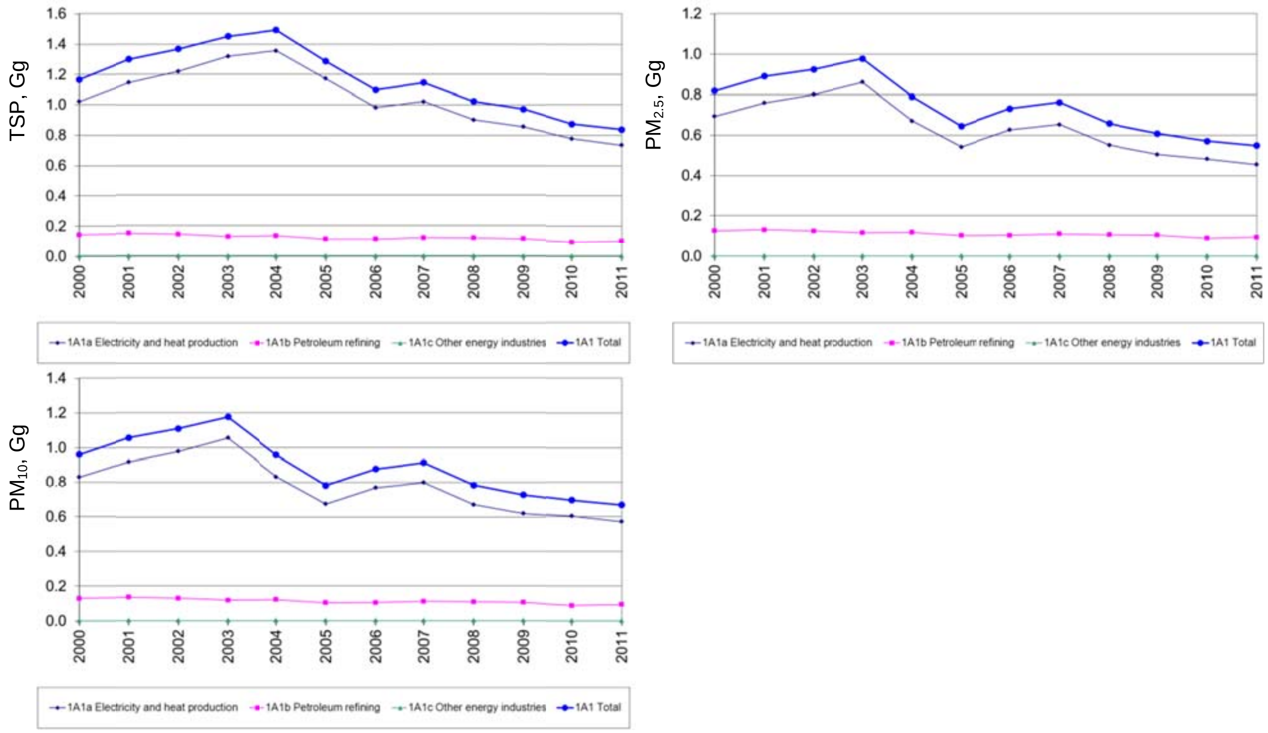


Figure 38   Time series for PM emission, 1A1 Energy industries.

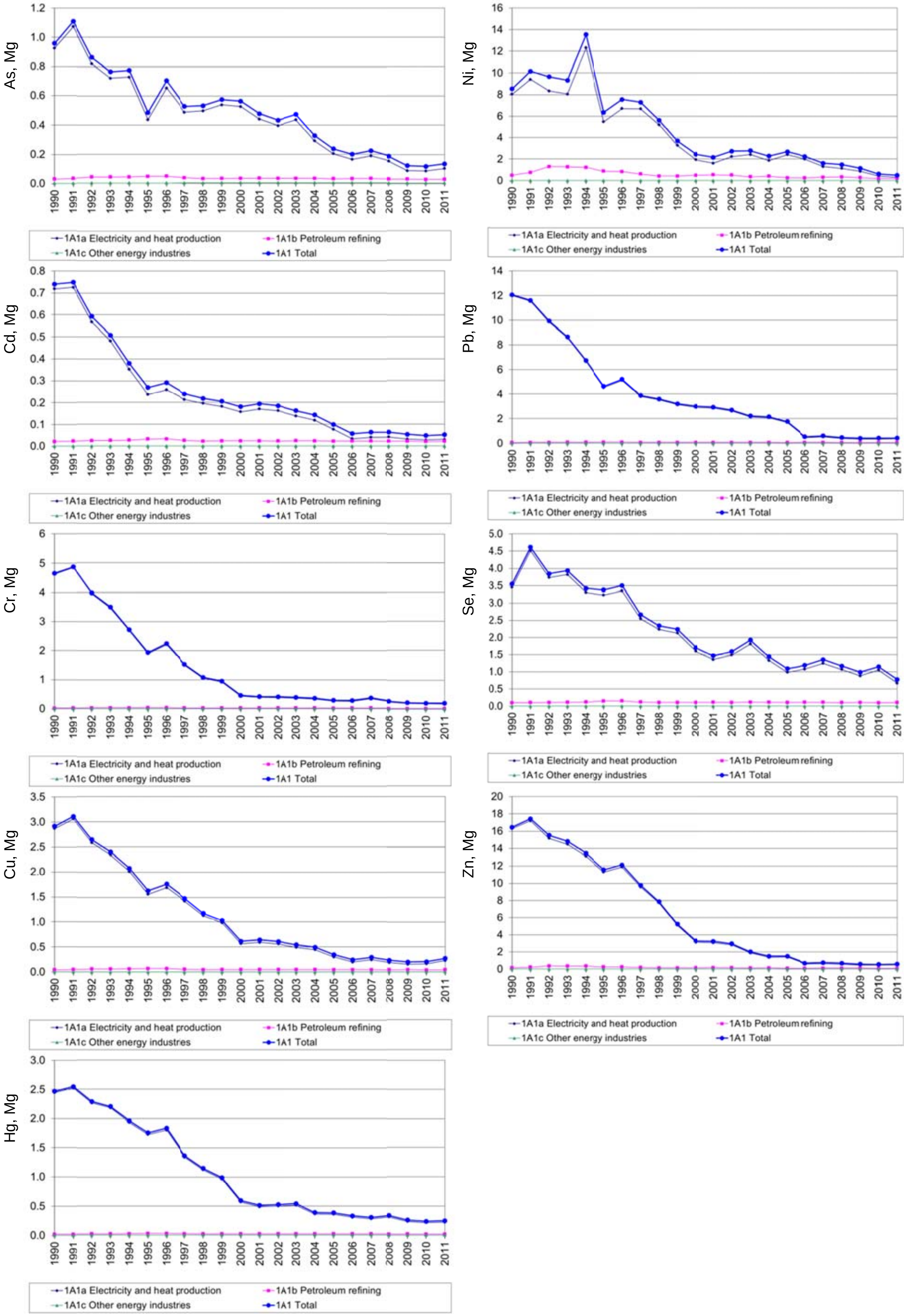


Figure 39 Time series for HM emission, 1A1 Energy industries.

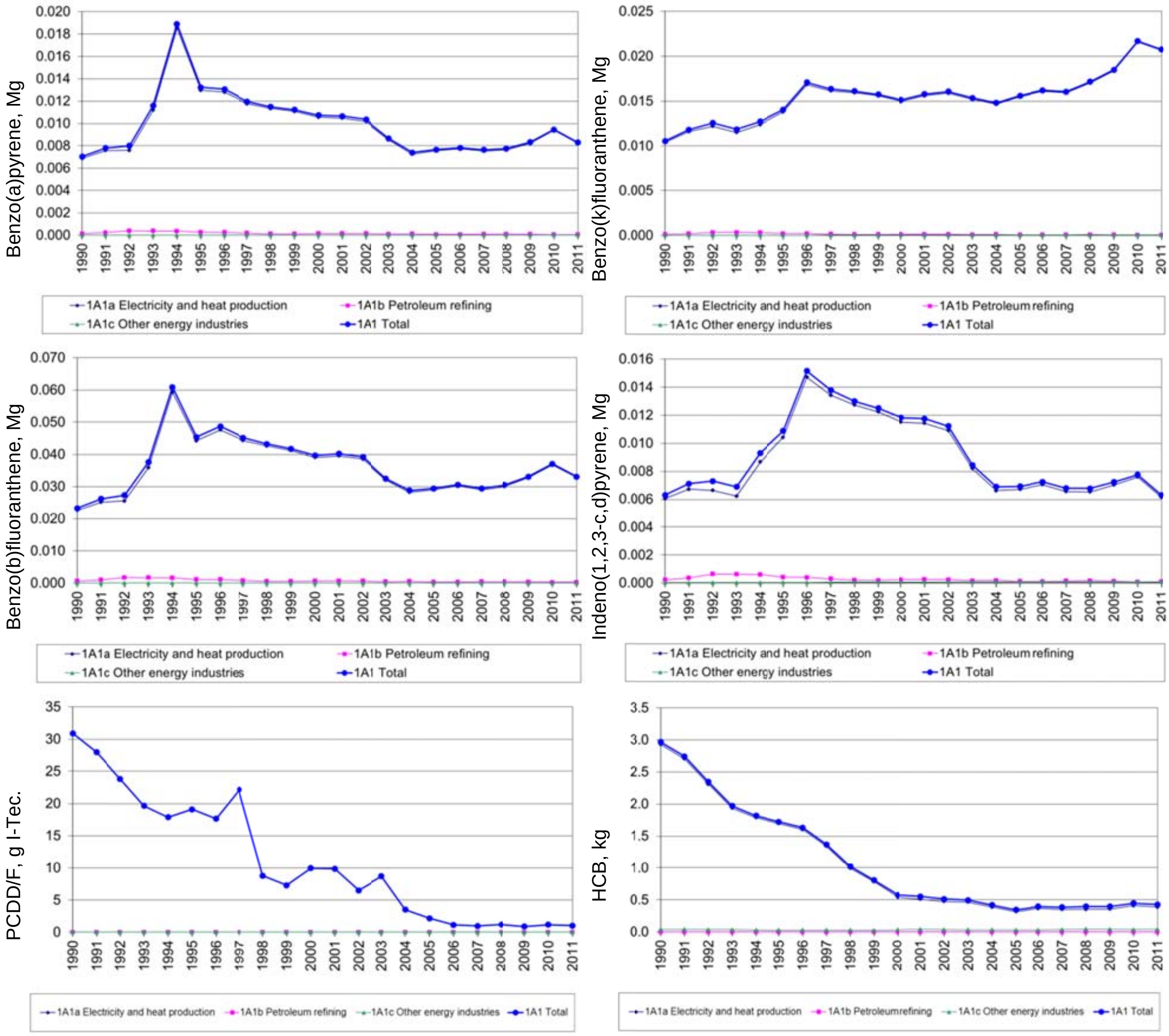


Figure 40 Time series for PAH, PCDD/F and HCB emission, 1A1 Energy industries.

5.1.1 1A1a Electricity and heat production

Public electricity and heat production is the largest source category regarding both fuel consumption and greenhouse gas emissions for stationary combustion. Figure 41 shows the time series for fuel consumption and emissions.

The fuel consumption in electricity and heat production was 1 % lower in 2011 than in 1990. As discussed in Chapter 2 the fuel consumption fluctuates mainly as a consequence of electricity trade. Coal is the fuel that is affected the most by the fluctuating electricity trade. Coal is the main fuel in the source category even in years with electricity import. The coal consumption in 2011 was 45 % lower than in 1990. Natural gas is also an important fuel and the consumption of natural gas has increased since 1990, but decreased since 2003. A considerable part of the natural gas is combusted in gas engines (Figure 35). The consumption of waste and biomass has increased.

The CO_2 emission was 34 % lower in 2011 than in 1990. This decrease – in spite of almost unchanged fuel consumption - is a result of the change of fuels used as discussed above.

The CH_4 emission has increase until the mid-nineties as a result of the considerable number of lean-burn gas engines installed in CHP plants in Denmark in this period. The decline in later years is due to liberalisation of the Danish electricity market, which means that the fuel consumption in gas engines has been decreasing (Figure 35). The emission in 2011 was 14 times the 1990 emission level.

The N_2O emission in 2011 was 11 % above the 1990 emission level. The emission fluctuates similar to the fuel consumption.

The SO_2 emission has decreased 98 % since 1990. This decrease is a result of both lower sulphur content in fuels and installation and improved performance of desulphurisation plants. The emission has also decreased in recent years and thus the 2011 emission is 25 % lower than the emission in 2010.

The NO_x emission has decreased 82 % due to installation of low NO_x burners, selective catalytic reduction (SCR) units and selective non-catalytic reduction (SNCR) units. The fluctuations in time series follow the fluctuations in fuel consumption and electricity trade.

The emission of NMVOC in 2011 was 4.3 times the 1990 emission level. This is a result of the large number of gas engines that has been installed in Danish CHP plants. The decreasing emission in 2004-2009 is results of the time series for natural gas consumption in gas engines (Figure 35). The emission of NMVOC from engines decreased in 1995-2007 as a result of introduction of an emission limits for unburned hydrocarbon[9] (DEPA 2005).

The CO emission was 34 % higher in 2011 than in 1990. The fluctuations follow the fluctuations of the fuel consumption. In addition, the emission from gas engines is considerable.

[9] Including methane.

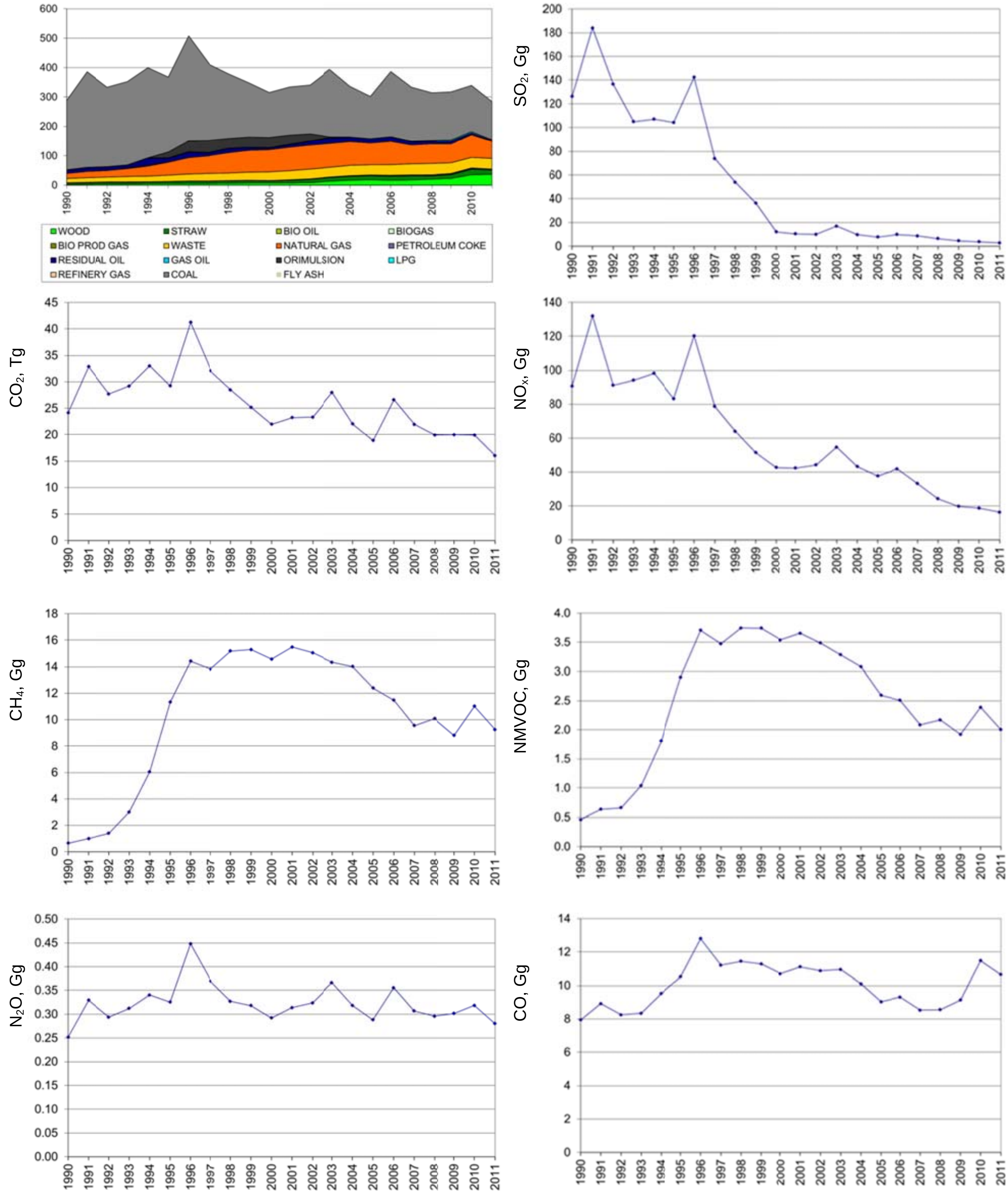


Figure 41 Time series for 1A1a Electricity and heat production.

5.1.2 1A1b Petroleum refining

Petroleum refining is a small source category regarding both fuel consumption and greenhouse gas emissions for stationary combustion. There are presently only two refineries operating in Denmark. Figure 42 shows the time series for fuel consumption and emissions.

The significant decrease in both fuel consumption and emissions in 1996 is a result of the closure of a third refinery.

The fuel consumption has increased 4 % since 1990 and the CO_2 emission has increased 3 %.

The CH_4 emission has increased 5 % since 1990 and 12 % since 2010. The reduction in CH_4 emission from 1995 to 1996 is caused by the closure of a refinery.

The N_2O emission was 57 % higher in 2011 than in 1990. The emission increased in 1990 – 1993 as a result of the installation of a gas turbine in one of the refineries. The gas turbine was installed in 1993 (DEA 2012b).

The N_2O emission factor for the refinery gas fuelled gas turbine has been assumed equal to the emission factor for natural gas fuelled turbines and thus the emission factor have been decreasing since 1994. This cause the decreasing trend in the time series since 1994.

The emission of SO_2 has shown a pronounced decrease (70 %) since 1990, mainly due to the decreased consumption of residual oil (61%) also shown in Figure 42. The NO_x emission in 2011 was 3 % lower than in 1990. Since 2005, data for both SO_2 and NO_x are plant specific data stated by the refineries.

The NMVOC emission time series follows the time series for fuel consumption.

Emissions from refineries are further discussed in Nielsen et al. (2013a)[10], Nielsen et al. (2013b), and Plejdrup et al., (2009).

[10] Chapter 3.5.

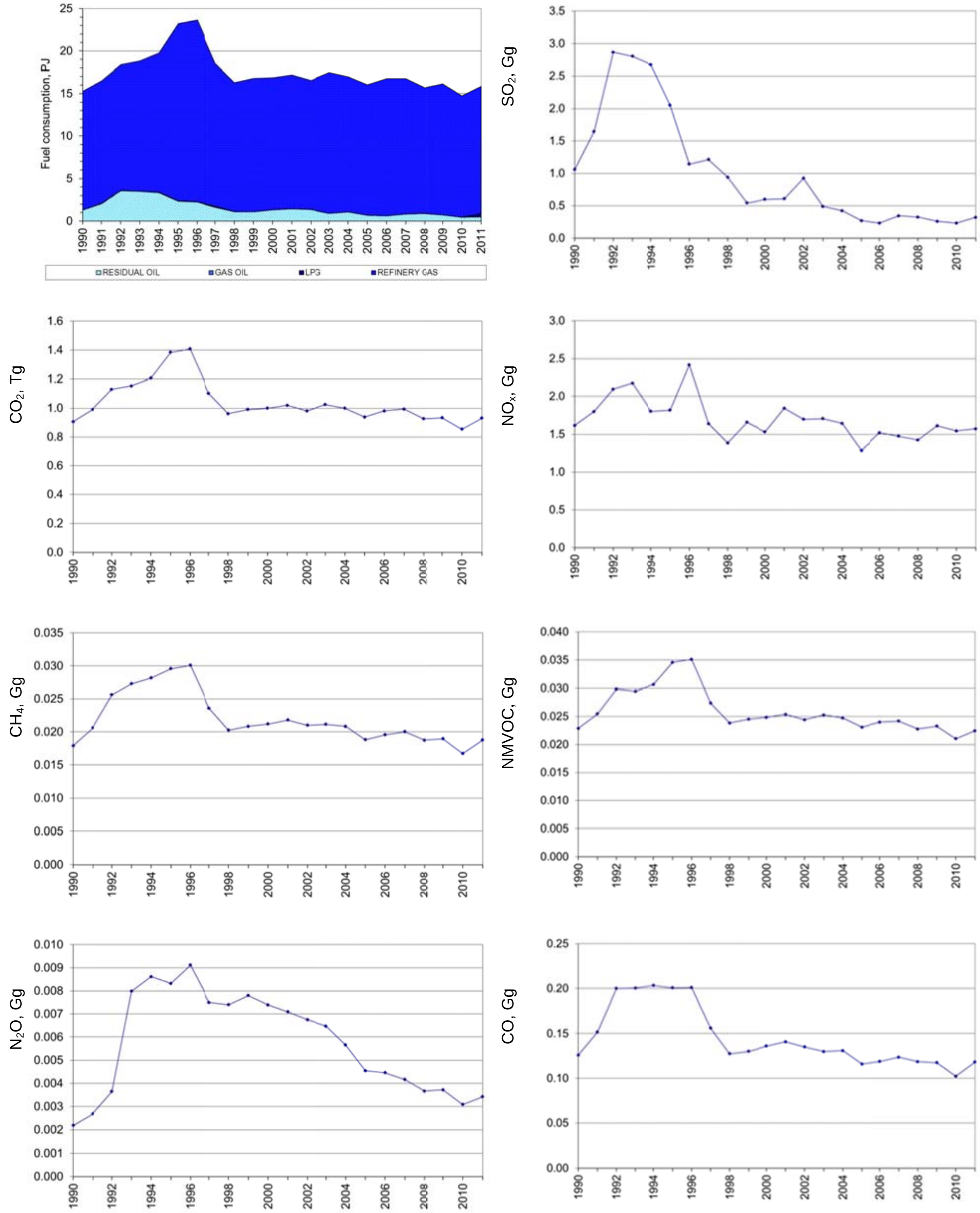


Figure 42 Time series for 1A1b Petroleum refining.

5.1.3 1A1c Other energy industries

The source category *Other energy industries* comprises natural gas consumption in the off-shore industry and in addition a small consumption in the Danish gas treatment plant[11]. Gas turbines are the main plant type.

The fuel consumption in 2011 was 2.6 times the consumption in 1990. The CO_2 emission follows the fuel consumption and the emission in 2011 was also 2.6 times the emission in 1990.

The time series for N_2O is incorrect. The emission factor time series for onshore gas turbines was erroneously applied to the off-shore gas turbines. The inconsistent emission factors will be corrected in the next inventory.

The emissions from all other pollutants follow the increase of fuel consumption.

[11] Nybro

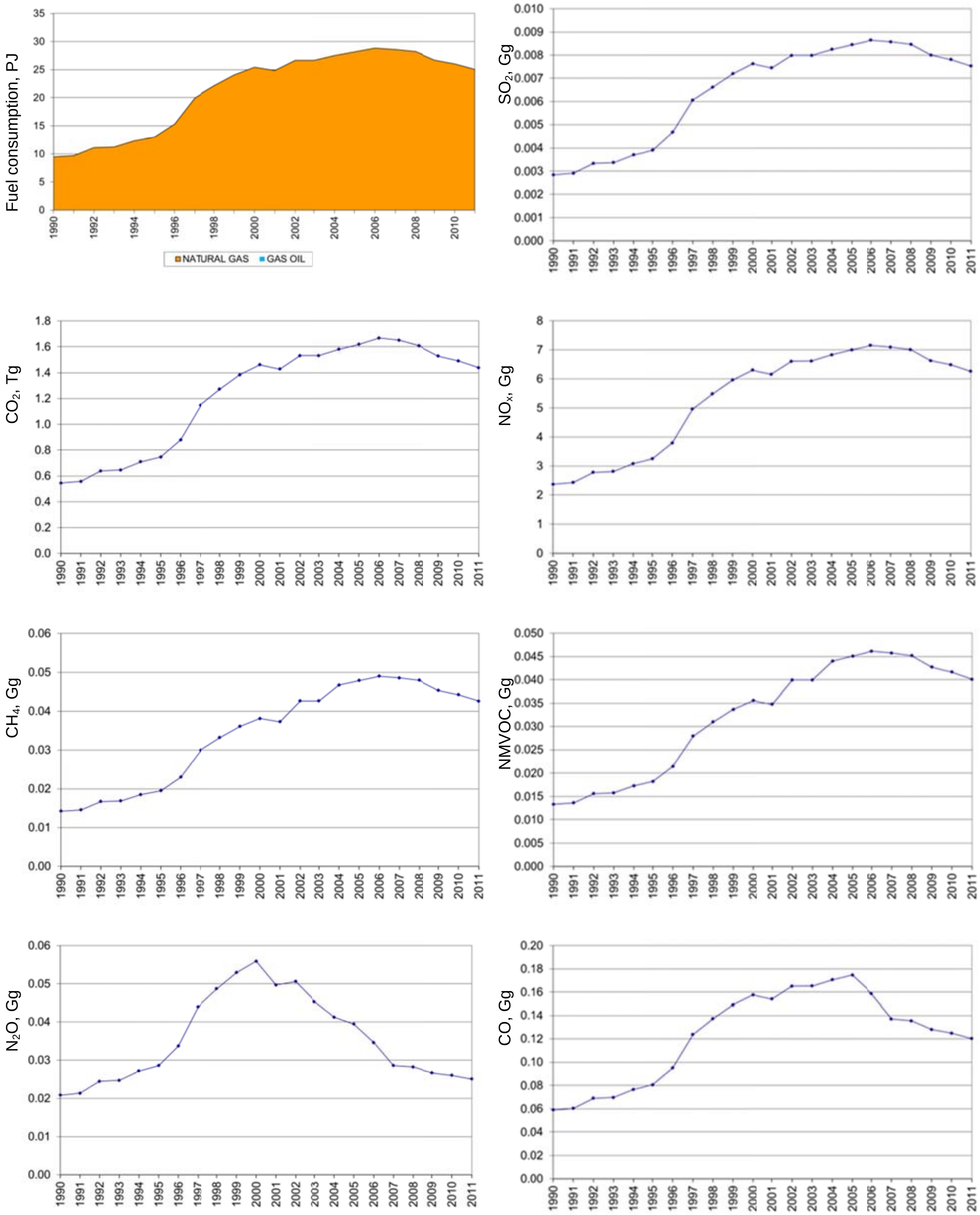


Figure 43 Time series for 1A1c Other energy industries.

5.2 1A2 Industry

Manufacturing industries and construction (Industry) consists of both stationary and mobile sources. In this chapter, only stationary sources are included.

The emission source category *1A2 Industry* consists of the subcategories:

- 1A2a Iron and steel
- 1A2b Non-ferrous metals
- 1A2c Chemicals
- 1A2d Pulp, paper and print
- 1A2e Food processing, beverages and tobacco
- 1A2f i Industry-Other

Figure 44 to 49 show the time series for fuel consumption and emissions. The subsector *Industry – Other* is the main subsector for fuel consumption and emissions. *Food processing, beverages and tobacco* is also an important subsector.

The total fuel consumption in industrial combustion was 15 % lower in 2011 than in 1990. The consumption of natural gas has increased since 1990 whereas the consumption of coal has decreased. The consumption of residual oil has decreased, but the consumption of petroleum coke increased. The biomass consumption has increased 45 % since 1990.

The greenhouse gas emission and the CO_2 emission are both rather stable until 2006 following the small fluctuations in fuel consumption. After 2006, the fuel consumption has decreased. Due to change of applied fuels, the greenhouse gas and CO_2 emissions have decreased more than the fuel consumption since 1990; both emissions have decreased 26 %.

The CH_4 emission has increased from 1994-2001 and decreased again from 2001-2007. In 2011, the emission was 1.9 times the level in 1990. The CH_4 emission follows the consumption of natural gas in gas engines (Figure 44). Most industrial CHP plants based on gas engines came in operation in the years 1995 to 1999. The decrease in later years is a result of the liberalisation of the electricity market.

The N_2O emission has decreased 48 % since 1990, mainly due to the decreased residual oil consumption. In recent years, combustion of wood is a considerable emission source.

The SO_2 emission has decreased 80 % since 1990. This is mainly a result of lower consumption of residual oil in the industrial sector. Further, the sulphur content of residual oil and several other fuels has decreased since 1990 due to legislation and tax laws.

The NO_x emission has decreased 58 % since 1990 due to the reduced emission from industrial boilers in general. Cement production is the main emission source accounting for more than 49 % of the industrial emission in 1990-2009[12]. In 2011, the NO_x emission from cement industry was 35 % of the industrial emission. The NO_x emission from cement production has been reduced by 70 % since 1990. The reduced emission is a result of installation of SCR on all production units at the cement production plant in 2004-2007[13]

[12] More than 60 % of sector 1A2f i.
[13] To meet emission limit.

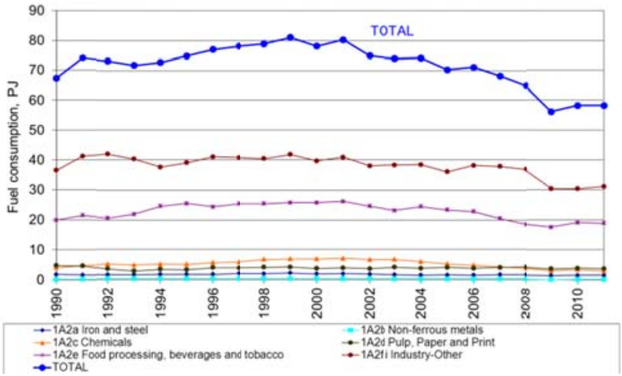
and improved performance of the SCR units in recent years. A NO_x tax was introduced in 2010 (DMT 2008).

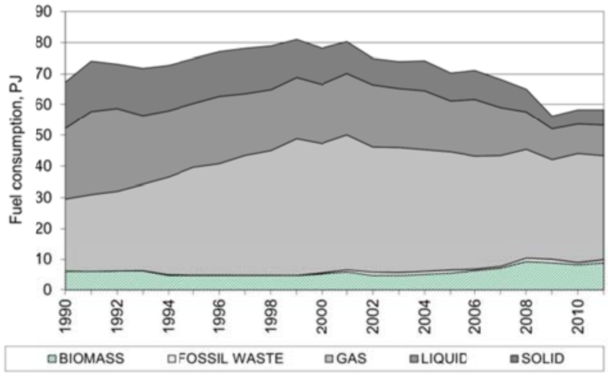
The NMVOC emission has decreased 72 % since 1990. The decrease is mainly a result of a decreased emission factor for combustion of wood in industrial boilers. The emission from gas engines has however increased considerably after 1995 due to the increased fuel consumption that is a result of the installation of a large number of industrial CHP plants (Figure 44). The NMVOC emission factor for gas engines is much higher than for boilers regardless of the fuel.

The CO emission in 2011 was 19 % lower than in 1990. The main source of emission is combustion in *Industry – Other*, primarily from wood combustion and cement production. The CO emission from mineral wool production is included under industrial processes (2A7d). In 1998-2000, the CO emission from the cement production plant was relatively high due to an increased emission from cement production. For 1997 onwards, the emission data for the cement production plant refer to emission measurements and thus the fluctuating time series is considered correct. For 1990-1996, a constant emission factor (in g per Mg product) has been applied.

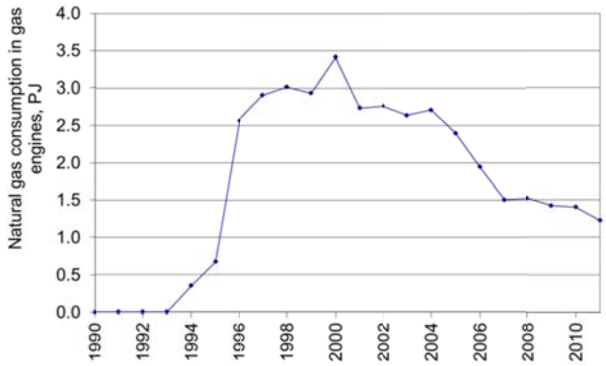
The time series for Hg differ from the time series for other heavy metals. Cement production is the main emission source, and plant specific emission data are available from the cement production plant from 2010. Until 2009, the emission estimate for cement production is based on a constant emission factor in g per Mg product. The decreasing emission of PM from cement production is expected to have at least some influence on the Hg emission. An improved time series for Hg from cement production will be estimated based on a linear decrease of the emission factor from 1997 to 2010.

The largest emission source for PCDD/F is cement production. Several emission measurements have been performed on the cement production plant and all applied emission factors (in g per Mg product) have been based on these emission measurements (Henriksen et al., 2006). However, the high emission factor applied for 1990-1995 (500 ng/Mg clinker) is based on only one emission measurement and thus the emission for these years might be inaccurate. The 2013 update of the EMEP/EEA Guidebook states the emission factor 4.1 ng/te clinker (0.0267 – 627 ng/te clinker). A change of emission factor will be considered for future inventories.





Fuel consumption in natural gas fuelled engines



Fuel consumption, residual oil and wood

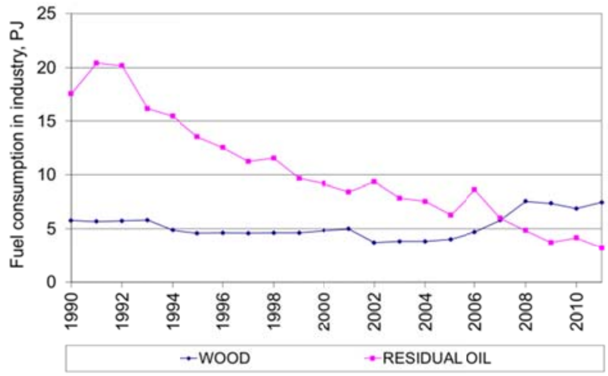


Figure 44   Time series for fuel consumption, 1A2 Industry.

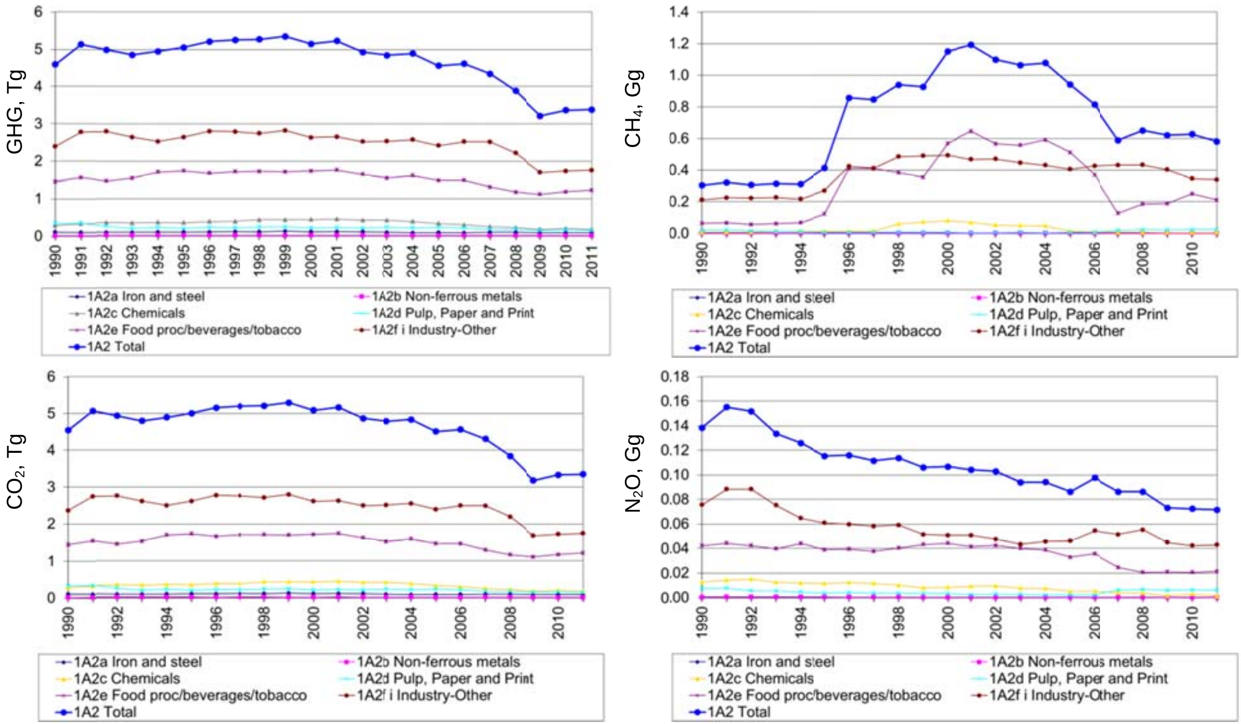


Figure 45   Time series for greenhouse gas emission, 1A2 Industry.

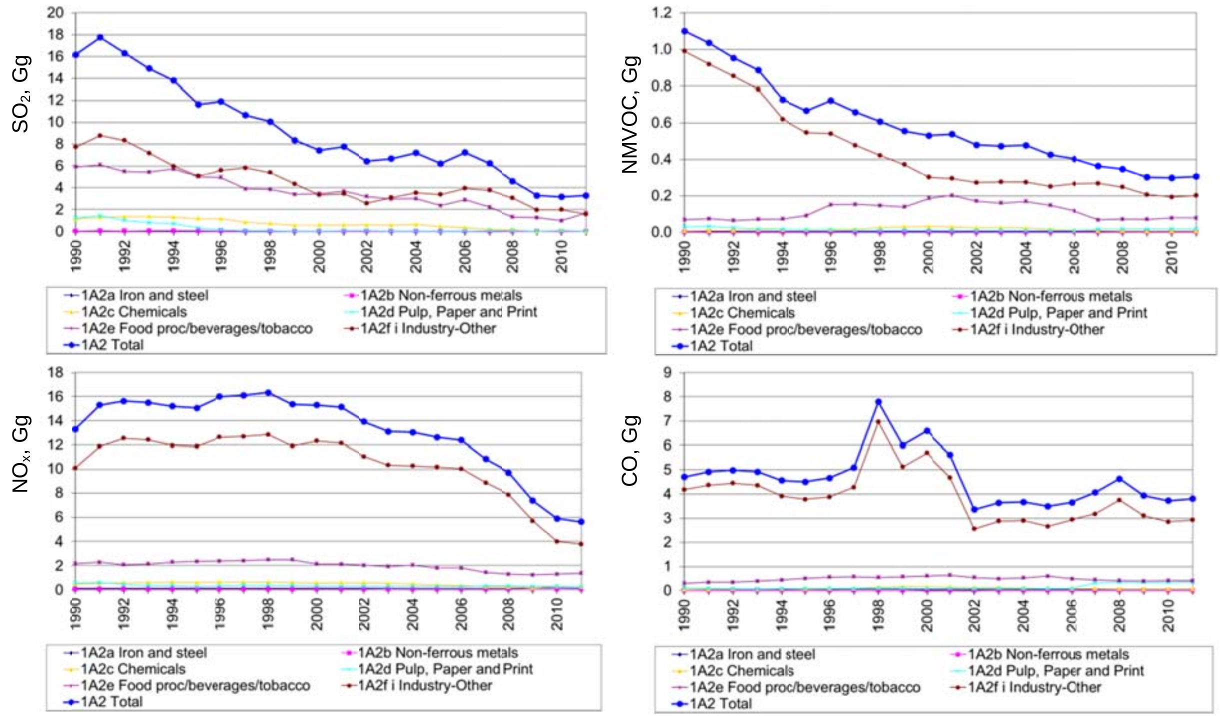


Figure 46 Time series for SO_2, NO_x, NMVOC and CO emission, 1A2 Industry.

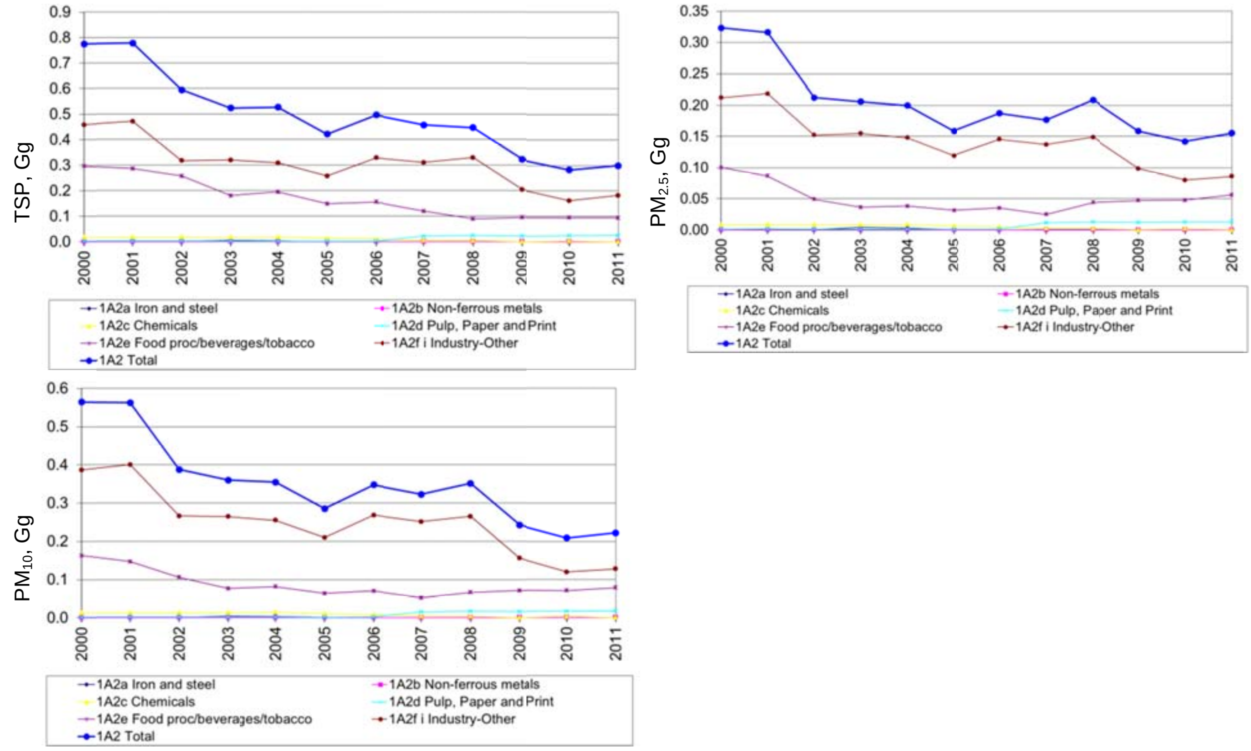


Figure 47 Time series for PM emission, 1A2 Industry.

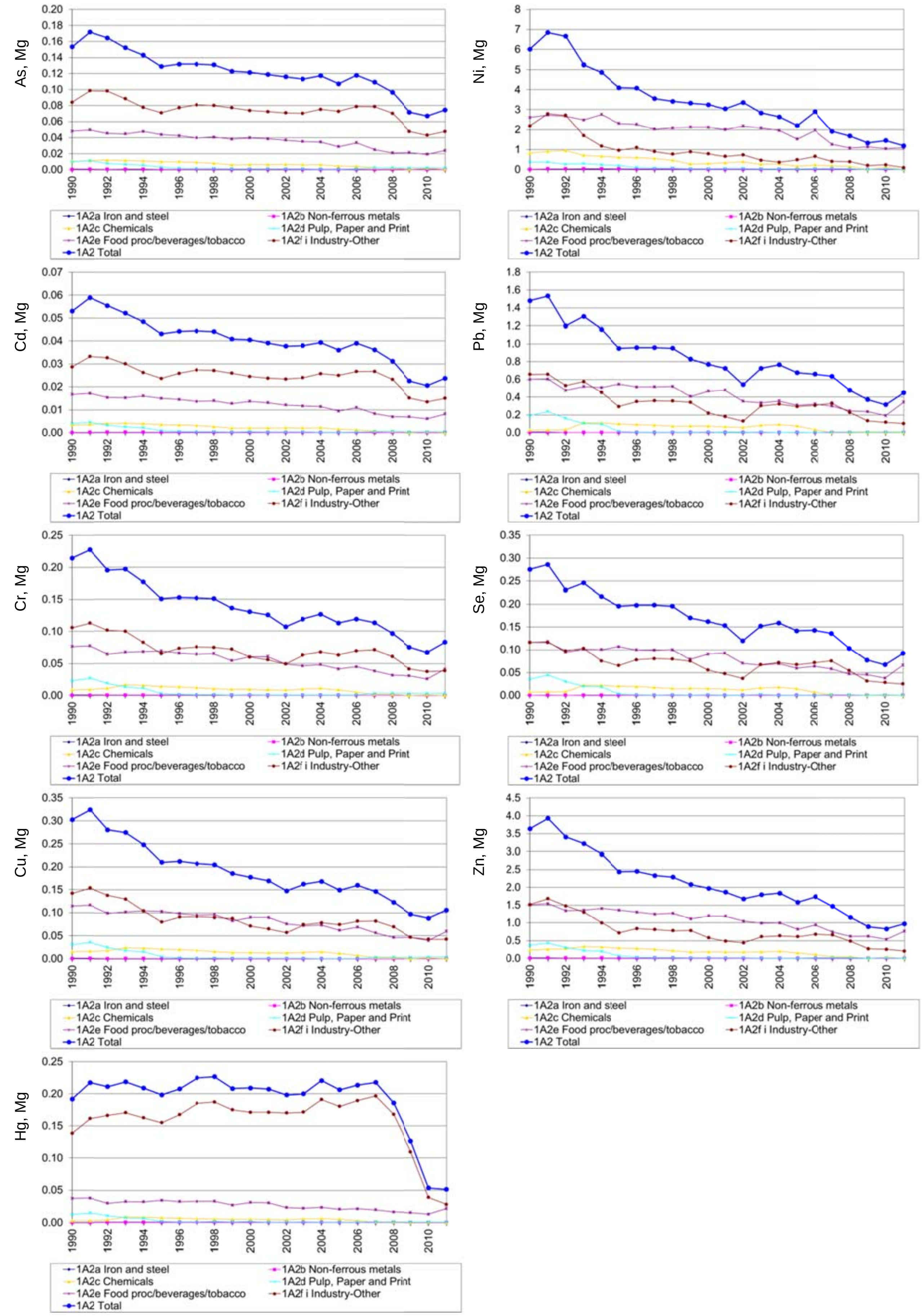


Figure 48 Time series for HM emission, 1A2 Industry.

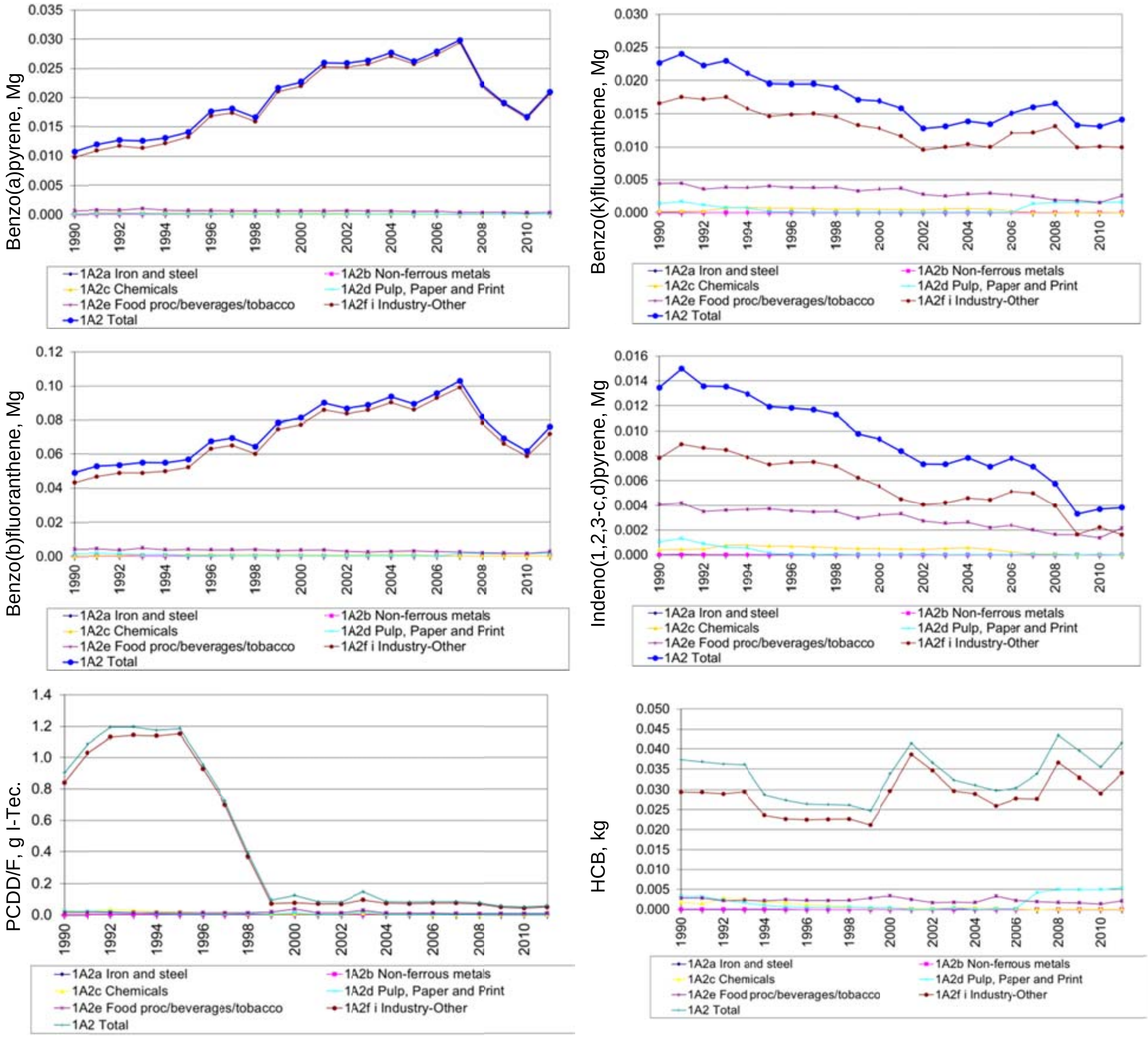


Figure 49 Time series for PAH, PCDD/F and HCB emission, 1A2 Industry.

5.2.1 1A2a Iron and steel

Iron and steel is a very small emission source category. Figure 50 shows the time series for fuel consumption and emissions.

Natural gas is the main fuel in the subsector.

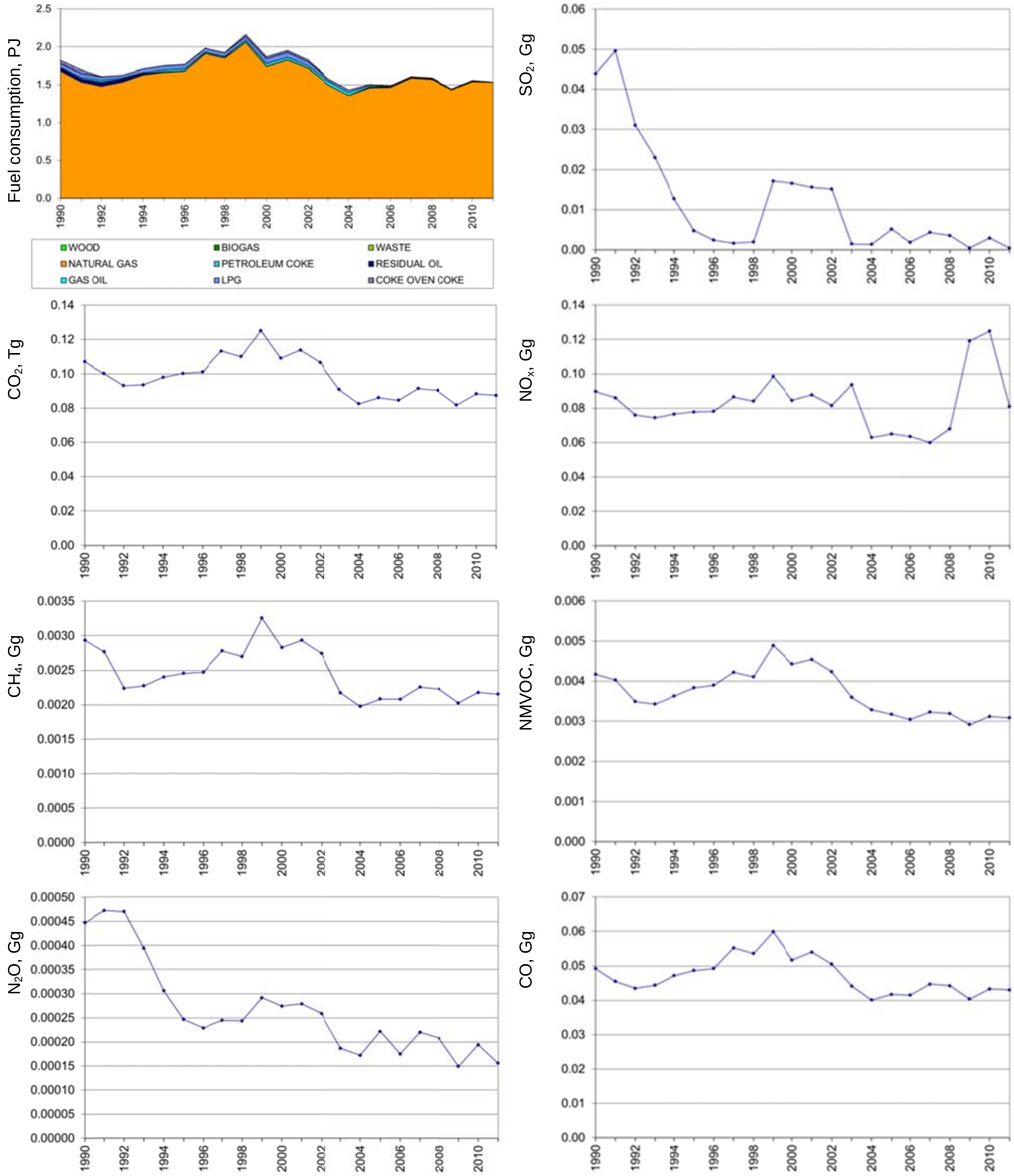


Figure 50 Time series for 1A2a Iron and steel.

5.2.2 1A2b Non-ferrous metals

Non-ferrous metals is a very small emission source category. Figure 51 shows the time series for fuel consumption and emissions.

Natural gas is the main fuel in the subsector. The consumption of residual oil has decreased and the SO_2 emission follows this fuel consumption. The emissions of NO_x, NMVOC and CO follow the fuel consumption.

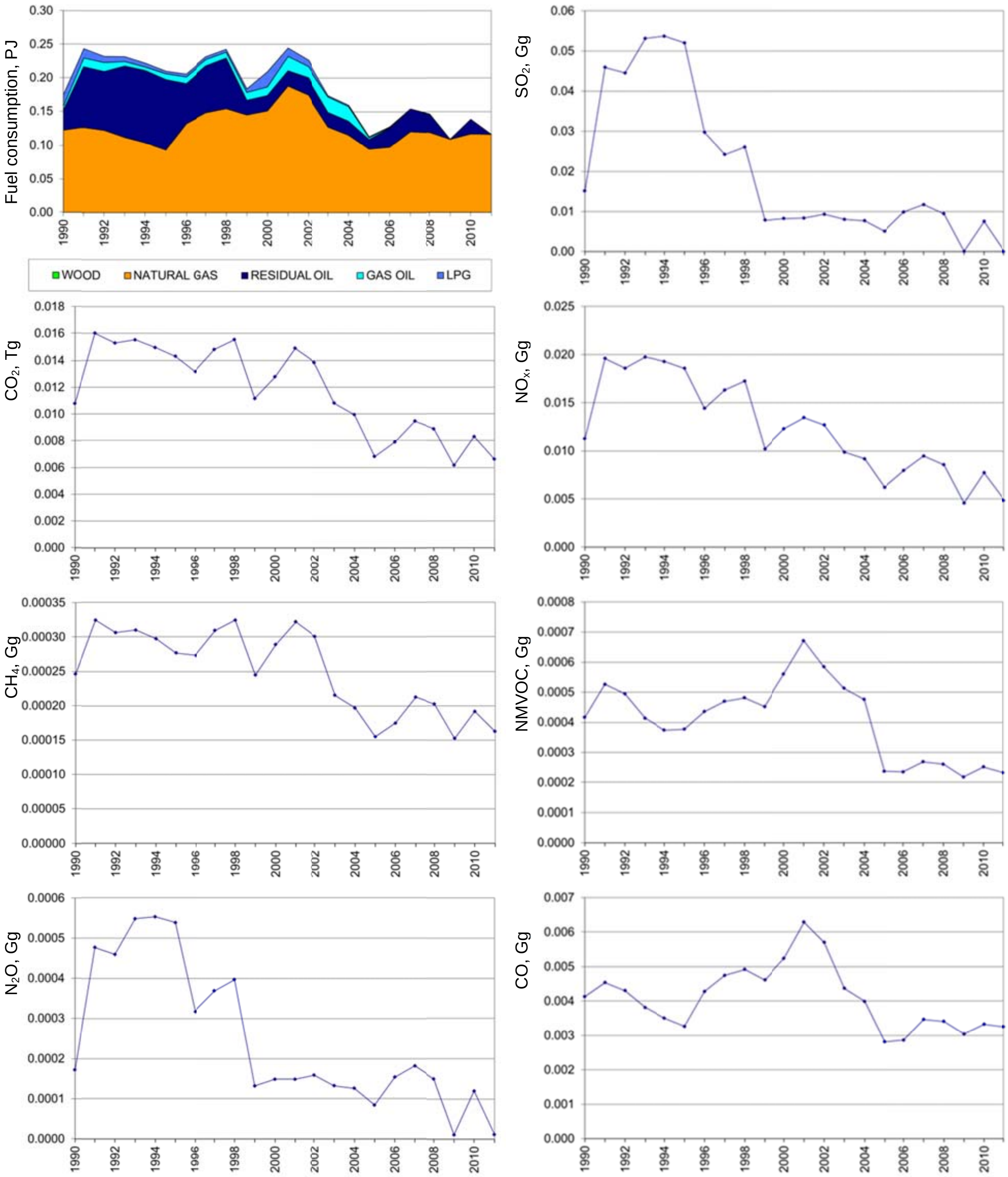


Figure 51 Time series for 1A2b Non-ferrous metals.

5.2.3 1A2c Chemicals

Chemicals is a minor emission source category. Figure 52 shows the time series for fuel consumption and emissions.

Natural gas is the main fuel in this subsector. The consumption of residual oil has decreased and the SO_2 emission follows this fuel consumption. The time series for CH_4, NMVOC and CO is related to consumption of natural gas in gas engines.

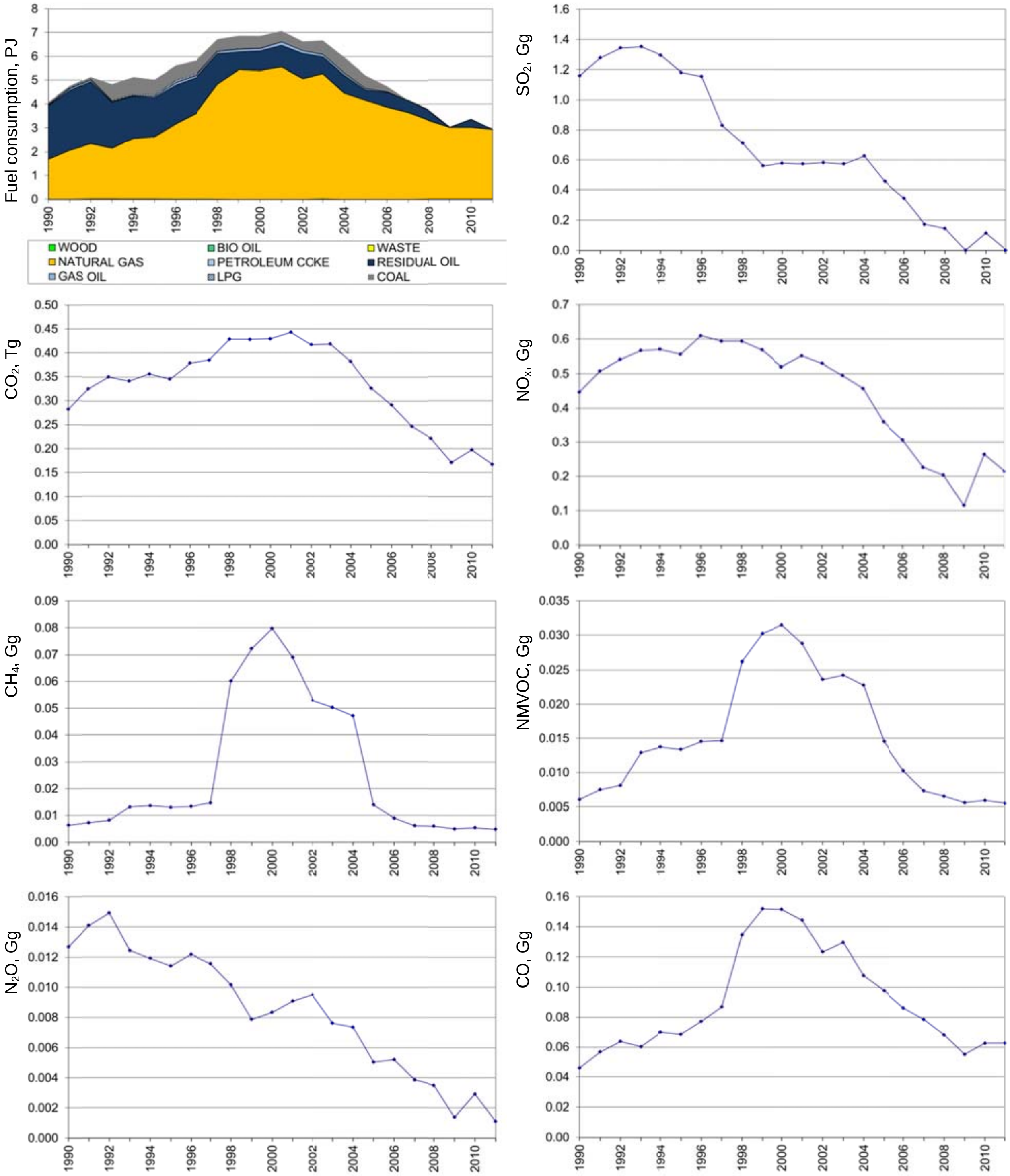


Figure 52 Time series for 1A2c Chemicals.

5.2.4 1A2d Pulp, paper and print

Pulp, paper and print is a minor emission source category. Figure 53 shows the time series for fuel consumption and emissions.

Natural gas and - since 2007 - also wood are the main fuels in the subsector.

The increased consumption of wood from 2006 to 2007 is reflected in both the CH_4, N_2O, NMVOC and CO emission time series.

The consumption of coal and residual oil has decreased and this is reflected in the SO_2 emission time series.

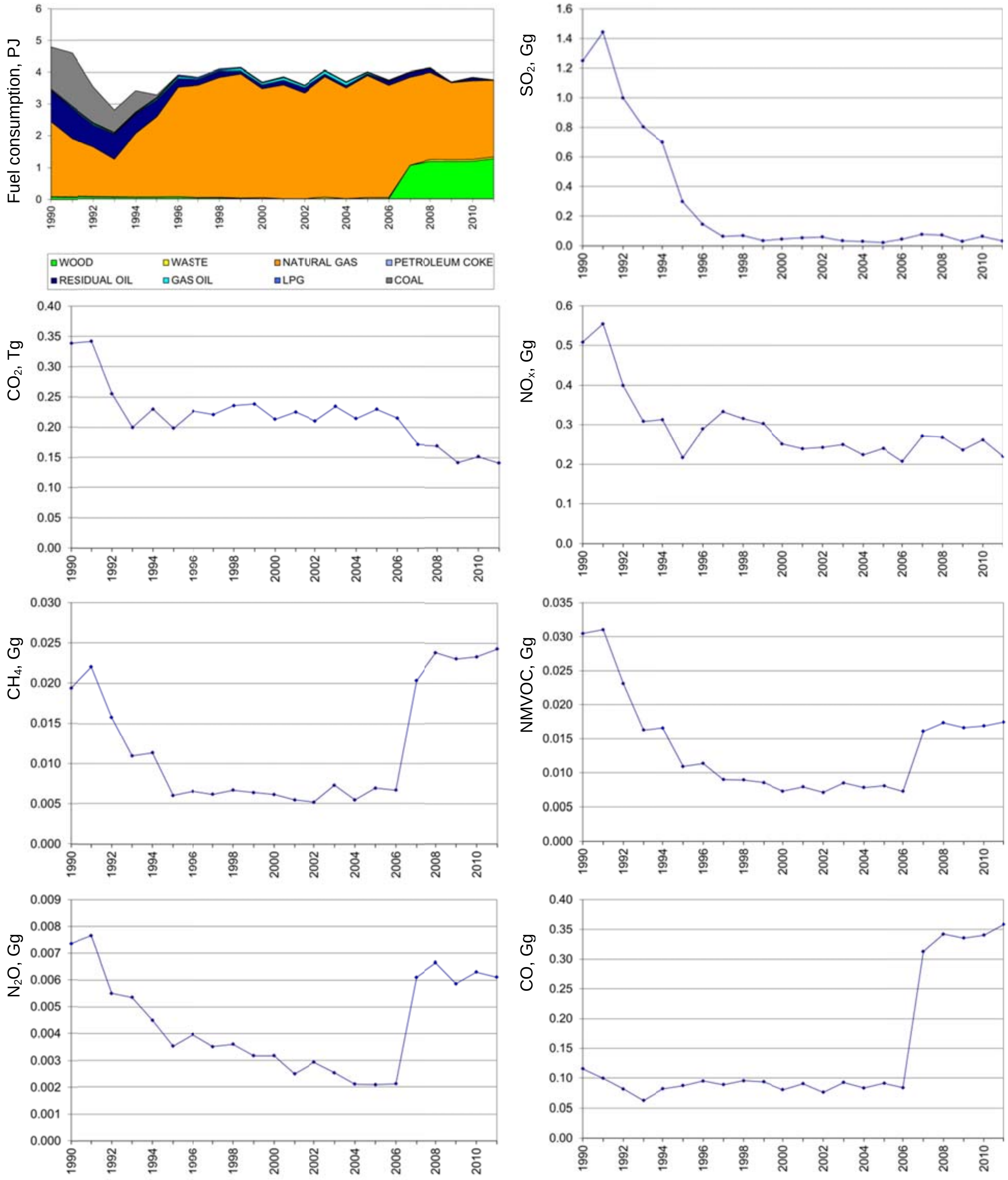


Figure 53 Time series for 1A2d Pulp, paper and print.

5.2.5 1A2e Food processing, beverages and tobacco

Food processing, beverages and tobacco is a considerable industrial subsector. Figure 54 shows the time series for fuel consumption and emissions.

Natural gas, residual oil and coal are the main fuels in the subsector. The consumption of coal and residual oil has decreased whereas the consumption of natural gas has increased. This is reflected in the SO_2 emission time series.

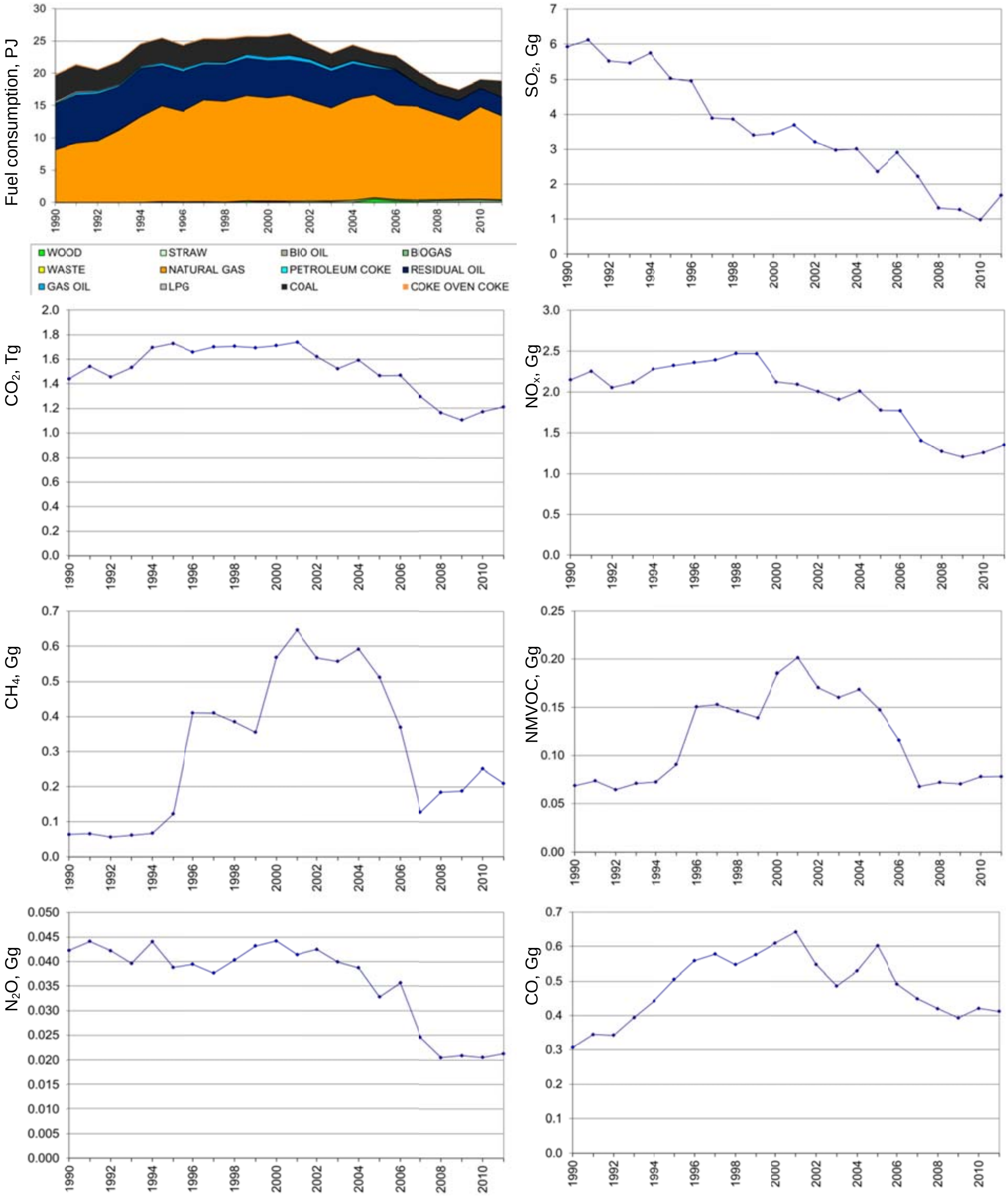


Figure 54 Time series for 1A2e Food processing, beverages and tobacco.

5.2.6 1A2f Industry – other

Industry - other is a considerable industrial subsector. Figure 55 shows the time series for fuel consumption and emissions.

The subsector includes cement production that is a major industrial emission source in Denmark. Thus, cement production account for 31 % of the fuel consumption in 2011. The fuel consumption share for cement production has been between 25 % and 42 % since 1990.

Natural gas is the main fuel in the subsector in recent years and the consumption has increased since 1990. Petroleum coke is also a major fuel in the sector and the consumption has increased since 1990. However, the consumption of petroleum coke has decreased since 2007. Petroleum coke is used mainly in the cement production plant. The consumption of wood has been high throughout the time series. Waste combusted in the cement production plant have been included in fuel category *waste* until 2005 whereas the consumption has been included in fuel category *industrial waste* in 2006 onwards. In future inventories, the consumption will be included in fuel category *industrial waste* all years. The consumption of coal has decreased to 22 % of the fuel consumption in 1990.

The time series for NO_x and CO are discussed above (page 63).

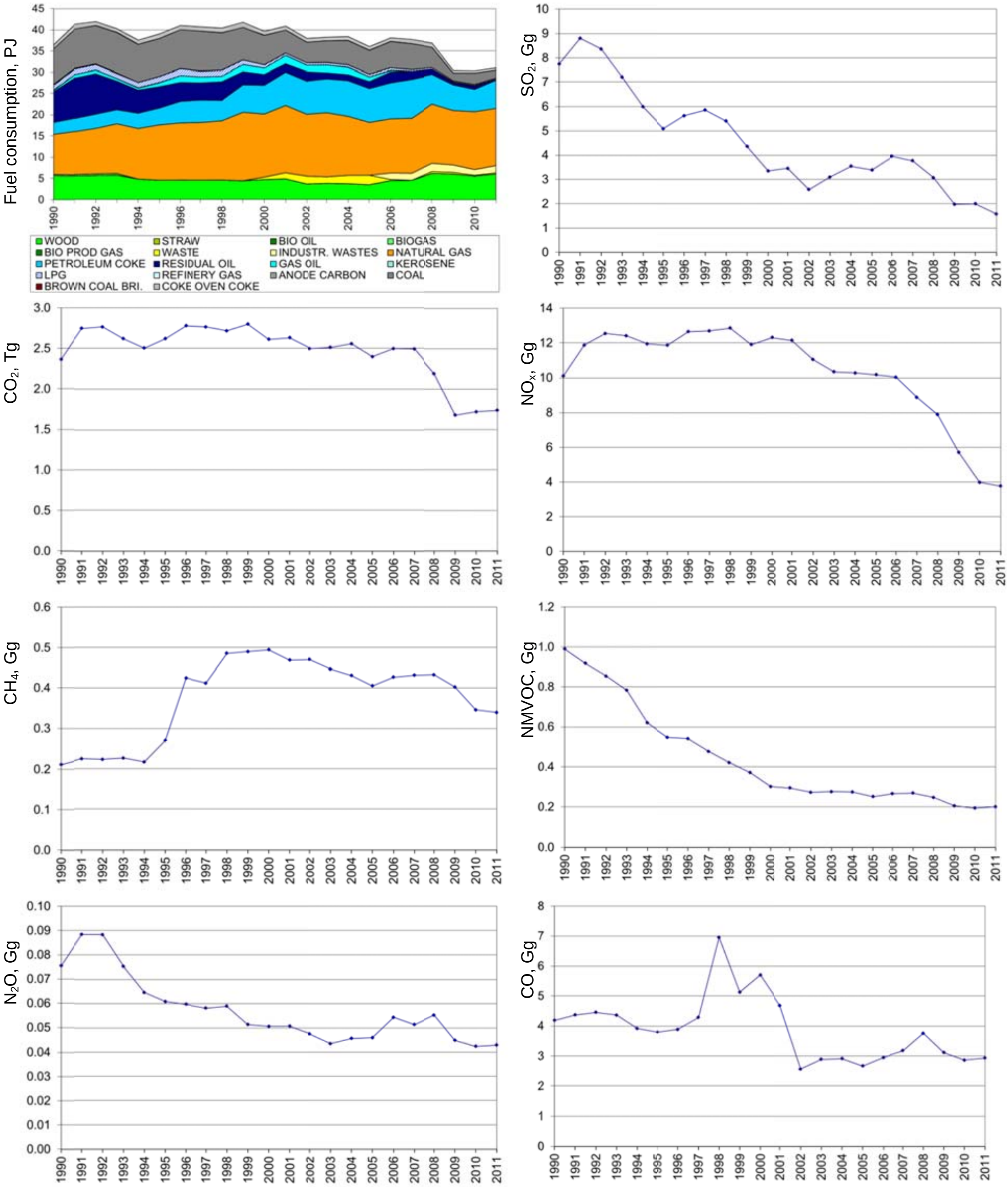


Figure 55 Time series for 1A2f Industry - other.

5.3 1A4 Other Sectors

The emission source category *1A4 Other Sectors* consists of the subcategories:

- 1A4a Commercial/Institutional plants.
- 1A4b Residential plants.
- 1A1c Agriculture/forestry.

Figure 56-Figure 61 present time series for this emission source category. *Residential plants* is the dominant subcategory accounting for the largest part of all emissions. Time series are discussed below for each subcategory.

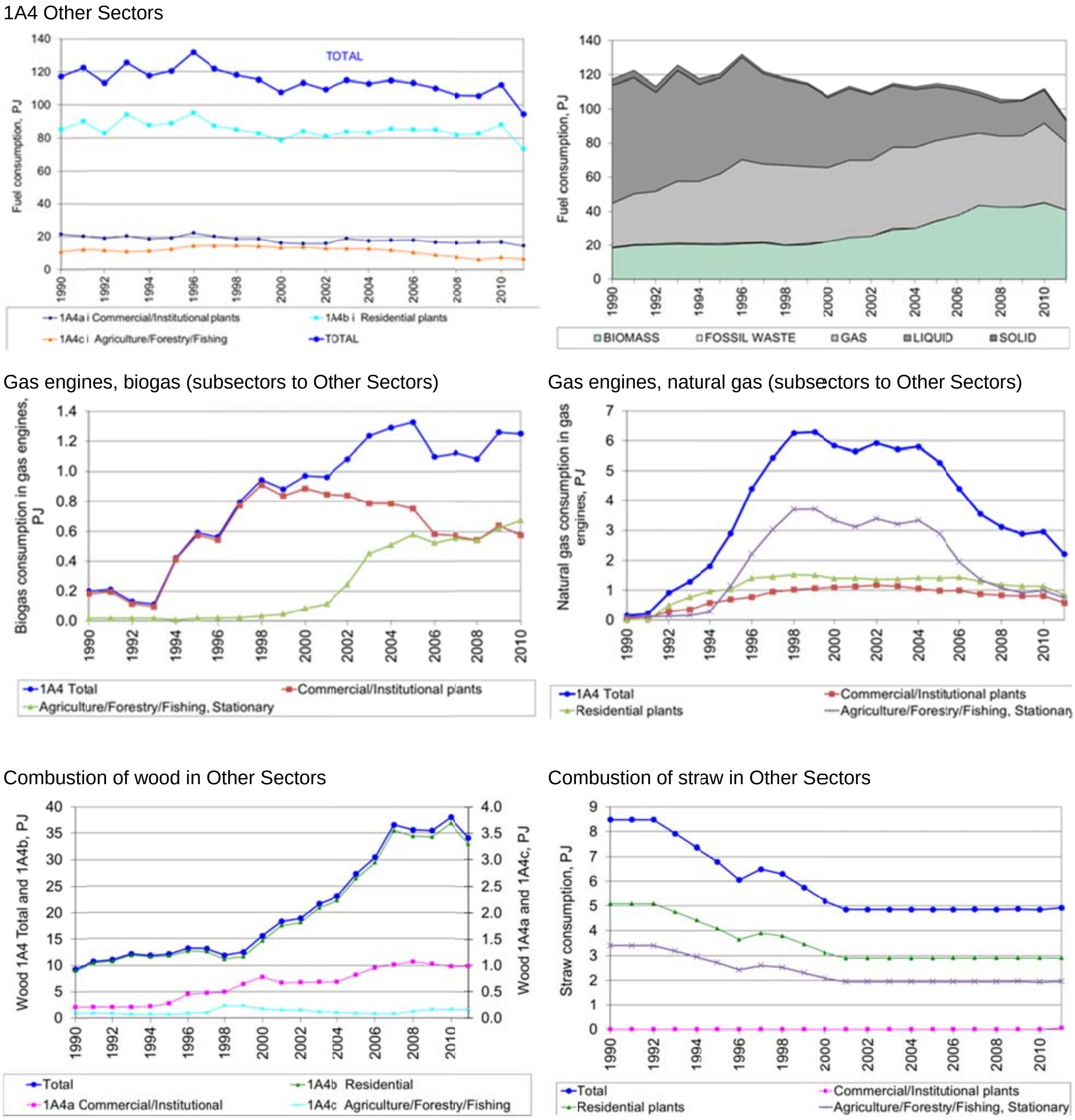


Figure 56 Time series for fuel consumption, 1A4 Other Sectors.

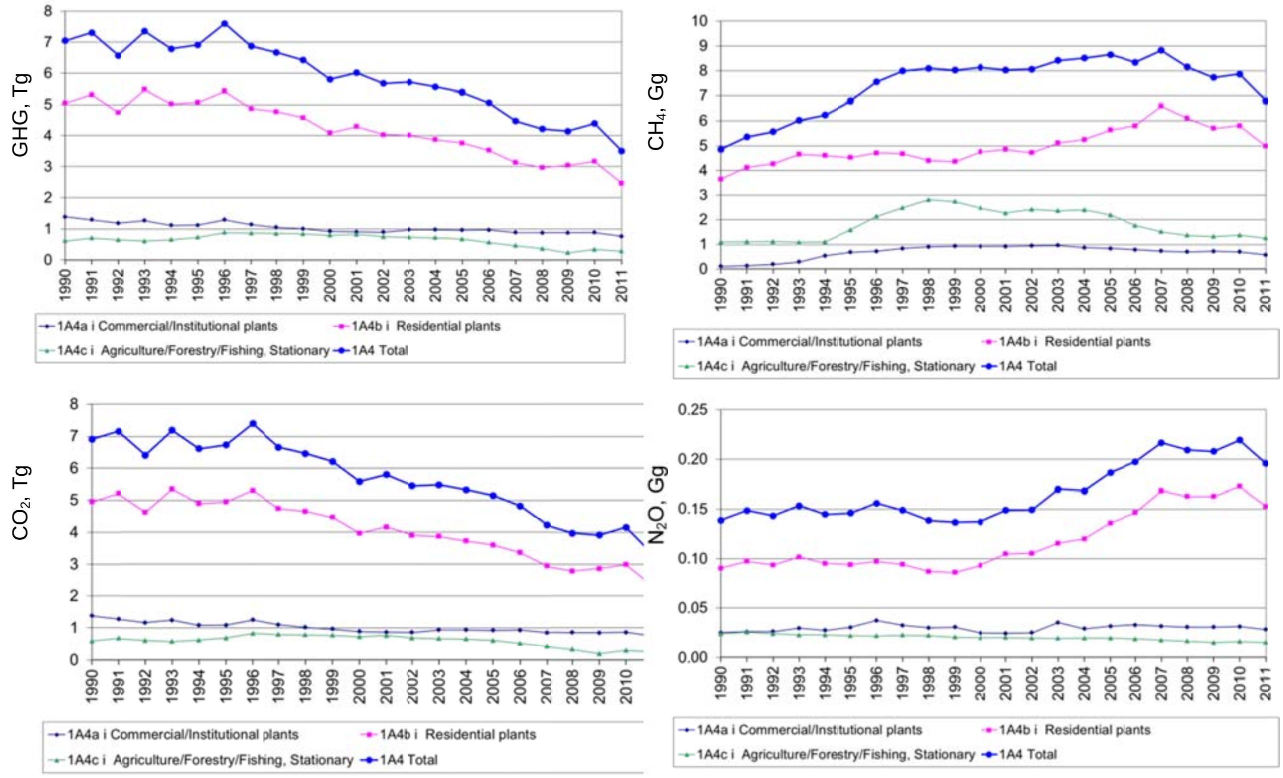


Figure 57 Time series for greenhouse gas emission, 1A4 Other Sectors.

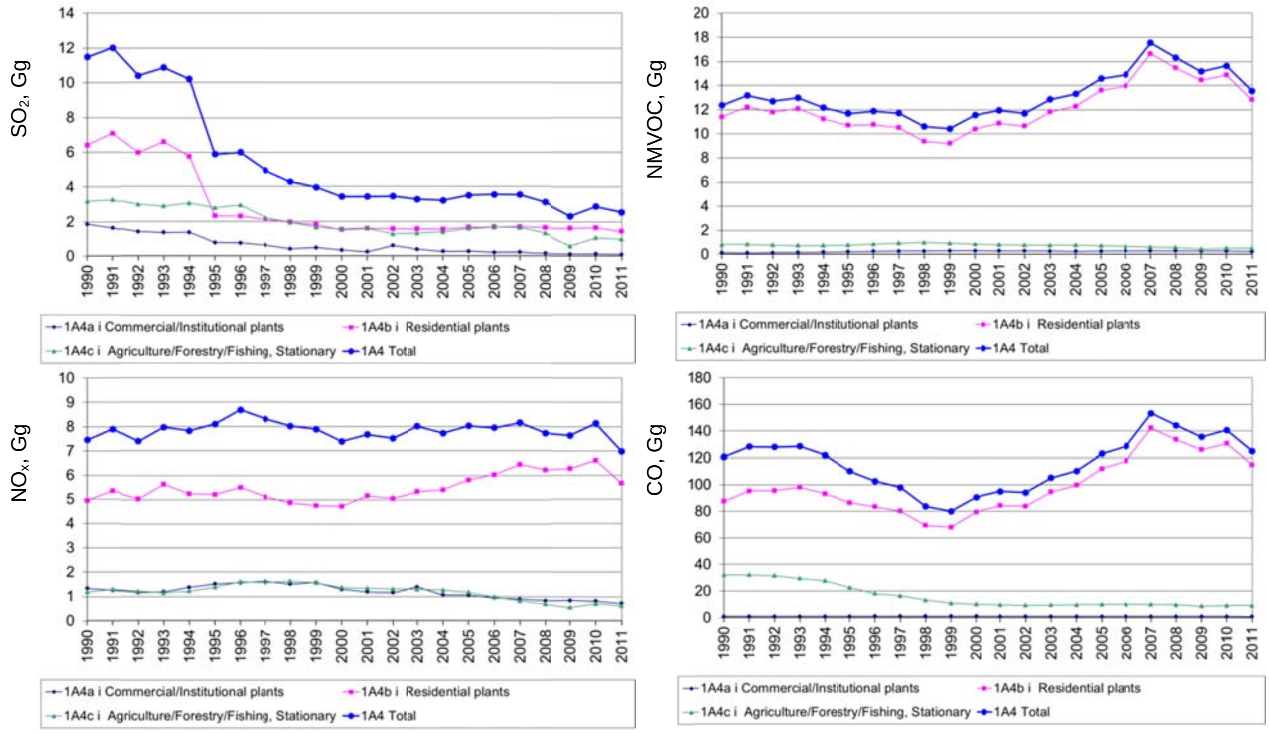


Figure 58 Time series for SO_2, NO_x, NMVOC and CO emission, 1A4 Other Sectors.

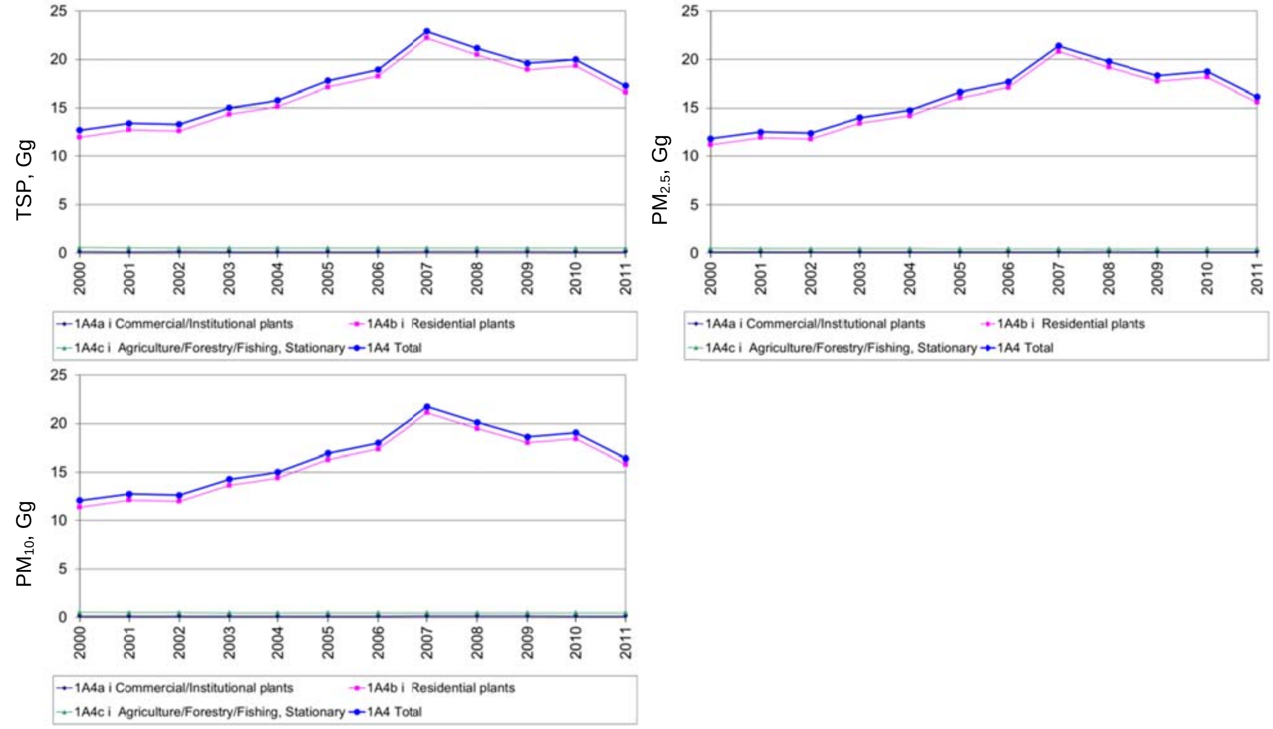


Figure 59 Time series for PM emission, 1A4 Other Sectors.

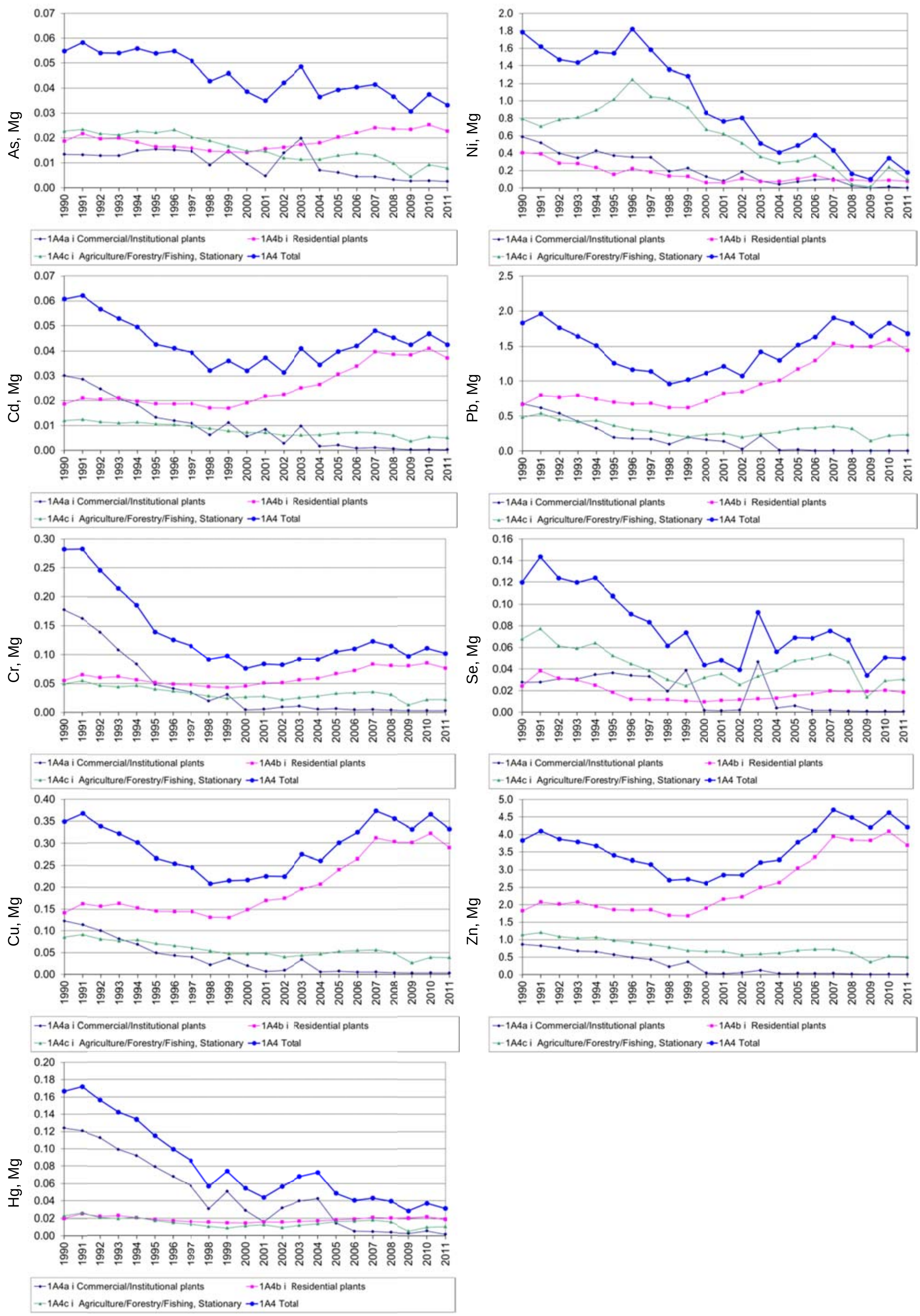


Figure 60 Time series for HM emission, 1A4 Other Sectors.

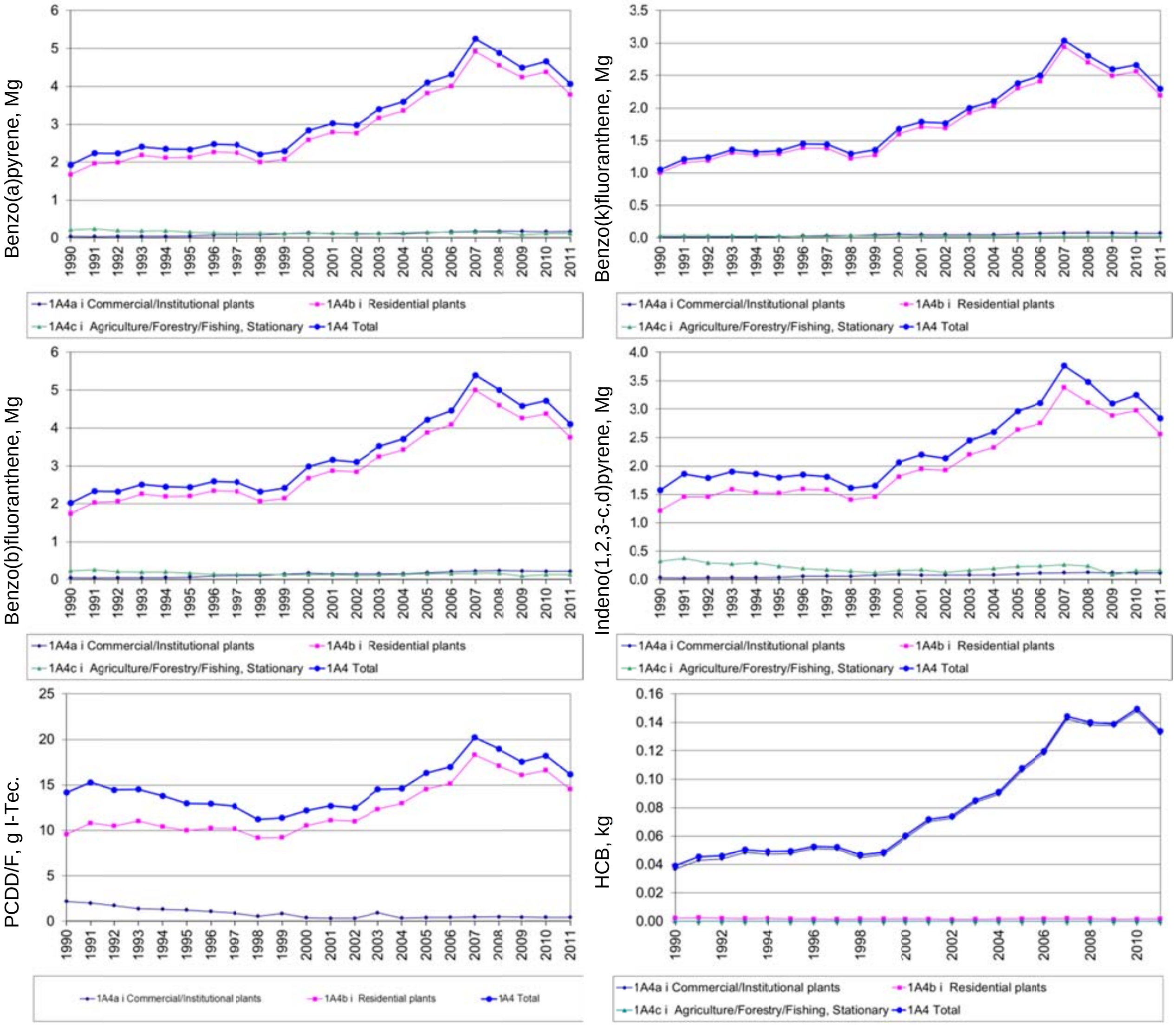


Figure 61 Time series for PAH, PCDD/F and HCB emission, 1A4 Other Sectors.

5.3.1 1A4a Commercial and institutional plants

The subcategory *Commercial and institutional plants* consists of both stationary and mobile sources. In this chapter, only stationary sources are included. The subcategory *Commercial and institutional plants* has low fuel consumption and emissions compared to the other stationary combustion emission source categories. Figure 62 shows the time series for fuel consumption and emissions.

The fuel consumption in commercial/institutional plants has decreased 32 % since 1990 and there has been a change of fuel type. The fuel consumption consists mainly of gas oil and natural gas. The consumption of gas oil has decreased whereas the consumption of natural gas has increased since 1990. The consumption of wood and biogas has also increased. The wood consumption in 2011 was 4.8 times the consumption in 1990.

The CO_2 emission has decreased 46 % since 1990. Both the decrease of fuel consumption and the change of fuels – from gas oil to natural gas - contribute to the decreased CO_2 emission.

The CH_4 emission in 2011 was 5.2 times the 1990 level. The increase is mainly a result of the increased emission from natural gas fuelled engines. The emissions from biogas fuelled engines and from combustion of wood also contribute to the increase. The time series for consumption of natural gas and biogas are shown in Figure 56.

The N_2O emission in 2011 was 13 % higher than in 1990. This increase is a result of the change of fuel from gas oil to natural gas boilers. The emission from wood combustion has also been increasing. The fluctuations of the N_2O emission follow the fuel consumption.

The SO_2 emission has decreased 95 % since 1990. The decrease is a result of both the change of fuel from gas oil to natural gas and of the lower sulphur content in gas oil and in residual oil. The lower sulphur content (0.05 % for gas oil since 1995 and 0.7 % for residual oil since 1997) is a result of Danish tax laws (DEPA 1998). New boilers and abatement equipment was installed in a large wastewater treatment plant in 2002, but the efficiency of the abatement equipment was not as expected in the first months. Thus, an increased emission from this plant has caused the increased SO_2 emission in 2002.

The NO_x emission was 47 % lower in 2011 than in 1990. The decrease is mainly a result of the lower fuel consumption but also the change from gas oil to natural gas has contributed to the decrease. The emission from gas engines and wood combustion has increased.

The NMVOC emission in 2011 was 1.8 times the 1990 emission level. The large increase is a result of the increased combustion of wood that is the main source of emission. The increased consumption of natural gas in gas engines (Figure 56) also contribute to the increased NMVOC emission.

The CO emission has decreased 16 % since 1990. The emission from wood and from natural gas fuelled engines and boilers have increased, whereas the emission from gas oil has decreased. This is a result of the change of fuels applied in the sector.

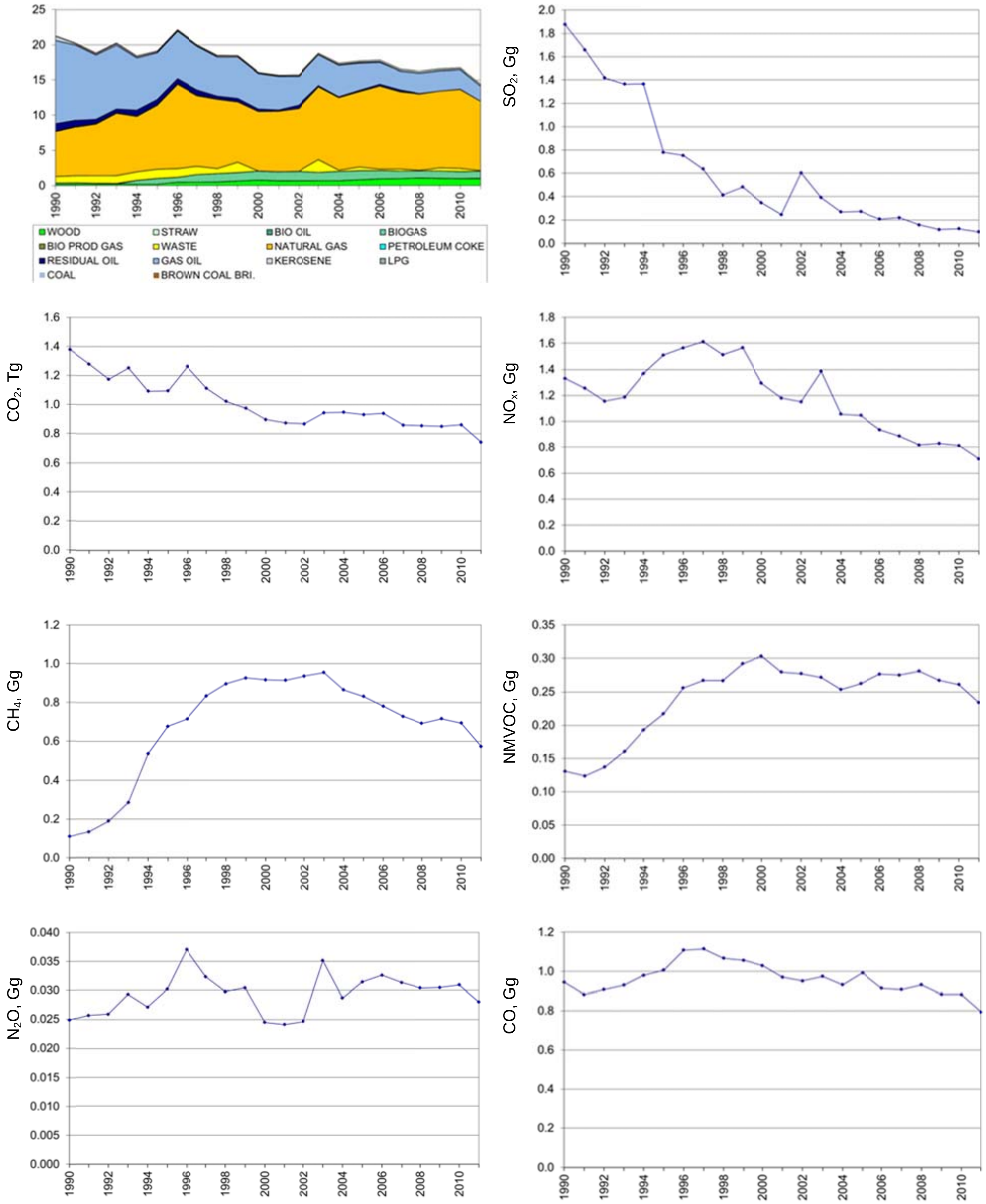


Figure 62 Time series for 1A4a Commercial /institutional.

5.3.2 1A4b Residential plants

The emission source category *Residential plants* consists of both stationary and mobile sources. In this chapter, only stationary sources are included. Figure 63 shows the time series for fuel consumption and emissions.

For residential plants, the total fuel consumption was 14 % lower in 2011 than in 1990. The large decrease from 2010 to 2011 is caused by higher temperature in the winter season of 2011. The consumption of gas oil has decreased since 1990 whereas the consumption of wood has increased considerably (3.7 times the 1990 level). The consumption of natural gas has also increased since 1990.

The CO_2 emission has decreased by 53 % since 1990. This decrease is mainly a result of the considerable change in fuels used from gas oil to wood and natural gas.

The CH_4 emission from residential plants has increased 36 % since 1990 due to the increased combustion of wood in residential plants, which is the main source of emission. The increased emission from gas engines also contributes to the increased emission.

The change of fuel from gas oil to wood has resulted in a 69 % increase of N_2O emission since 1990 due to a higher emission factor for wood than for gas oil.

The large decrease (77 %) of SO_2 emission from residential plants is mainly a result of a change of sulphur content in gas oil since 1995. The lower sulphur content (0.05 %) is a result of Danish tax laws (DEPA 1998). In addition, the consumption of gas oil has decreased and the consumption of natural gas that results in very low SO_2 emissions has increased.

The NO_x emission has increased by 15 % since 1990 due to the increased emission from wood combustion. The emission factor for wood is higher than for gas oil.

The emission of NMVOC has increased 13 % since 1990 as a result of the increased combustion of wood. The emission factor for wood has decreased since 2000, due to improved technology, but not as much as the increase in consumption of wood. The emission factor for wood and straw is higher than for liquid or gaseous fuels.

The CO emission has increased 31 % due to the increased use of wood that is the main source of emission. The emission factor for wood has decreased since 2000, due to improved technology, but not as much as the increase in consumption of wood. The emission from combustion of straw has decreased since 1990.

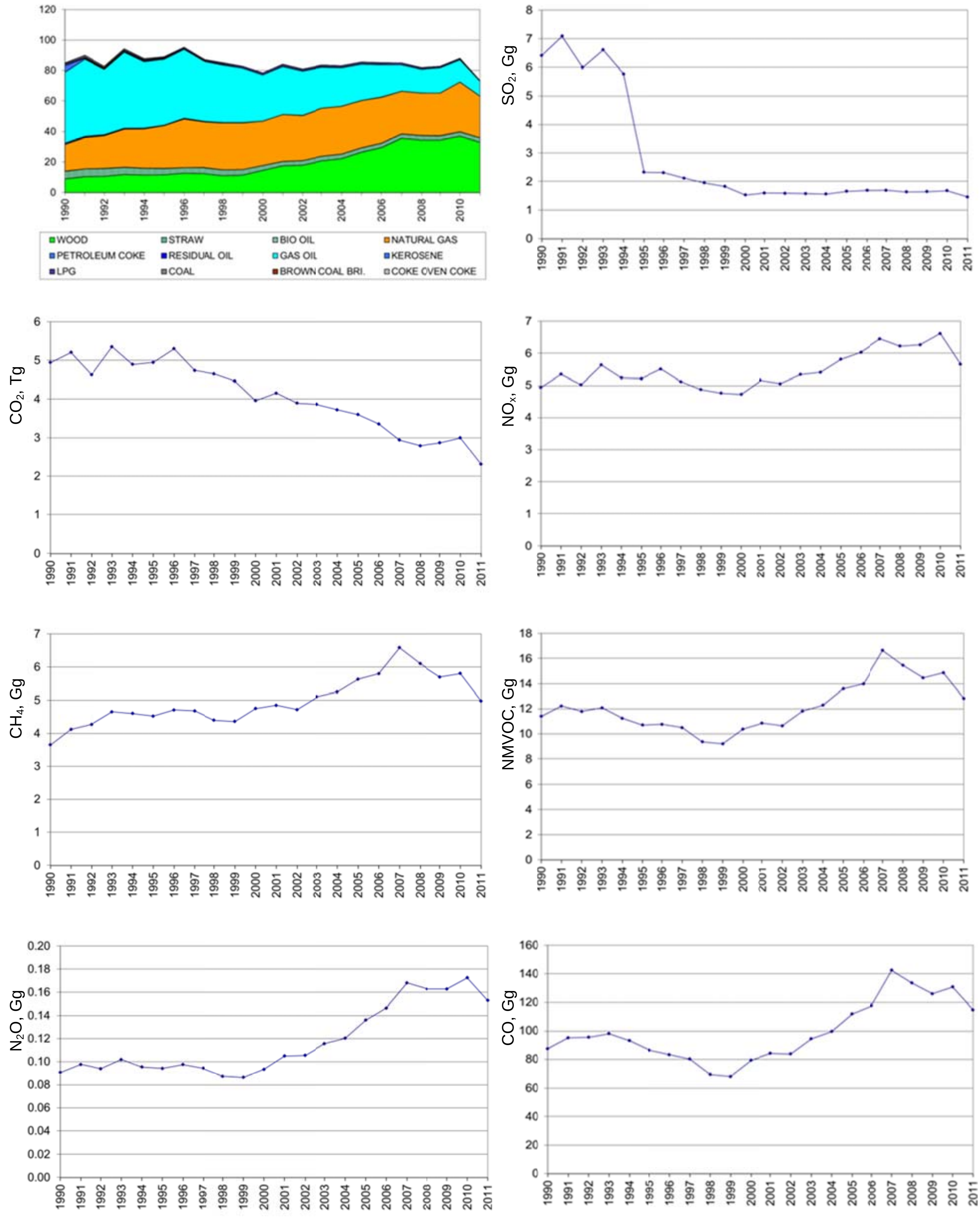


Figure 63 Time series for 1A4b Residential plants.

5.3.3 1A4c Agriculture/forestry

The emission source category *Agriculture/forestry* consists of both stationary and mobile sources. In this chapter, only stationary sources are included. Figure 64 shows the time series for fuel consumption and emissions.

For plants in agriculture/forestry, the fuel consumption has decreased 41 % since 1990. A considerable decrease in the fuel consumption has taken place since year 2000.

The type of fuel that has been applied has changed since 1990. In the years 1994-2004, the consumption of natural gas was high, but in recent years, the consumption decreased again. A large part of the natural gas consumption has been applied in gas engines (Figure 56). Most CHP plants in agriculture/forestry based on gas engines came in operation in 1995-1999. The decrease in later years is a result of the liberalisation of the electricity market.

The consumption of straw has decreased since 1990. The consumption of both residual oil and gas oil has increased after 1990 but has decreased again in recent years.

The CO_2 emission in 2011 was 57 % lower than in 1990. The CO_2 emission increased from 1990 to 1996 due to increased fuel consumption. Since 1996, the CO_2 emission has decreased in line with the decrease in fuel consumption.

The CH_4 emission in 2011 was 14 % higher than the emission in 1990. The emission follows the time series for natural gas combusted in gas engines (Figure 56). The emission from combustion of straw has decreased as a result of the decreasing consumption of straw in the sector.

The emission of N_2O has decreased by 37 % since 1990. The decrease is a result of the lower fuel consumption as well as the change of fuel. The decreasing consumption of straw contributes considerably to the decrease of emission.

The SO_2 emission was 68 % lower in 2011 than in 1990. The emission decreased mainly in the years 1996-2002. The main emission sources are coal, residual oil and straw.

The emission of NO_x was 48 % lower in 2011 than in 1990.

The emission of NMVOC has decreased 41 % since 1990. The major emission source is combustion of straw. The consumption of straw has decreased since 1990. The emission from gas engines has increased mainly due to increased fuel consumption.

The CO emission has decreased 71 % since 1990. The major emission source is combustion of straw. In addition to the decrease of straw consumption, the emission factor for straw has also decreased since 1990.

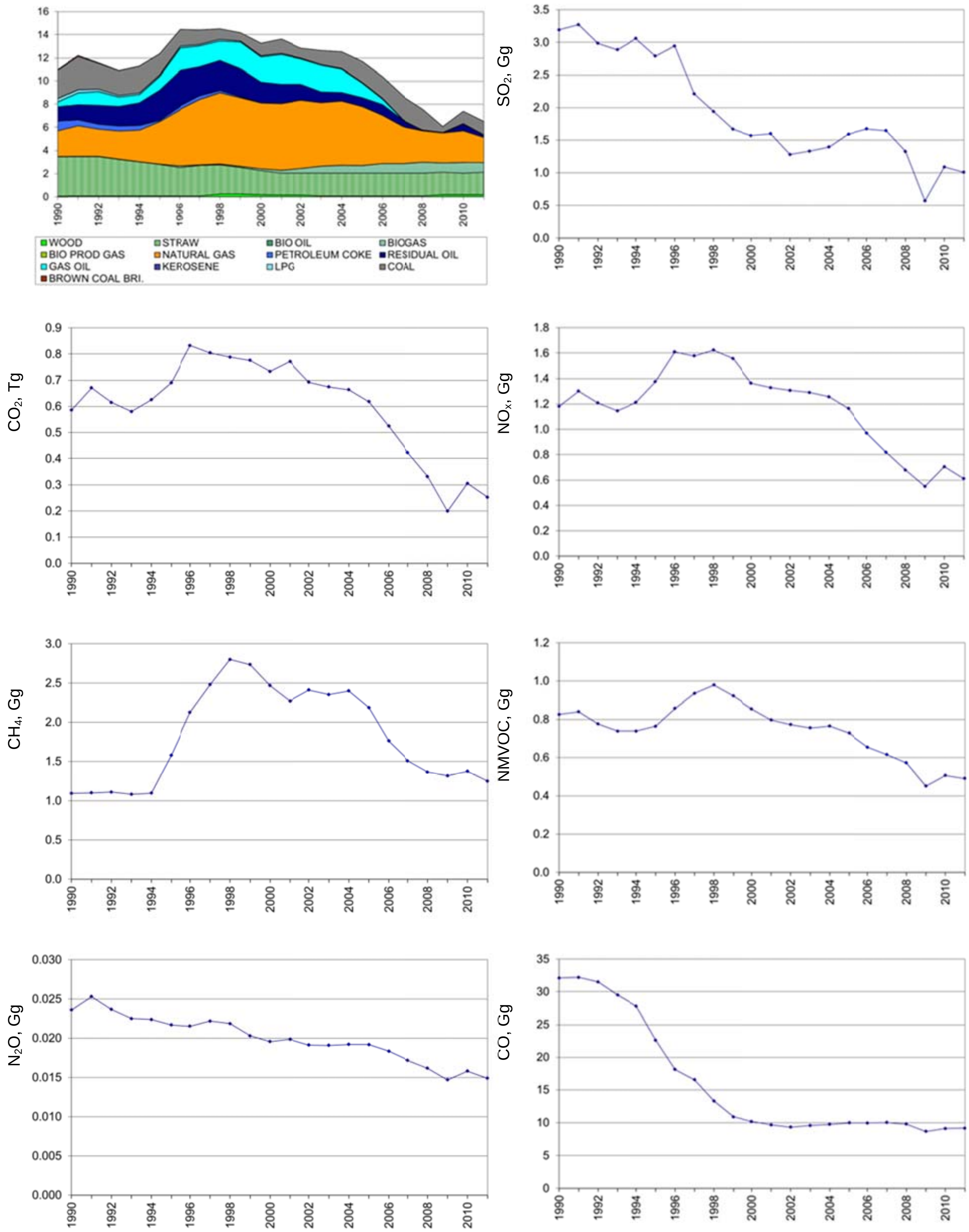


Figure 64 Time series for 1A4c Agriculture/forestry.

6 Geographical distribution of the emissions

The Danish SPREAD model is used to make a spatial distribution of all emissions included in the national emission inventories. The SPREAD model provides gridded emissions on a grid of 1 km x 1 km. Gridding is carried out on the most disaggregated level possible, to ensure that all emissions are distributed in the most accurate way. The methodologies will not be discussed further here, but can be found in Plejdrup & Gyldenkærne (2011). Figure 65 illustrates the gridded emission of SO_2 in 2010 on the 1 km x 1 km grid. Grid cells with large emissions are symbolised by circles to be visible on the map.

Gridded emissions have been reported to the LRTAP Convention in 2012 for the years 2005 and 2010. The national emissions are disaggregated to a grid of 50x50 km². Gridded data are reported for SO_2, NO_x, NMVOC, NH_3, CO, PM_{10}, $PM_{2.5}$, Cd, Hg, Pb, PCDD/F, PAH, and HCB. The reported gridded emission data are available on the EU EIONET (European Environment Information and Observation Network) homepage[14].

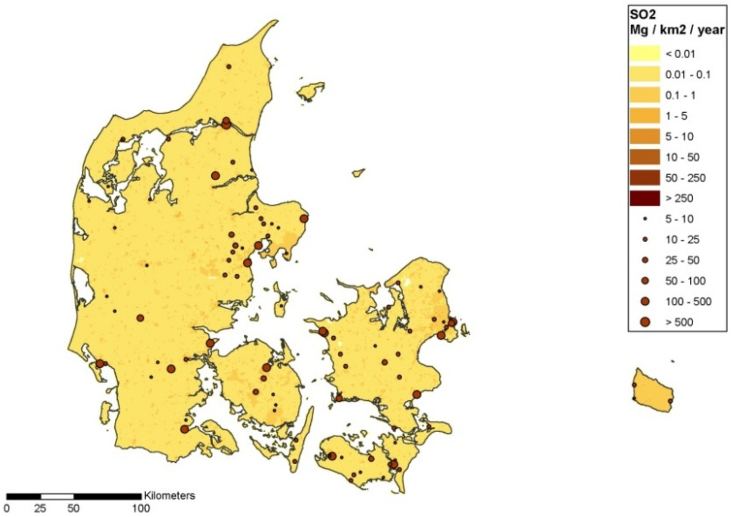


Figure 65 Gridded SO_2 emission from stationary combustion in 2011.

[14] http://cdr.eionet.europa.eu/dk

7 Methodological issues

The Danish emission inventory is based on the CORINAIR (CORe INventory on AIR emissions) system, which is a European program for air emission inventories. CORINAIR includes methodology structure and software for inventories. The methodology is described in the EMEP/EEA air pollutant emission inventory guidebook, 2009 update (EEA 2009). Emission data are stored in an Access database, from which data are transferred to the reporting formats.

In the Danish emission database all activity rates and emissions are defined in SNAP sector categories (Selected Nomenclature for Air Pollution) according the CORINAIR system. The emission inventories are prepared from a complete emission database based on the SNAP source categories. Aggregation to the source category codes used in CRF is based on a correspondence list enclosed in Annex 1.

The emission inventory for stationary combustion is based on activity rates from the Danish energy statistics. General emission factors for various fuels, plants and sectors have been determined. Some large plants, such as power plants, are registered individually as large point sources and plant-specific emission data are used.

Recalculations and improvements are shown in Chapter 11.

7.1 Tiers

The type of emission factor and the applied tier level for each emission source are shown in Table 24 below. The tier levels have been determined based on the Revised 1996 IPCC Guidelines (IPCC 1997).

The fuel consumption data for transformation are technology specific. For end-use of fuels, the disaggregation to specific technologies is less detailed. However, for residential wood combustion the technology disaggregation is less detailed.

Distinguishing between tier level 2 and tier 3 has been based on the emission factor. The tier level definitions have been interpreted as follows:

- Tier 1: The emission factor is an IPCC default tier 1 value.
- Tier 2: The emission factors are country specific and based on a few emission measurements or on IPCC tier 2 emission factors.
- Tier 3: Based on plant specific emission data or on a country specific emission factor based on a considerable number of plant specific emission measurements and detailed technology knowledge.

Table 24 gives an overview of the calculation methods and type of emission factor. The table also shows which of the source categories are key in any of the key source analysis[15].

[15] Key category according to the KCA tier 1 or tier 2 for Denmark (excluding Greenland and Faroe Islands), including LULUCF, level 1990/ level 2011/ trend.

Table 24 Methodology and type of emission factor.

		Tier	EMF 1)	Key category 2)
Stationary Combustion, Coal	CO_2	Tier 3[16] (Tier 3 / Tier 1[17])	PS (CS / D)	Yes
Stationary Combustion, brown coal briquettes	CO_2	Tier 1	D	No
Stationary Combustion, Coke	CO_2	Tier 1	D	No
Stationary Combustion, Fossil waste	CO_2	Tier 3	CS	Yes
Stationary Combustion, Petroleum coke	CO_2	Tier 2	CS	Yes
Stationary Combustion, Residual oil	CO_2	Tier 3 / Tier 3 / Tier 1 2)	PS / CS / D[18]	Yes
Stationary Combustion, Gas oil	CO_2	Tier 2 / Tier 3	CR / PS	Yes
Stationary Combustion, Kerosene	CO_2	Tier 1	D	Yes
Stationary Combustion, LPG	CO_2	Tier 1	D	No
Stationary Combustion, Refinery gas	CO_2	Tier 3	PS / CS	Yes
Stationary Combustion, Natural gas	CO_2	Tier 3	CS / PS[19]	Yes
Stationary Combustion, SOLID	CH_4	Tier 2 / Tier 1	D(2) / D	No
Stationary Combustion, LIQUID	CH_4	Tier 2 / Tier 2 / Tier 1	D(2) / CS / D	No
Stationary Combustion, GAS	CH_4	Tier 2 / Tier 3	D(2) / CS	No
Natural gas fuelled engines, GAS	CH_4	Tier 3	CS	Yes
Stationary Combustion, WASTE	CH_4	Tier 2	CS	No
Stationary Combustion, BIOMASS	CH_4	Tier 2 / Tier 1	D(2) / CS / D	Yes
Biogas fuelled engines, BIOMASS	CH_4	Tier 3	CS	No
Stationary Combustion, SOLID	N_2O	Tier 2 / Tier 1	CS / D	Yes
Stationary Combustion, LIQUID	N_2O	Tier 2 / Tier 1	D(2) / D / CS	Yes
Stationary Combustion, GAS	N_2O	Tier 1 / Tier 2	D / CS / D(2)	Yes
Stationary Combustion, WASTE	N_2O	Tier 2	CS	Yes
Stationary Combustion, BIOMASS	N_2O	Tier 1 / Tier 2	D / CS / D(2)	Yes

1) D: IPCC tier 1, D(2): IPCC tier 2/3, CR: Corinair default, CS: Country specific, PS: Plant specific.

2) KCA tier 1 or tier 2 for Denmark (excluding Greenland and Faroe Islands), including LULUCF, level 1990/ level 2011/ trend.

7.2 Large point sources

Large emission sources such as power plants, waste incineration plants, industrial plants and refineries are included as large point sources in the Danish emission database. Each point source may consist of more than one part, e.g. a power plant with several units. By registering the plants as point sources in the database, it is possible to use plant-specific emission factors.

In the inventory for the year 2011, 76 stationary combustion plants are specified as large point sources. These point sources include:

- Power plants and decentralised CHP plants (combined heat and power plants).
- Waste incineration plants.
- Large industrial combustion plants.
- Petroleum refining plants.

The criteria for selection of point sources consist of the following:

- All centralized power plants, including smaller units.
- All units with a capacity above 25 MW_e.
- All district heating plants with an installed effect of 50 MW_{th} or above and significant fuel consumption.
- All waste incineration plants obligated to report environmental data annually according to Danish law (DEPA, 2010a).

16 For 2006 onwards. Country specific emission factors and tier 2 have been applied for 1990-2005.

17 For coal combustion in other source sectors than 1A1a corresponding to 3 % of the coal consumption in 2010.

18 Residual oil not applied in source category 1A1a.

19 Off shore gas turbines and a few power plants.

- Industrial plants,
  - with an installed effect of 50 MW_{th} or above and significant fuel consumption.
  - with significant process related emissions.

The fuel consumption of stationary combustion plants registered as large point sources in the 2011 inventory was 277 PJ. This corresponds to 58 % of the overall fuel consumption for stationary combustion.

A list of the large point sources for 2011 and the fuel consumption rates is provided in Annex 5. The number of large point sources registered in the databases increased from 1990 to 2011.

The emissions from a point source are based either on plant specific emission data or, if plant specific data are not available, on fuel consumption data and the general Danish emission factors. Annex 5 shows which of the emission data for large point sources are plant-specific and the corresponding share of the emission from stationary combustion.

The emission shares from point sources with plant specific data compared to the total emission from stationary combustion are shown in Table 25.

Table 25 Emission share from plant specific data compared to total emission from stationary combustion.

Pollutant	Share from plant specific data, %
CO_2	51
CH_4	-
N_2O	-
SO_2	49
NO_x	44
NMVOC	0.03
CO	1
NH_3	2
TSP	3
PM_{10}	2
$PM_{2.5}$	2
As	20
Cd	9
Cr	22
Cu	19
Hg	65
Ni	7
Pb	4
Se	67
Zn	6
HCB	-
PCDD/F	1

CO_2 emission factors are plant specific for the major power plants, refineries and for cement production. SO_2 and NO_x emissions from large point sources are often plant-specific based on emission measurements. Emissions of CO and NMVOC are also plant-specific for some plants. Plant-specific emission data are obtained from:

- CO_2 data reported under the EU Emission Trading Scheme (ETS).

- Annual environmental reports / environmental reporting available on the Danish EPA home page[20] (PRTR data)
- Annual plant-specific reporting of SO_2 and NO_x from power plants >25MW$_e$ prepared for the Danish Energy Agency and Energinet.dk.
- Emission data provided by DONG Energy and Vattenfall, the two major electricity suppliers.
- Emission data provided by industrial plants.

The EU ETS data are discussed in the Chapter 8.1.2 (see page 98).

Annual environmental reports for the plants include a considerable number of emission data sets. Emission data from annual environmental reports are, in general, based on emission measurements, but some emissions have potentially been calculated from general emission factors.

If plant-specific emission factors are not available, general area source emission factors are used.

Emissions of the greenhouse gases CH_4 and N_2O from the large point sources are all based on the area source emission factors.

7.3 Area sources

Fuels not combusted in large point sources are included as source category specific area sources in the emission database. Plants such as residential boilers, small district heating plants, small CHP plants and some industrial boilers are defined as area sources. Emissions from area sources are based on fuel consumption data and emission factors. Further information on emission factors is provided below in the Chapter 8 (see page 97).

7.4 Activity rates, fuel consumption

The fuel consumption rates are based on the official Danish energy statistics prepared by the Danish Energy Agency (DEA). DCE aggregates fuel consumption rates to SNAP categories. Some fuel types in the official Danish energy statistics are added to obtain a less detailed fuel aggregation level cf. Annex 3. The calorific values on which the energy statistics are based are also enclosed in Annex 3. The correspondence list between the energy statistics and SNAP categories is enclosed in Annex 9.

The fuel consumption of the CRF category *Manufacturing industries and construction* (corresponding to SNAP category 03) is disaggregated into industrial subsectors based on the DEA data set aggregated for the Eurostat reporting (DEA 2012c).

The fuel consumption data flow is shown in Figure 66. Further details for the external data sets are included in chapter 10.3.1.

[20] http://www3.mst.dk/Miljoeoplysninger/PrtrPublicering/Index

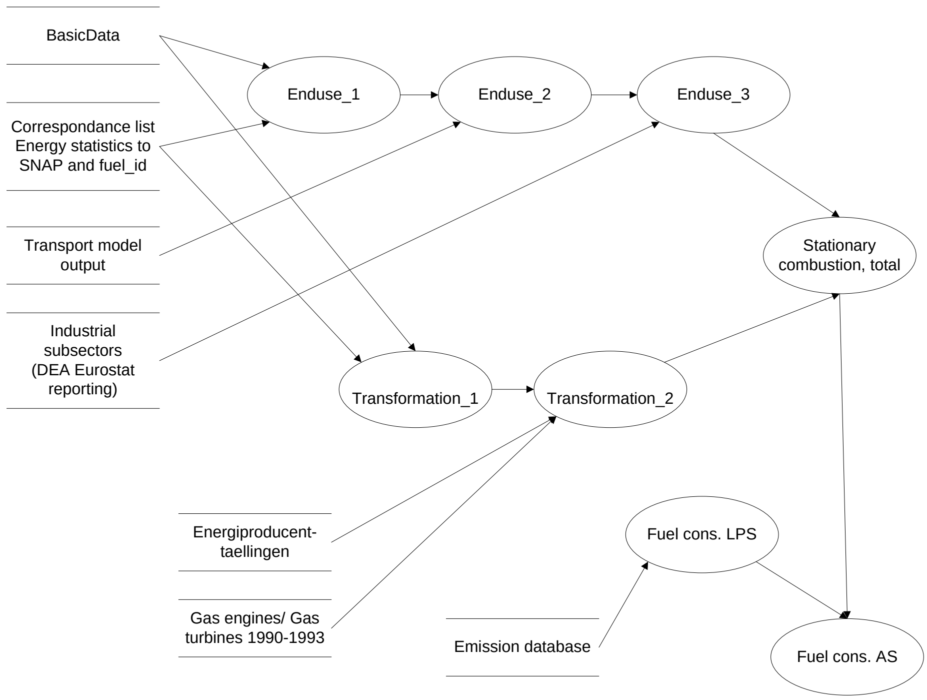


Figure 66 Fuel consumption data flow.

Both traded and non-traded fuels are included in the Danish energy statistics. Thus, for example, estimation of the annual consumption of non-traded wood is included.

Petroleum coke purchased abroad and combusted in Danish residential plants (border trade of 628 TJ in 2011) is not included in the Danish inventory. This is in agreement with the IPCC Guidelines (IPCC 1997).

The fuel consumption data for large point sources refer to the EU Emission Trading Scheme (EU ETS) data for plants for which the CO_2 emission also refer to EU ETS, see page 97.

For all other large point sources, the fuel consumption refers to a DEA database (DEA 2012b). The DEA compiles a database for the fuel consumption of each district heating and power-producing plant, based on data reported by plant operators. The consistency between EU ETS reporting and the DEA database (DEA, 2012b) is checked by the DEA and any discrepancies are corrected prior to the use in the emission inventory.

The fuel consumption of area sources is calculated as total fuel consumption in the energy statistics minus fuel consumption of large point sources.

The Danish national energy statistics includes three fuels used for non-energy purposes; bitumen, white spirit and lubricants. The total consumption for non-energy purposes is relatively low, e.g. 12.4 PJ in 2011. The use of white spirit is included in the inventory in *Solvent and other product use*. The emissions associated with the use of bitumen and lubricants are included in *Industrial Processes.* For lubricants the CO_2 emission is included under industrial processes but for all other pollutants the emission contribution from the oxidation of lubricants are included in the emission factors for stationary combustion and hence included under stationary combustion. The non-energy use of fuels is included in the reference approach for Climate Convention reporting and appropriately corrected in line with the Revised 1996 IPCC Guidelines (IPCC 1997).

In Denmark, all incineration of municipal, industrial, medical and hazardous waste is done with energy recovery. Thus, incineration of waste is included as stationary combustion in the source category *Fuel combustion* (subcategories *1A1*, *1A2* and *1A4)*.

Fuel consumption data are presented in Chapter 2.

7.5 Town gas

Town gas has been included in the fuel category natural gas. The consumption of town gas in Denmark is very low, e.g. 0.6 PJ in 2011. In 1990, the town gas consumption was 1.6 PJ and the consumption has been steadily decreasing throughout the time series.

In Denmark, town gas is produced based on natural gas. The use of coal for town gas production ceased in the early 1980s.

An indicative composition of town gas according to the largest supplier of town gas in Denmark is shown in Table 26 (KE, 2013).

Table 26 Composition of town gas 2009 (KE, 2013).

Component	Town gas, % (mol.)
Methane	43.9
Ethane	2.9
Propane	1.1
Butane	0.5
Carbon dioxide	0.4
Nitrogen	40.5
Oxygen	10.7

The lower heating value of the town gas currently used is 19.3 MJ per Nm^3 and the CO_2 emission factor 56.1 kg per GJ. This is very close to the emission factor used for natural gas of 56.97 kg per GJ. According to the supplier, both the composition and heating value will change during the year. It has not been possible to obtain a yearly average.

In earlier years, the composition of town gas was somewhat different. Table 27 shows data for town gas composition in 2000-2005. These data are constructed with the input from Københavns Energi (KE) (Copenhagen Energy) and Danish Gas Technology Centre (DGC), (Jeppesen, 2007; Kristensen, 2007). The data refer to three measurements performed several years apart; the first in 2000 and the latest in 2005.

Table 27 Composition of town gas, information from the period 2000-2005.

Component	Town gas, % (mol.)
Methane	22.3-27.8
Ethane	1.2-1.8
Propane	0.5-0.9
Butane	0.13-0.2
Higher hydrocarbons	0-0.6
Carbon dioxide	8-11.6
Nitrogen	15.6-20.9
Oxygen	2.3-3.2
Hydrogen	35.4-40.5
Carbon monoxide	2.6-2.8

The lower calorific value has been between 15.6 and 17.8 MJ per Nm^3. The CO_2 emission factors - derived from the few available measurements - are in the range of 52-57 kg per GJ.

The Danish approach includes town gas as part of the fuel category natural gas and thus indirectly assumes the same CO_2 emission factor. This is a conservative approach ensuring that the CO_2 emissions are not underestimated.

Due to the scarce data available and the very low consumption of town gas compared to consumption of natural gas (< 0.5 %), the methodology will be applied unchanged in future inventories.

7.6 Waste

All waste incineration in Denmark is utilised for heat and/or power production and thus included in the energy sector. The waste incinerated in Denmark for energy production consists of the waste fractions shown in Figure 67. In 2009[21], 3 % of the incinerated waste was hazardous waste[22]. Updated data will be included in the emission inventory reported in 2015.

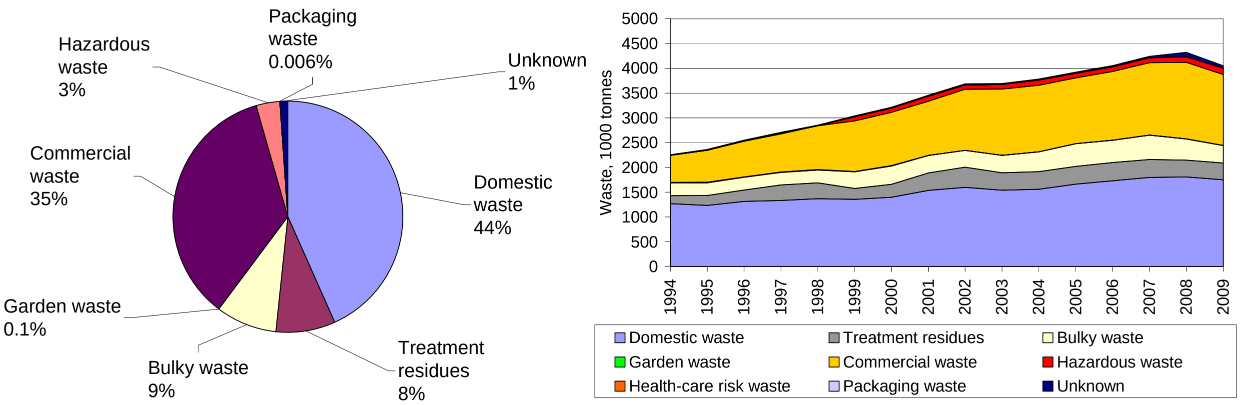


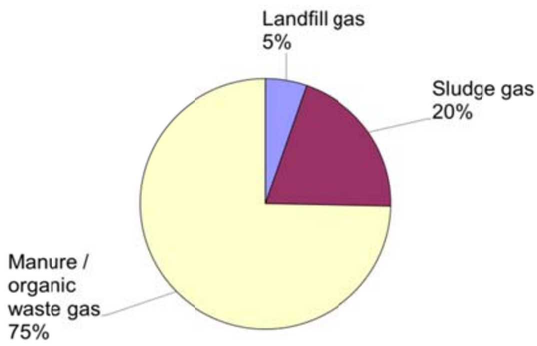
Figure 67 Waste fractions (weight) for incinerated waste in 2009 and the corresponding time series 1994-2009 (ISAG, 2011).

In connection with the project estimating an improved CO_2 emission factor for waste (Astrup et al., 2012), the fossil energy fraction have been recalculated. The fossil fraction was not measured/estimated as part of the project, but the flue gas measurements combined with data from Fellner & Rechberger (2011) indicated a fossil energy part of 45 %. The energy statistics have now applied this fraction in the national statistics. Thus, the fossil energy fraction has now been coordinated between DEA and DCE.

7.7 Biogas

Biogas includes landfill gas, sludge gas and manure/organic waste gas[23]. The Danish energy statistics specifies production and consumption of each of the biogas types. In 2011, 75 % of the produced biogas was based on manure /organic waste.

[21] Currently, data are only available for 1994-2009.
[22] In 2001 onwards, health-care risk waste is included in hazardous waste in the ISAG database.
[23] Based on manure with addition of other organic waste.



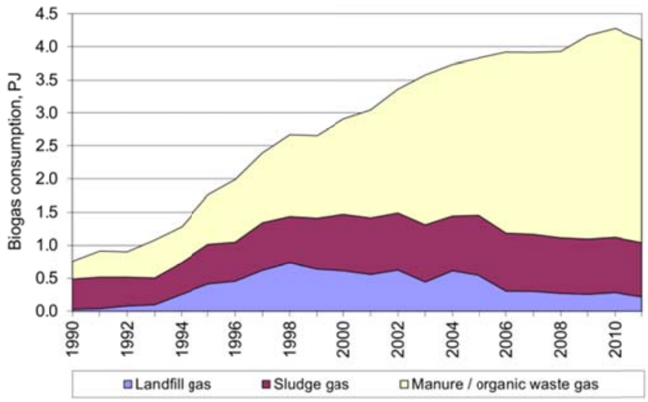


Figure 68 Biogas types 2011 and the corresponding time series 1990-2011 (DEA, 2012a).

7.8 Residential wood combustion

The emission inventory uses the wood consumption in residential plants as reported by the DEA. To break the consumption down to the different technologies available, the number of appliances and the consumption per appliance is estimated.

The annual consumption for the different types of appliances is shown in Table 28 based on Illerup et al. (2007).

Table 28 Definition of the different wood burning technologies and the estimated annual consumption per appliance.

Technology	Description	Annual consumption, GJ
Old stove	Stove pre-1990	19.8
New stove	Stove with DS mark 1990-2005	26.9
Modern stove	Stove conforming with Danish legislation (DEPA 2008)	25.1
Eco labelled stove / new advanced stove		25.1
Other stoves (e.g. fireplaces)		17.9
Old boilers with hot water storage	pre-1980	162.8
Old boilers without hot water storage		140.7
New boilers with hot water storage	post-1980	146.1
New boilers without hot water storage		142.6
Pellet boilers		144.7

The number of wood stoves in Denmark is estimated to be around 750 000 excluding fireplaces (Evald 2010; Evald 2012).The number of fireplaces is estimated at around 16 000 (Illerup et al., 2007).The number of residential wood boilers is estimated to be around 47 000 (Illerup et al., 2007).

For wood stoves, the following assumptions are made:

- Prior to 2004 and after 2008, a replacement rate of 25 000 wood stoves per annum (Hessberg, 2012)
- Between 2004 and 2008, the replacement rate was higher peaking with 40 000 in 2006 (Hessberg, 2012)
- Before 2007, the replacements are considered to be 75 % modern stoves and 25 % new stoves (Hessberg, 2012)
- From 2007, the replacements are considered to be 90 % eco-labelled stoves and 10 % modern stoves (Hessberg, 2012)
- Until 2020 it is considered that the replaced stoves are distributed to 60 % old stoves, 30 % new stoves and 10 % modern stoves (Hessberg, 2012)
- The stock distribution in 2010 is estimated as 27 % old stoves, 42 % new stoves, 16 % modern stoves and 15 % eco-labelled stoves (Evald, 2010; Evald, 2012; Hessberg, 2012)
- The number of other stoves has been assumed constant for all years (Nielsen, 2013)

For wood boilers the following assumptions are made:

- The annual replacement is 5 % (Illerup et al., 2007)
- The replacements are all considered new boilers and 80 % with accumulation tank (Illerup et al., 2007)
- The replaced boilers are all old boilers (Nielsen 2013)
- The number of wood boilers has been assumed constant for all years (Nielsen 2013)

For pellet boilers/stoves, the energy statistics provides directly the consumption of wood pellets. Emissions are calculated directly based on the amount of wood pellets in the energy statistics and no breakdown into different technologies are made.

The number of wood burning appliances in 2011 is shown in Table 29.

Table 29 Number of wood burning appliances in 2011.

Technology	Number of appliances
Old stove	187 500
New stove	307 500
Modern stove	120 000
Eco labelled stove / new advanced stove	135 000
Other stoves (e.g. fireplaces)	16 210
Old boilers with hot water storage	6181
Old boilers without hot water storage	4726
New boilers with hot water storage	23 620
New boilers without hot water storage	12 111

The wood consumption is calculated by multiplying the number of appliances (as shown in Table 29) with the estimated wood consumption per appliance (as shown in Table 28). This bottom-up calculated consumption is then scaled to match the total wood consumption as reported by the DEA in the official energy statistics.

Technology specific emission factors are shown in Chapter 8.15.

8 Emission factors

For each fuel and SNAP category (sector and e.g. type of plant), a set of general area source emission factors has been determined. The emission factors are either nationally referenced or based on the international guidebooks: EMEP/EEA Guidebook (EEA 2009)[24] and IPCC Reference Manual (IPCC 1997).

An overview of the type of emission factor is shown in Table 24. A complete list, of emission factors including time series and references, is provided in Annex 4.

8.1 EU ETS data for CO_2

The CO_2 emission factors for some large power plants and for combustion in the cement industry and refineries are plant specific and based on the reporting to the EU Emission Trading Scheme (EU ETS). In addition, emission factors for offshore gas turbines and refinery gas is based on EU ETS data[25]. The EU ETS data have been applied for the years 2006 - 2011.

8.1.1 Methodology, criteria for implementation and QA/QC

The Danish emission inventory for stationary combustion only includes data from plants using higher tier methods as defined in the EU decision (EU Commission, 2007), where the specific methods for determining carbon contents, oxidation factor and calorific value are specified. The EU decision includes rules for measuring, reporting and verification.

For each of the plants included individually in the Danish inventory all applied methodologies are specified in individual monitoring plans that are approved by Danish authorities (DEA) prior to the reporting of the emissions. The plants/fuels included individually in the Danish inventory all apply the Tier 3 methodology for calculating the CO_2 emission factor. This selection criteria results in a dataset for which the emission factor values are based on fuel quality measurements[26], not default values from the Danish UNFCCC reporting. All fuel analyses are performed according to ISO 17025.

The power plants/fuels selected based on emission factor methodology apply the tiers for activity data, net calorific value (NCV), emission factor and oxidation factor listed below.

Coal

The CO_2 emission factor for coal is based on analysis of C content of the coal (g C per kg) and coal weight measurements. However, NCV values are also measured according to high tier methods in spite of the fact that this value is not input data for the calculation of total CO_2 emission.

- Fuel flow: Tier 4 methodology (± 1.5 %). For coal, the activity data (weight) is based on measurements on belt conveyor scale. The uncertainty is below the required ± 1.5 %.

[24] And former editions of the EMEP/Corinair Guidebook.
[25] See page 134 and 134.
[26] Applying specific methods defined in the EU decision.

- NCV: Tier 3 methodology. Data are based on measurements according to ISO 13909 / ISO 18283 (sampling) and ISO 1928 (NCV). The uncertainty for data is below ± 0.5 %.
- Emission factor: The emission factor is C-content of the coal. Tier 3 methodology (± 0.5 %) is applied and the measurements are performed according to ISO 13909 (sampling) and ISO/TS 12902 (C-content).
- Oxidation factor: Based on Tier 3 methodology except for one plant that applies Tier 1 methodology[27]. The Tier 3 methodology is based on measurements of C-content in bottom ash and fly ash according to ISO/TS 12902 or on burning loss measurements according to ISO 1171. The uncertainty has been estimated to 0.5 %. For Tier 1 the oxidation factor is assumed to be 1.

Residual oil

- Fuel flow: Tier 4 methodology (± 1.5 %) for most plants. However, a few of the included plants apply Tier 3 methodology (± 2.5 %).
- NCV: Tier 3 methodology. Data are based on sampling according to API Manual of Petroleum Measurement Standards / ASTM D 270 and fuel analysis (NCV) according to ASTM D 240 / ISO 1928 / data stated by the fuel supplier.
- Emission factor: Tier 3 methodology according to API Manual of Petroleum Measurement Standards / ASTM D 4057 (sampling) and ISO 12902 / ASTM D 5291 (C-content).
- Oxidation factor: Based on Tier 2 or Tier 3 methodology, both resulting in the oxidation factor 1 with an uncertainty of 0.8 %.

For coal and residual oil fuel analyses are required for each 20,000 tonnes or at least six times each year. The fuel analyses are performed by accredited laboratories[28].

QC of EU ETS data

DCE performs QC checks on the reported emission data, see Nielsen et al. (2013a). Based on the QC checking DCE excluded the oxidation factor for coal for one stationary combustion plant for 2011.

Additional data analysis performed as a result of the former review will result in exclusion of one dataset for 2008, two datasets for 2007 and one dataset for 2006. The oxidation factors for these datasets are outliers. This will be corrected in the reporting in 2013.

8.1.2 EU ETS data presentation

The EU ETS data include plant specific emission factors for coal, residual oil, gas oil, natural gas, refinery gas, petroleum coke and fossil waste. The EU ETS data account for 51 % of the CO_2 emission from stationary combustion.

EU ETS data for coal

EU ETS data for 2011 were available from 15 coal fired plants. The plant specific information accounts for 98 % of the Danish coal consumption and 47 % of the total (fossil) CO_2 emission from stationary combustion plants. The average CO_2 emission factor for coal for these 15 units was 94.7 kg per GJ (Table 30). The plants all apply bituminous coal.

[27] In addition DCE have assumed the oxidation factor to be 1 for a plant for which the stated oxidation factor was rejected in the QC work.
[28] EN ISO 17025.

Table 30 EU ETS data for 15 coal fired plants, 2011.

	Average	Min	Max
Heating value, GJ per tonne[29]	24.3	23.6	25.6
CO_2 implied emission factor, kg per GJ[1)]	94.73	93.23	96.40
Oxidation factor	0.996	0.990	1.000

1) Including oxidation factor.

Table 31 CO_2 implied emission factor time series for coal fired plants based on EU ETS data.

Year	CO_2 implied emission factor, kg per GJ[1)]
2006	94.4
2007	94.3
2008	94.0
2009	93.6
2010	93.6
2011	94.7

1) Including oxidation factor.

EU ETS data for residual oil

EU ETS data for 2011 based on higher tier methodologies were available from 13 plants combusting residual oil. Aggregated data and time series are shown in Table 32 and Table 33. The EU ETS data accounts for 44 % of the residual oil consumption in stationary combustion.

Table 32 EU ETS data for 13 plants combusting residual oil.

	Average	Min	Max
Heating value, GJ per tonne	40.5	38.0	40.9
CO_2 implied emission factor, kg per GJ	79.17	77.30	84.21
Oxidation factor	1.000	1.000	1.000

Table 33 CO_2 implied emission factor time series for residual oil fired power plant units based on EU ETS data.

Year	CO_2 implied emission factor, kg per GJ[1)]
2006	78.2
2007	78.1
2008	78.5
2009	78.9
2010	79.2
2011	79.2

1) Including oxidation factor.

EU ETS data for gas oil combusted in power plants or refineries

EU ETS data for 2011 based on higher tier methodologies were included from 2 plants combusting gas oil. Aggregated data and time series are shown in Table 34 and Table 35. The EU ETS data accounts for less than 0.05 % of the gas oil consumption in stationary combustion.

Table 34 EU ETS data for gas oil applied in power plants/refineries.

	Average	Min	Max
CO_2 implied emission factor, kg per GJ	74.72	73.73	74.94
Oxidation factor	1.000	1.000	1.000

[29] One data set has been excluded as part of the QC work.

Table 35 CO_2 implied emission factor time series for gas oil based on EU ETS data.

Year	CO_2 implied emission factor, kg per GJ[1)]
2006	75.1
2007	74.9
2008	73.7
2009	75.1
2010	74.8
2011	74.7

1) Including oxidation factor.

EU ETS data for industrial plants

Plant specific CO_2 emission factors from EU ETS have also been applied for the some industrial plants including cement industry, sugar production, glass wool production, lime production, and vegetable oil production.

EU ETS data for natural gas applied in offshore gas turbines

EU ETS data have been applied to estimate an average CO_2 emission factor for natural gas applied in offshore gas turbines, see page 105.

EU ETS data for refinery gas

EU ETS data are also applied for the two refineries in Denmark. The emission factor for refinery gas is based on EU ETS data, see page 105.

8.2 CO_2, other emission factors

The CO_2 emission factors that are not included in EU ETS data or that are included but based on lower tier methodologies are not plant specific in the Danish inventory. The emission factors that are not plant specific accounts for 49 % of the fossil CO_2 emission.

The CO_2 emission factors applied for 2011 are presented in Table 36. Time series have been estimated for:

- Coal applied for production of electricity and district heating
- Residual oil applied for production of electricity and district heating
- Refinery gas
- Natural gas applied in off shore gas turbines
- Natural gas, other
- Industrial waste, biomass part

For all other fuels, the same emission factor has been applied for 1990-2011.

In the reporting to the UNFCCC, the CO_2 emission is aggregated to five fuel types: Solid fuels, Liquid fuels, Gaseous fuels, Biomass and Other fuels. The correspondence list between the DCE fuel categories and the IPCC fuel categories is also provided in Table 36.

Only emissions from fossil fuels are included in the total national CO_2 emission. The biomass emission factors are also included in the table, because emissions from biomass are reported to the UNFCCC as a memo item.

The CO_2 emission factor from incineration of waste (37 + 75.1 kg per GJ) is divided into two parts: The emission from combustion of the fossil content of the waste, which is included in the national total, and the emission from combustion of the rest of the waste – the biomass part, which is reported as a memo item. In the UNFCCC reporting, the fuel consumption and emissions from the fossil content of the waste is reported in the fuel category, *Other fuels*.

Table 36 CO_2 emission factors (applied if EU ETS data are not available[30]), 2011.

Fuel	Emission factor kg per GJ Bio-mass	Fossil fuel	Reference type	IPCC fuel category
Coal, source category 1A1a Public electricity and heat production		94.73 1)	Country specific	Solid
Coal, Other source categories		94.6 3)	IPCC (1997)	Solid
Brown coal briquettes		94.6	IPCC (1997)	Solid
Coke oven coke		108 3)	IPCC (1997)	Solid
Anodic carbon		108 1)	IPCC (1997)	Solid
Fly ash (from coal)		93.6	Country specific	Solid
Petroleum coke		92 3)	Country specific	Liquid
Residual oil, source category 1A1a Public electricity and heat production		79.25 1)	Country specific	Liquid
Residual oil, other source categories		77.4 3)	IPCC (1997)	Liquid
Gas oil		74 1)	EEA (2007)	Liquid
Kerosene		71.9	IPCC (1997)	Liquid
Orimulsion		80 2)	Country specific	Liquid
LPG		63.1	IPCC (1997)	Liquid
Refinery gas		57.881	Country specific	Liquid
Natural gas, off shore gas turbines		57.379	Country specific	Gas
Natural gas, other		56.97	Country specific	Gas
Waste	75.1 3)4)	+ 37 3)4)	Country specific	Biomass and Other fuels
Straw	110		IPCC (1997)	Biomass
Wood	110		IPCC (1997)	Biomass
Bio oil	74		Country specific	Biomass
Biogas	83.6		Country specific	Biomass
Biomass gasification gas	142.9 5)		Country specific	Biomass

1) Plant specific data from EU ETS incorporated for individual plants.
2) Not applied in 2011. Orimulsion was applied in Denmark in 1995 – 2004.
3) Plant specific data from EU ETS incorporated for cement industry and sugar, lime and glass wool production.
4) The emission factor for waste is (37+75.1) kg CO_2 per GJ waste. The fuel consumption and the CO_2 emission have been disaggregated to the two IPCC fuel categories *Biomass* and *Other fuels* in CRF. The IEF[31] for CO_2, Other fuels is 82.22 kg CO_2 per GJ fossil waste.
5) Includes a high content of CO_2 in the gas.

8.2.1 Coal

As mentioned above[32], EU ETS data have been utilised for the years 2006 - 2011 in the emission inventory. In 2011, the implied emission factor (including oxidation factor) for the plants[33] using coal was 94.73 kg per GJ. The implied emission factor values were between 93.23 and 96.40 kg per GJ.

In 2011, only 2 % of the CO_2 emission from coal consumption was based on the emission factor, whereas 98 % of the coal consumption was covered by EU ETS data. All coal applied in Denmark is bituminous coal (DEA, 2012c).

30 Plant specific emission factors from EU ETS are discussed above.
31 Not including cement production.
32 EU ETS data for CO2.
33 Including industrial plants.

The emission factors for coal combustion in source category *1A1a Public electricity and heat production* in the years 2006-2011 refer to the implied emission factors of the EU ETS data estimated for each year. For the years 1990-2005, the emission factor for coal in source category *1A1a Public electricity and heat production* refer to the average IEF for 2006-2009.

Time series for net calorific value (NCV) of coal are available in the Danish energy statistics. NCV for *Electricity plant coal* fluctuates in the interval 24.3-25.8 GJ per tonne.

The correlation between NCV and CO_2 IEF (including the oxidation factor) in the EU ETS data (2006-2009) have been analysed and the results are shown in Annex 10. However, a significant correlation between NCV and IEF have not been found in the dataset and thus an emission factor time series based on the NCV time series was not relevant. In addition, the correlation of NCV and CO_2 emission factors has been analysed. This analysis is also shown in Annex 10. As expected, the correlation was better in this dataset, but still insufficient for estimating a time series for the CO_2 emission factor based on the NCV time series.

As mentioned above all coal applied in Denmark is bituminous coal and within the range of coal qualities applied in the plants reporting data to EU ETS a correlation could not be documented.

For other sectors apart from 1A1a, the applied emission factor 94.6 kg per GJ refers to IPCC Guidelines (IPCC, 1997). This emission factor has been applied for all years.

Time series for the CO_2 emission factor are shown in Table 37.

Table 37 CO_2 emission factors for coal, time series.

Year	1A1a Public electricity and heat production kg per GJ	Other source categories kg per GJ
1990-2005	94.0	94.6
2006	94.4	94.6
2007	94.3	94.6
2008	94.0	94.6
2009	93.6	94.6
2010	93.6	94.6
2011	94.73	94.6

8.2.2 Brown coal briquettes

The emission factor for brown coal briquettes, 94.6 kg per GJ, is based on a default value from the IPCC Guidelines (IPCC, 1997) assuming full oxidation. The default value in the IPCC Guidelines is 25.8 t C per TJ, corresponding to $25.8 \cdot (12+2 \cdot 16)/12 = 94.6$ kg CO_2 per GJ assuming full oxidation. The same emission factor has been applied for 1990-2011.

8.2.3 Coke oven coke

The emission factor for coke oven coke, 108 kg per GJ, is based on a default value from the IPCC Guidelines (IPCC, 1997) assuming full oxidation. The default value in the IPCC guidelines is 29.5 t C per TJ, corresponding to 29.5 ·

(12+2·16)/12 = 108 kg CO_2 per GJ assuming full oxidation. The same emission factor has been applied for 1990-2011.

8.2.4 Anodic carbon

Anodic carbon has been applied in Denmark in 2009-2011 in two mineral wool production units. EU ETS data are available for both plants and thus the area source emission factor have not been applied.

8.2.5 Fly ash (from coal)

Fly ash from coal combustion is applied in some power plants. The emission factor 93.6 kg/GJ have been applied. This is the emission factor for coal consumption in power plants in 2009-2010. The emission factor for 1990-2005 will be applied in future inventories (94 kg/GJ).

The emission factor have however not been applied due to the fact that plant specific data are available from the EU ETS dataset.

8.2.6 Petroleum coke

The emission factor for petroleum coke, 92 kg per GJ, has been estimated by SK Energy (a former major power plant operator in eastern Denmark) in 1999 based on a fuel analysis carried out by dk-Teknik in 1993 (Bech, 1999). The emission factor level was confirmed by a new fuel analysis, which, however, is considered confidential. The same emission factor has been applied for 1990-2011.

Plant specific EU ETS data have been utilised for the cement production for the years 2006 - 2011. This consumption represents more than 98 % of the consumption of petroleum coke in Denmark.

Plant specific emission factors from EU ETS data are now available for one power plant and the cement production plant. Both plants state emission factors that are higher than 92 kg/GJ. Thus, the area source emission factor 93 kg/GJ that is based on EU ETS data for 2006-2010 will be applied in the next inventory for all years. Due to the fact that in 2011 less than 2 % of the CO_2 emission from petroleum coke consumption was based on the area source emission factor the error is very low[34].

8.2.7 Residual oil

As mentioned above[35] EU ETS data have been utilised for the 2006 - 2011 emission inventories. In 2011, the implied emission factor (including oxidation factor) for the power plants and refineries[36] combusting residual oil was 79.25 kg per GJ. The implied emission factor values were between 77.30 and 84.21 kg per GJ.

In 2011, 56 % of the CO_2 emission from residual oil consumption was based on the emission factor, whereas 44 % of the residual oil consumption was covered by EU ETS data[37].

[34] The total consumption of petroleum coke was 6.5 PJ in 2011.
[35] EU ETS data for CO2.
[36] Not including data from industrial plants.
[37] Including EU ETS data for cement production.

The emission factors for residual oil combustion in source category *1A1a Public electricity and heat production* in the years 2006-2011 refer to the implied emission factors of the EU ETS data estimated for each year. For the years 1990-2005, the emission factor for residual oil in source category *1A1a Public electricity and heat production* refer to the average IEF for 2006-2009.

For other source categories apart from 1A1a, the applied emission factor 77.4 kg per GJ refers to the IPCC Guidelines (IPCC, 1997). This emission factor has been applied for all years.

Time series for the CO_2 emission factor are shown in Table 38.

Table 38 CO_2 emission factors for residual oil, time series.

Year	Source category 1A1a Public electricity and heat production kg per GJ	Other source categories kg per GJ
1990-2005	78.4	77.4
2006	78.2	77.4
2007	78.1	77.4
2008	78.5	77.4
2009	78.9	77.4
2010	79.2	77.4
2011	79.25	77.4

8.2.8 Gas oil

The emission factor for gas oil, 74 kg per GJ, refers to EEA (2007). The emission factor is consistent with the IPCC default emission factor for gas oil (74.1 kg per GJ assuming full oxidation). The CO_2 emission factor has been confirmed by the two major power plant operators in 1996 (Christiansen, 1996; Andersen, 1996). The same emission factor has been applied for 1990-2011.

Plant specific EU ETS data have been utilised for a few plants in the 2006 - 2011 emission inventories. In 2011, the implied emission factor for the power plants using gas oil was 74.72 kg per GJ. The EU ETS CO_2 emission factors were in the interval 73.73 - 74.94 kg per GJ. In 2011, 0.04 % of the CO_2 emission from gas oil consumption was based on EU ETS data.

8.2.9 Kerosene

The emission factor for kerosene, 71.9 kg per GJ, refers to IPCC Guidelines (IPCC, 1997). The same emission factor has been applied for 1990-2011.

8.2.10 Orimulsion

The emission factor for orimulsion, 80 kg per GJ, refers to the Danish Energy Agency (DEA, 2012a). The IPCC default emission factor is almost the same: 80.7 kg per GJ assuming full oxidation. The CO_2 emission factor has been confirmed by the only major power plant operator using orimulsion (Andersen, 1996). The same emission factor has been applied for all years. Orimulsion has only been used in Denmark in 1995-2004.

8.2.11 LPG

The emission factor for LPG, 63.1 kg per GJ, refers to IPCC Guidelines (IPCC, 1997). The same emission factor has been applied for 1990-2011.

8.2.12 Refinery gas

The emission factor applied for refinery gas refers to EU ETS data for the two refineries in operation in Denmark. Implied emission factors for Denmark have been estimated annually based on the EU ETS data since 2006. The average implied emission factor (57.6 kg per GJ) for 2006-2009 have been applied for the years 1990-2005. This emission factor is consistent to the emission factor stated in the 2006 IPCC Guidelines (IPCC, 2006). The time series is shown in Table 39.

Table 39 CO_2 emission factors for refinery gas, time series.

Year	CO_2 emission factor, kg per GJ
1990-2005	57.6
2006	57.812
2007	57.848
2008	57.948
2009	56.814
2010	57.134
2011	57.881

8.2.13 Natural gas, offshore gas turbines

EU ETS data for the fuel consumption and CO_2 emission for offshore gas turbines are available for the years 2006-2011. Based on data for each oilfield implied emission factors have been estimated for 2006-2011. The average value for 2006-2009 has been applied for the years 1990-2005. The time series is shown in Table 40.

Table 40 CO_2 emission factors for offshore gas turbines, time series.

Year	CO_2 emission factor, kg per GJ
1990-2005	57.469
2006	57.879
2007	57.784
2008	56.959
2009	57.254
2010	57.314
2011	57.379

8.2.14 Natural gas, other source categories

The CO_2 emission factor for natural gas is estimated by the Danish gas transmission company, Energinet.dk[38]. The calculation is based on gas analysis carried out daily by Energinet.dk at Egtved.

In 2011, there was a 13.8 PJ import of natural gas in Denmark, a 117 PJ export and a consumption that added up to 156 PJ. Before 2010, only natural gas from the Danish gas fields have been utilised in Denmark. If the import of natural gas increases further, the methodology for estimating the CO_2 emission factor might be revised based on an on-going dialog with the Danish Energy Agency and Energinet.dk. However, Energinet.dk have stated that the difference between the emission factor based on measurements at Egtved and the average value at Froeslev very close to the border differs less than 0.3 % for 2011 (Bruun 2012).

[38] Former Gastra and before that part of DONG. Historical data refer to these companies.

Energinet.dk and the Danish Gas Technology Centre have calculated emission factors for 2000-2011. The emission factor applied for 1990-1999 refers to Fenhann & Kilde (1994). This emission factor was confirmed by the two major power plant operators in 1996 (Christiansen, 1996; Andersen, 1996). The time series for the CO_2 emission factor is provided in Table 41.

Table 41 CO_2 emission factor time series for natural gas.

Year	CO_2 emission factor, kg per GJ
1990-1999	56.9
2000	57.1
2001	57.25
2002	57.28
2003	57.19
2004	57.12
2005	56.96
2006	56.78
2007	56.78
2008	56.77
2009	56.69
2010	56.74
2011	56.97

8.2.15 Waste

The CO_2 emission from incineration of waste is divided into two parts: The emission from combustion of the fossil content of the waste, which is included in the national total, and the emission from combustion of the rest of the waste – the biomass part, which is reported as a memo item.

The CO_2 emission factor is based on the project, *Biogenic carbon in Danish combustible waste* that included emission measurements from five Danish waste incineration plants (Astrup et al., 2012). The average fossil emission factor for waste was estimated to be 37 kg/GJ waste and the interval for the five plants was 25 – 51 kg/GJ. The five plants represent 44 % of the incinerated waste in 2010. The emission factor 37 kg/ GJ waste corresponds to 82.22 kg/GJ fossil waste.

The total CO_2 emission factor for waste refers to a Danish study (Jørgensen & Johansen, 2003). Based on emission measurements on five waste incineration plants the total CO_2 emission factor for waste incineration has been determined to 112.1 kg per GJ. Thus, the biomass emission factor has been determined to 75.1 kg/GJ waste.

Plant specific EU ETS data have been utilised for cement production in the 2006 - 2011 emission inventories.

8.2.16 Wood

The emission factor for wood, 110 kg per GJ, refers IPCC (1997). The same emission factor has been applied for 1990-2011.

8.2.17 Straw

The emission factor for wood, 110 kg per GJ, refers IPCC (1997). The same emission factor has been applied for 1990-2011.

8.2.18 Bio oil

The emission factor is assumed to be the same as for gas oil – 74 kg per GJ. The consumption of bio oil is below 2 PJ.

8.2.19 Biogas

In Denmark, 3 different types of biogas are applied: Manure/organic waste based biogas, landfill based biogas and wastewater treatment biogas (sludge gas). Manure / organic waste based biogas represent 75 % of the consumption, see page 94.

The emission factor for biogas, 83.6 kg per GJ, is based on a biogas with 65 % (vol.) CH_4 and 35 % (vol.) CO_2. Danish Gas Technology Centre has stated that this is a typical manure-based biogas as utilised in stationary combustion plants (Kristensen, 2001). The same emission factor has been applied for 1990-2011.

8.2.20 Biomass gasification gas

Biomass gasification gas applied in Denmark is based on wood. The gas composition is known for three different plants and the applied emission factor have been estimated by Danish Gas Technology Centre (Kristensen, 2010) based on the gas composition measured on the plant that with the highest consumption. The emission factor is 142.9 kg/GJ includes a high content of CO_2 in the gas.

The consumption of biomass gasification gas is below 0.3 PJ for all years.

8.3 CH_4 emission factors

The CH_4 emission factors applied for 2011 are presented in Table 42. In general, the same emission factors have been applied for 1990-2011. However, time series have been estimated for both natural gas fuelled engines and biogas fuelled engines, residential wood combustion, natural gas fuelled gas turbines[39] and waste incineration plants[39].

Emission factors for CHP plants < 25 MW_e refer to emission measurements carried out on Danish plants (Nielsen et al., 2010a; Nielsen & Illerup, 2003; Nielsen et al., 2008). The emission factors for residential wood combustion are based on technology dependent data.

Emission factors that are not nationally referenced all refer to the IPCC Guidelines (IPCC, 1997).

Gas engines combusting natural gas or biogas account for more than half the CH_4 emission from stationary combustion plants. The relatively high emission factor for gas engines is well-documented and further discussed below.

[39] A minor emission source.

Table 42 CH_4 emission factors 2011.

Fuel group	Fuel	CRF source category	CRF source category	SNAP	Emission factor, g per GJ	Reference
SOLID	COAL	1A1a	Electricity and heat production	010101 010102 010104	0.9	IPCC (1997), Tier 2, Table 1-15, Utility Boiler, Pulverised Bituminous Combustion, Wet bottom.
		1A2 e-f	Industry - other	all	10	IPCC (1997), Tier 2, Table 1-19, Commercial coal boilers.
		1A4b i	Residential	020200	300	IPCC (1997), Tier 1, Table 1-7, Residential, coal.
		1A4c i	Agriculture/ forestry	020300	10	IPCC (1997), Tier 2, Table 1-19, Commercial coal boilers.[1)]
	BROWN COAL BRI.	1A2	Industry	030800	10	IPCC (1997), Tier 1, Table 1-7, Industry, coal.
		1A4b i	Residential	020200	300	IPCC (1997), Tier 1, Table 1-7, Residential, coal.
	COKE OVEN COKE	1A2 e-f	Industry	all	10	IPCC (1997), Tier 2, Table 1-19, Commercial coal boilers.
		1A4b i	Residential	020200	300	IPCC (1997), Tier 1, Table 1-7, Residential, coal.
	ANODIC CARBON	1A2f i	Industry - other	032000	10	IPCC (1997), Tier 2, Table 1-19, Commercial coal boilers.
LIQUID	PETROLEUM COKE	1A1a	Commercial/ Institutional	010102	3	IPCC (1997), Tier 1, Table 1-7, Energy industries, oil.
		1A2f	Industry – other	all	2	IPCC (1997), Tier 1, Table 1-7, Industry, oil.
		1A4a	Commercial/ Institutional	020100	10	IPCC (1997), Tier 1, Table 1-7, Commercial, oil.
		1A4b	Residential	020200	10	IPCC (1997), Tier 1, Table 1-7, Residential, oil.
	RESIDUAL OIL	1A1a	Electricity and heat production	010101	0.9	IPCC (1997), Tier 2, Table 1-15, Utility Boiler, Residual fuel oil.
				010102 010103	1.3	Nielsen et al. (2010a)
				010104	3	IPCC (1997), Tier 1, Table 1-7, Energy industries, oil.
				010105	4	IPCC (1997), Tier 2, Table 1-15, Utility, Large diesel engines.
				010203	0.9	IPCC (1997), Tier 2, Table 1-15, Utility Boiler, Residual fuel oil.
		1A1b	Petroleum refining	010306	3	IPCC (1997), Tier 1, Table 1-7, Energy industries, oil.
		1A2 a-f	Industry	all	1.3	Nielsen et al. (2010a)
		1A4c i	Agriculture/ forestry	020300	1.4	IPCC (1997), Tier 2, Table 1-19, Commercial, residual fuel oil[1)].
				020304	4	IPCC (1997), Tier 2, Table 1-15, Utility, Large diesel engines.
	GAS OIL	1A1a	Electricity and heat production	010101 010102 010103	0.9	IPCC (1997), Tier 2, Table 1-15, Utility Boiler, distillate fuel oil.
				010104	3	IPCC (1997), Tier 1, Table 1-7, Energy industries, oil.
				010105	24	Nielsen et al. (2010a)
				010202 010203	0.9	IPCC (1997), Tier 2, Table 1-15, Utility Boiler, distillate fuel oil.
		1A1b	Petroleum refining	010306	3	IPCC (1997), Tier 1, Table 1-7, Energy industries, oil.
		1A2 c-f	Industry	Other	0.2	IPCC (1997), Tier 2, Table 1-16, Industry, distillate fuel oil.
				Turbines	2	IPCC (1997), Tier 1, Table 1-7, Industry, oil.
				Engines	24	Nielsen et al. (2010a)
		1A4a	Commercial/ Institutional	020100 020103	0.7	IPCC (1997), Tier 2, Table 1-19, Commercial, distillate fuel oil.
				020105	24	Nielsen et al. (2010a)
		1A4b i	Residential	020200	0.7	IPCC (1997), Tier 2, Table 1-18, Residential, distillate fuel oil.

Fuel group	Fuel	CRF source catego-ry	CRF source category	SNAP	Emission factor, g per GJ	Reference
		1A4c	Agriculture/ forestry	020302	0.7	IPCC (1997), Tier 2, Table 1-19, Commercial, distillate fuel oil.
	KEROSENE	1A2 f	Industry	all	0.2	IPCC (1997), Tier 2, Table 1-16, Industry, distillate fuel oil.
		1A4a	Commercial/ Institutional	020100	0.7	IPCC (1997), Tier 2, Table 1-19, Commercial, distillate fuel oil.
		1A4b i	Residential	020200	0.7	IPCC (1997), Tier 2, Table 1-18, Residential, distillate fuel oil.
		1A4c i	Agriculture/ forestry	020300	0.7	IPCC (1997), Tier 2, Table 1-19, Commercial, distillate fuel oil[1].
	LPG	1A1a	Electricity and heat production	010101 010102 010103 010203	3	IPCC (1997), Tier 1, Table 1-7, Energy Industries, oil.
		1A2 a-f	Industry	all	2	IPCC (1997), Tier 1, Table 1-7, Industry, oil
		1A4a	Commercial/ Institutional	020100 020105	10	IPCC (1997), Tier 1, Table 1-7, Commercial, oil.
		1A4b i	Residential	020200	1.1	IPCC (1997), Tier 2, Table 1-18, Residential propane/butane furnaces.
		1A4c i	Agriculture/ forestry	020300	10	IPCC (1997), Tier 1, Table 1-7, Agriculture, oil.
	REFINERY GAS	1A1b	Petroleum refining	010304	1.7	Assumed equal to natural gas fuelled gas turbines. Nielsen et al. (2010a)
				010306	1	Assumed equal to natural gas fuelled plants. IPCC (1997), Tier 1, Table 1-7, Natural gas
GAS	NATURAL GAS	1A1a	Electricity and heat production	010101 010102 010103	0.1	IPCC (1997), Tier 2, Table 1-15, Utility Boiler, natural gas.
				010104	1.7	Nielsen et al. (2010a)
				010105	481	Nielsen et al. (2010a)
				010202 010203	0.1	IPCC (1997), Tier 2, Table 1-15, Utility Boiler, natural gas.
		1A1c	Other energy industries	010504	1.7	Nielsen et al. (2010a)
		1A2 a-f	Industry	Other	1.4	IPCC (1997), Tier 2, Table 1-16, Industry, natural gas boilers.
				Gas turbines	1.7	Nielsen et al. (2010a)
				Engines	481	Nielsen et al. (2010a)
		1A4a	Commercial/ Institutional	020100 020103	1.2	IPCC (1997), Tier 2, Table 1-19, Commercial, natural gas boilers.
				020105	481	Nielsen et al. (2010a)
		1A4b i	Residential	020200 020202	5	IPCC (1997), Tier 1, Table 1-7, Residential, natural gas.
				020204	481	Nielsen et al. (2010a)
		1A4c i	Agriculture/ forestry	020300	1.2	IPCC (1997), Tier 2, Table 1-19, Commercial, natural gas boilers[1].
				020304	481	Nielsen et al. (2010a)
WASTE	WASTE	1A1a	Electricity and heat production	010102 010103 010104 010203	0.34	Nielsen et al. (2010a)
		1A2a-f	Industry	all	30	IPCC (1997), Tier 1, Table 1-7, Industry, wastes.
		1A4a	Commercial/ Institutional	020103	30	IPCC (1997), Tier 1, Table 1-7, Industry, wastes.
	INDUSTRIAL WASTE	1A2f	Industry	031600	30	IPCC (1997), Tier 1, Table 1-7, Industry, wastes.
BIO-MASS	WOOD	1A1a	Electricity and heat production	010101 010102 010103 010104	3.1	Nielsen et al. (2010a)
				010203	30	IPCC (1997), Tier 1, Table 1-7, Energy industries, wood

Fuel group	Fuel	CRF source catego-ry	CRF source category	SNAP	Emission factor, g per GJ	Reference
		1A2 d-f	Industry	all	15	IPCC (1997), Tier 2, Table 1-16, Industry, wood stoker boilers.
		1A4a	Commercial/ Institutional	020100	30	IPCC (1997), Tier 1, Table 1-7, Industry, wood[2].
		1A4b i	Residential	020200 020202	107	DCE estimate based on technology distribution [3]
		1A4c i	Agriculture/ forestry	020300 020303	30	IPCC (1997), Tier 1, Table 1-7, Industry, wood[2].
	STRAW	1A1a	Electricity and heat production	010101 010102 010103 010104	0.47	Nielsen et al. (2010a)
				010203	30	IPCC (1997), Tier 1, Table 1-7, Energy industries, other biomass
		1A4a i	Commercial/Institutional	020103	300	IPCC (1997), Tier 1, Table 1-7, Commercial/Institutional, other biomass.
		1A4b i	Residential	020200	300	IPCC (1997), Tier 1, Table 1-7, Residential, other biomass.
		1A4c i	Agriculture/ forestry	020300 020302	300	IPCC (1997), Tier 1, Table 1-7, Agriculture, other biomass.
	BIO OIL	1A1a	Electricity and heat production	010102	0.9	IPCC (1997), Tier 2, Table 1-15, Utility Boiler, distillate fuel oil.
				010105	24	Nielsen et al. (2010a) assumed same emission factor as for gas oil fuelled engines.
				010202 010203	0.7	IPCC (1997), Tier 2, Table 1-19, Commercial, distillate fuel oil.
		1A4b i	Residential	020200	0.7	IPCC (1997), Tier 2, Table 1-18, Residential, distillate fuel oil.
	BIOGAS	1A1a	Electricity and heat production	010101 010102	1	IPCC (1997), Tier 1, Table 1-7, Energy industries, natural gas. Assumed similar to natural gas (DCE assumption).
				010105	434	Nielsen et al. (2010a)
				010203	1	IPCC (1997), Tier 1, Table 1-7, Energy industries, natural gas. Assumed similar to natural gas (DCE assumption).
		1A2 e	Industry	Other	5	IPCC (1997), Tier 1, Table 1-7, Industry, natural gas. Assumed similar to natural gas (DCE assumption).
				Engines	434	Nielsen et al. (2010a)
		1A4a	Commercial/ Institutional	020100 020103	5	IPCC (1997), Tier 1, Table 1-7, Commercial, natural gas. Assumed similar to natural gas (DCE assumption).
				020105	434	Nielsen et al. (2010a)
		1A4c i	Agriculture/ forestry	020300	5	IPCC (1997), Tier 1, Table 1-7, Agriculture, natural gas. Assumed similar to natural gas (DCE assumption).
				020304	434	Nielsen et al. (2010a)
	BIO PROD GAS	1A1a	Electricity and heat production	010105	13	Nielsen et al. (2010a)
		1A4a	Commercial/Institutional	030105	13	Nielsen et al. (2010a)

1) Assumed same emission factors as for commercial plants. Plant capacity and technology are similar for Danish plants.
2) Assumed same emission factor as for industrial plants. Plant capacity and technology is similar to industrial plants rather than to residential plants.
3) Aggregated emission factor based on the technology distribution in the sector (Nielsen & Hessberg, 2011) and technology specific emission factors.

8.3.1 CHP plants

A considerable part of the electricity production in Denmark is based on decentralised CHP plants, and well-documented emission factors for these plants are, therefore, of importance. In a project carried out for the electricity transmission company, Energinet.dk, emission factors for CHP plants

<25MW_e have been estimated. The work was reported in 2010 (Nielsen et al., 2010a).

The work included waste incineration plants, CHP plants combusting wood and straw, natural gas and biogas-fuelled (reciprocating) engines, natural gas fuelled gas turbines, gas oil fuelled engines, gas oil fuelled gas turbines, steam turbines fuelled by residual oil and engines fuelled by biomass gasification gas. CH_4 emission factors for these plants all refer to Nielsen et al. (2010a). The estimated emission factors were based on existing emission measurements as well as on emission measurements carried out within the project. The number of emission data sets was comprehensive. Emission factors for subgroups of each plant type were estimated, e.g. the CH_4 emission factor for different gas engine types has been determined.

Time series for the CH_4 emission factors are based on a similar project estimating emission factors for year 2000 (Nielsen & Illerup, 2003).

8.3.2 Natural gas, gas engines

SNAP 010105, 030905, 030705, 031005, 031205, 031305, 031405, 031605, 020105, 020204 and 020304

The emission factor for natural gas engines refers to the Nielsen et al. (2010a). The emission factor includes the increased emission during start/stop of the engines estimated by Nielsen et al. (2008). Emission factor time series for the years 1990-2007 have been estimated based on Nielsen & Illerup (2003). The following three references are discussed below:

Nielsen et al. (2010a):

> CH_4 emission factors for gas engines were estimated for 2003-2006 and for 2007-2011. The dataset was split in two due to new emission limits for the engines from October 2006. The emission factors were based on emission measurements from 366 (2003-2006) and 157 (2007-2010) engines respectively. The engines from which emission measurements were available for 2007-2010 represented 38 % of the gas consumption. The emission factors were estimated based on fuel consumption for each gas engine type and the emission factor for each engine type. The majority of emission measurements that were not performed within the project related solely to the emission of total unburned hydrocarbon (CH_4 + NMVOC). A constant disaggregation factor was estimated based on 9 emission measurements including both CH_4 and NMVOC.

Nielsen & Illerup (2003):

> The emission factor for natural gas engines was based on 291 emission measurements in 114 different plants. The plants from which emission measurements were available represented 44 % of the total gas consumption in gas engines in year 2000.

Nielsen et al. (2008):

> This study calculated a start/stop correction factor. This factor was applied to the time series estimated in Nielsen & Illerup (2003). Further, the correction factors were applied in Nielsen et al. (2010a).

The emission factor for lean-burn gas engines is relatively high, especially for pre-chamber engines, which account for more than half the gas consumption in Danish gas engines. However, the emission factors for different pre-chamber engine types differ considerably.

The installation of natural gas engines in decentralised CHP plants in Denmark has taken place since 1990. The first engines installed were relatively small open-chamber engines but later mainly pre-chamber engines were installed. As mentioned above, pre-chamber engines have a higher emission factor than open-chamber engines; therefore, the emission factor has increased during the period 1990-1995. After that technical improvements of the engines have been implemented as a result of upcoming emission limits that most installed gas engines had to meet in late 2006 (DEPA, 2005).

The time series were based on:

- Full load emission factors for different engine types in year 2000 (Nielsen & Illerup, 2003), 2003-2006 and 2007-2011 (Nielsen et al., 2010a).
- Data for year of installation for each engine and fuel consumption of each engine 1994-2002 from the Danish Energy Agency (DEA, 2003).
- Research concerning the CH_4 emission from gas engines carried out in 1997 (Nielsen & Wit, 1997).
- Correction factors including increased emission during start/stop of the engines (Nielsen et al., 2008).

Table 43 Time series for the CH_4 emission factor for natural gas fuelled engines.

Year	Emission factor, g per GJ
1990	266
1991	309
1992	359
1993	562
1994	623
1995	632
1996	616
1997	551
1998	542
1999	541
2000	537
2001	522
2002	508
2003	494
2004	479
2005	465
2006	473
2007	481
2008	481
2009	481
2010	481
2011	481

8.3.3 Gas engines, biogas

SNAP 010105, 030905, 020105 and 020304

The emission factor for biogas engines was estimated to 434 g per GJ in 2011. The emission factor is lower than the factor for natural gas, mainly because most biogas fuelled engines are lean-burn open-chamber engines - not pre-chamber engines.

Time series for the emission factor have been estimated. The emission factors for biogas engines were based on Nielsen et al. (2010a) and Nielsen & Illerup (2003). The two references are discussed below. The time series are shown in Table 44.

Nielsen et al. (2010a):

> CH_4 emission factors for gas engines were estimated for 2006 based on emission measurements performed in 2003-2011. The emission factor was based on emission measurements from 10 engines. The engines from which emission measurements were available represented 8 % of the gas consumption. The emission factor was estimated based on fuel consumption for each gas engine type and the emission factor for each engine type. The majority of emission measurements that were not performed within the project related solely to the emission of total unburned hydrocarbon (CH_4 + NMVOC). A constant disaggregation factor was estimated based on 3 emission measurements including both CH_4 and NMVOC.

Nielsen & Illerup (2003):

> The emission factor for natural gas engines was based on 18 emission measurements from 13 different engines. The engines from which emission measurements were available represented 18 % of the total biogas consumption in gas engines in year 2000. Emission factors for 1990 – 2000 are estimated.

Table 44 Time series for the CH_4 emission factor for biogas fuelled engines.

Year	Emission factor, g per GJ
1990	239
1991	251
1992	264
1993	276
1994	289
1995	301
1996	305
1997	310
1998	314
1999	318
2000	323
2001	342
2002	360
2003	379
2004	397
2005	416
2006	434
2007	434
2008	434
2009	434
2010	434
2011	434

8.3.4 Gas turbines, natural gas

SNAP 010104, 010504, 030604 and 031104

The emission factor for gas turbines was estimated to be below 1.7 g per GJ in 2005 (Nielsen et al., 2010a). The emission factor was based on emission measurements on five plants. The emission factor in year 2000 was 1.5 g per GJ (Nielsen & Illerup, 2003). A time series have been estimated.

8.3.5 CHP, wood

SNAP 010101, 010102, 010103 and 010104

The emission factor for CHP plants combusting wood was estimated to be below 3.1 g per GJ (Nielsen et al., 2010a) and the emission factor 3.1 g per GJ has been applied for all years. The emission factor was based on emission measurements on two plants.

8.3.6 CHP, straw

SNAP 010101, 010102, 010103 and 010104

The emission factor for CHP plants combusting straw was estimated to be below 0.47 g per GJ (Nielsen et al., 2010a) and the emission factor 0.47 g per GJ has been applied for all years. The emission factor was based on emission measurements on four plants.

8.3.7 CHP, waste

SNAP 010102, 010103, 010104 and 010203

The emission factor for CHP plants combusting waste was estimated to be below 0.34 g per GJ in 2006 (Nielsen et al., 2010a) and 0.59 g per GJ in year

2000 (Nielsen & Illerup, 2003). A time series have been estimated. The emission factor was based on emission measurements on nine plants.

The emission factor has also been applied for district heating plants.

8.3.8 Residential wood combustion

SNAP 020200, 020202 and 020204

The emission factor for residential wood combustion is based on technology specific data. The emission factor time series is shown in Table 45.

Table 45 CH_4 emission factor time series for residential wood combustion.

Year	Emission factor, g per GJ
1990-2000	198.0
2001	175.0
2002	165.1
2003	161.8
2004	158.2
2005	149.2
2006	138.8
2007	139.1
2008	130.7
2009	120.1
2010	114.0
2011	107.5

The emission factors for each technology and the corresponding reference are shown in Table 46. The emission factor time series are estimated based on time series (2000-2011) for wood consumption in each technology (Nielsen & Hessberg, 2011). The time series for wood consumption in the ten different technologies are illustrated in Figure 69. The consumption in pellet boilers and new stoves has increased.

Table 46 Technology specific CH_4 emission factors for residential wood combustion.

Technology	Emission factor, g per GJ	Reference
Old stoves	430	Paulrud et al. (2005)
New stoves	350	DCE assumption.
Modern stoves	50	Assumed equal to modern manually fed boilers.
Eco labelled stove	2	Olsson & Kjällstrand (2005)
Other stoves	430	Assumed equal to old stoves
Old manually fed boilers with accumulator tank	211	Paulrud et al. (2005)
Old manually fed boilers without accumulator tank	256	Paulrud et al. (2005)
Modern manually fed boilers with accumulator tank	50	Johansson et al. (2004)
Modern manually fed boilers without accumulator tank	50	Johansson et al. (2004)
Pellet boilers	3	Paulrud et al. (2005)
Other boilers	430	Assumed equal to old stoves

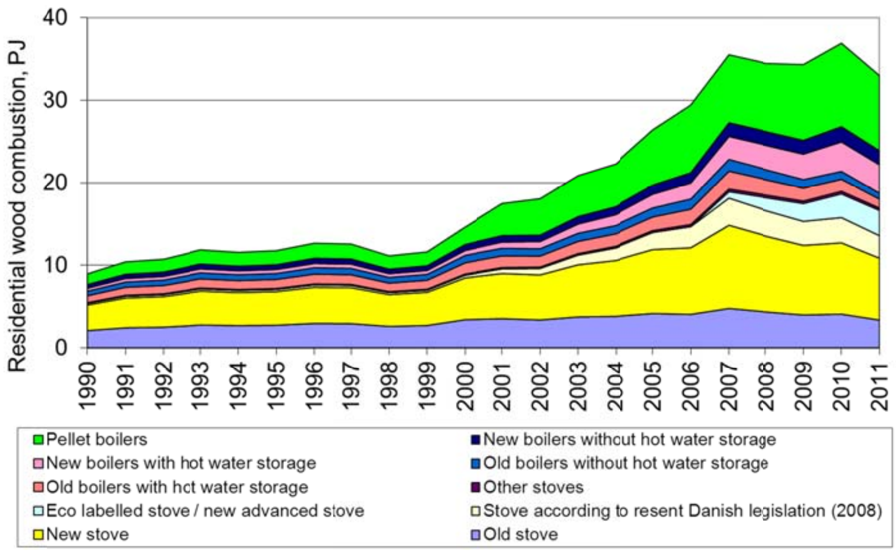


Figure 69 Technology specific wood consumption in residential plants.

8.3.9 Other stationary combustion plants

Emission factors for other plants refer to the IPCC Guidelines (IPCC, 1997).

8.4 N_2O emission factors

The N_2O emission factors applied for the 2011 inventory are listed in Table 47. Time series have been estimated for natural gas fuelled gas turbines and refinery gas fuelled turbines. All other emission factors have been applied unchanged for 1990-2011.

Emission factors for natural gas fuelled reciprocating engines, natural gas fuelled gas turbines, CHP plants < 300 MW combusting wood, straw or residual oil, waste incineration plants, engines fuelled by gas oil and gas engines fuelled by biomass gasification gas all refer to emission measurements carried out on Danish plants, Nielsen et al. (2010a).

The emission factor for coal-powered plants in public power plants refers to research conducted by Elsam (now part of DONG Energy). The emission factor for offshore gas turbines refers to the Danish study concerning CHP plants (Nielsen & Illerup, 2003).

The emission factor for natural gas has been applied for refinery gas. Denmark uses two different N_2O emission factors for refinery gas, one when the gas is utilised in gas turbines and one for use in boilers. The emission factor for gas turbines is nationally referenced while the emission factor for boilers is based on the Revised 1996 IPCC Guidelines (IPCC, 1997). Refinery gas has similar properties as natural gas, i.e. similar nitrogen content in the fuel, which means that N_2O formation will be similar under similar combustion conditions. This is the reasoning behind choosing the emission factor for natural gas rather than for liquid fuel for both turbines and boilers.

All emission factors that are not nationally referenced refer to the IPCC Guidelines (IPCC, 1997).

Table 47 N_2O emission factors 2011.

Fuel group	Fuel	CRF source category	CRF source category	SNAP	Emission factor, g per GJ	Reference
SOLID	COAL	1A1a	Electricity and heat production	010101 010102 010104	0.8	Henriksen (2005)
		1A2 e-f	Industry	all	1.4	IPCC (1997), Tier 1, Table 1-8, Industry, coal
		1A4b i	Residential	020200	1.4	IPCC (1997), Tier 1, Table 1-8, Residential, coal
		1A4c i	Agriculture/ forestry	020300	1.4	IPCC (1997), Tier 1, Table 1-8, Commercial, coal
	BROWN COAL BRI.	1A2f	Industry-Other	all	1.4	IPCC (1997), Tier 1, Table 1-8, Industry, coal
		1A4b i	Residential	020200	1.4	IPCC (1997), Tier 1, Table 1-8, Residential, coal
	COKE OVEN COKE	1A2 e-f	Industry	all	1.4	IPCC (1997), Tier 1, Table 1-8, Industry, coal
		1A4b i	Residential	020200	1.4	IPCC (1997), Tier 1, Table 1-8, Residential, coal
	ANODIC CARBON	1A2f	Industry - other	032000	1.4	IPCC (1997), Tier 1, Table 1-8, Industry, coal
LIQUID	PETROLEUM COKE	1A1a	Electricity and heat production	010102	0.6	IPCC (1997), Tier 1, Table 1-8, Utility, oil
		1A2f	Industry – other	all	0.6	IPCC (1997), Tier 1, Table 1-8, Industry, oil
		1A4a	Commercial/ Institutional	020100	0.6	IPCC (1997), Tier 1, Table 1-8, Commercial, oil
		1A4b	Residential	020200	0.6	IPCC (1997), Tier 1, Table 1-8, Residential oil
	RESIDUAL OIL	1A1a	Electricity and heat production	010101	0.3	IPCC (1997), Tier 2, Table 1-15, Utility, residual fuel oil
				010102 010103	5	Nielsen et al. (2010a)
				010104 010105	0.6	IPCC (1997), Tier 1, Table 1-8, Energy industries, oil
				010203	0.3	IPCC (1997), Tier 2, Table 1-15, Utility, residual fuel oil
		1A1b	Petroleum refining	010306	0.6	IPCC (1997), Tier 1, Table 1-8, Energy industries, oil
		1A2 a-f	Industry	all	5	Nielsen et al. (2010a)
		1A4c i	Agriculture/ forestry	020300	0.3	IPCC (1997), Tier 2, Table 1-19, Commercial, fuel oil
				020304	0.6	IPCC (1997), Tier 2, Table 1-15, Utility, residual fuel oil
	GAS OIL	1A1a	Electricity and heat production	010101 010102 010103	0.4	IPCC (1997), Tier 2, Table 1-15, Utility, distillate fuel oil
				010104	0.6	IPCC (1997), Tier 1, Table 1-8, Energy industries, oil
				010105	2.1	Nielsen et al. (2010a)
				010202 010203	0.4	IPCC (1997), Tier 2, Table 1-15, Utility, distillate fuel oil
		1A1b	Petroleum refining	010306	0.6	IPCC (1997), Tier 1, Table 1-8, Energy industries, oil
		1A2 c-f	Industry	Other	0.4	IPCC (1997), Tier 2, Table 1-16, Industry, distillate fuel oil boilers
				Turbines	0.6	IPCC (1997), Tier 1, Table 1-8, Industry, oil
				Engines	2.1	Nielsen et al. (2010a)

Fuel group	Fuel	CRF source category	CRF source category	SNAP	Emission factor, g per GJ	Reference
		1A4a	Commercial/ Institutional	020100 020103	0.4	IPCC (1997), Tier 2, Table 1-19, Commercial, distillate fuel oil
				020105	2.1	Nielsen et al. (2010a)
		1A4b i	Residential	020200	0.6	IPCC (1997), Tier 1, Table 1-8, Residential, oil
		1A4c	Agriculture/ forestry	020302	0.4	IPCC (1997), Tier 2, Table 1-19, Commercial, distillate fuel oil
	KEROSENE	1A2	Industry	all	0.4	IPCC (1997), Tier 2, Table 1-16, Industry, distillate fuel oil boilers
		1A4a	Commercial/ Institutional	020100	0.4	IPCC (1997), Tier 2, Table 1-19, Commercial, distillate fuel oil
		1A4b i	Residential	020200	0.6	IPCC (1997), Tier 1, Table 1-8, Residential, oil
		1A4c i	Agriculture/ forestry	020300	0.4	IPCC (1997), Tier 2, Table 1-19, Commercial, distillate fuel oil[1)]
	LPG	1A1a	Electricity and heat production	010101 010102 010103 010203	0.6	IPCC (1997), Tier 1, Table 1-8, Energy industries, oil
		1A2 a-f	Industry	all	0.6	IPCC (1997), Tier 1, Table 1-8, Industry, oil
		1A4a	Commercial/ Institutional	020100 020105	0.6	IPCC (1997), Tier 1, Table 1-8, Commercial, oil
		1A4b i	Residential	020200	0.6	IPCC (1997), Tier 1, Table 1-8, Residential, oil
		1A4c i	Agriculture/ forestry	020300	0.6	IPCC (1997), Tier 1, Table 1-8, Agriculture, oil
	REFINERY GAS	1A1b	Petroleum refining	010304	1	Assumed equal to natural gas fuelled turbines. Based on Nielsen et al. (2010a).
				010306	0.1	IPCC (1997), Tier 1, Table 1-8, Energy industries, natural gas
GAS	NATURAL GAS	1A1a	Electricity and heat production	010101 010102 010103	0.1	IPCC (1997), Tier 1, Table 1-8, Energy industries, natural gas
				010104	1	Nielsen et al. (2010a)
				010105	0.58	Nielsen et al. (2010a)
				010202 010203	0.1	IPCC (1997), Tier 1, Table 1-8, Energy industries, natural gas
		1A1c	Other energy industries	010504	1	Nielsen et al. (2010a)
		1A2 a-f	Industry	other	0.1	IPCC (1997), Tier 1, Table 1-8, Industry, natural gas
				Gas turbines	1	Nielsen et al. (2010a)
				Engines	0.58	Nielsen et al. (2010a)
		1A4a	Commercial/ Institutional	020100 020103	2.3	IPCC (1997), Tier 2, Table 1-19, Commercial, natural gas boilers
				020105	0.58	Nielsen et al. (2010a)
		1A4b i	Residential	020200 020202	0.1	IPCC (1997), Tier 1, Table 1-8, Residential, natural gas
				020204	0.58	Nielsen et al. (2010a)
		1A4c i	Agriculture/ forestry	020300	2.3	IPCC (1997), Tier 2, Table 1-19, Commercial, natural gas boilers[1)]
				020304	0.58	Nielsen et al. (2010a)

Fuel group	Fuel	CRF source catego-ry	CRF source category	SNAP	Emission factor, g per GJ	Reference
WA-STE	WASTE	1A1a	Electricity and heat pro-duction	010102 010103 010104 010203	1.2	Nielsen et al. (2010a)
		1A2 c-f	Industry	all	4	IPCC (1997), Tier 1, Table 1-8, Industry, wastes
		1A4a	Commercial/ Institutional	020103	4	IPCC (1997), Tier 1, Table 1-8, Commercial, wastes
	INDUSTR. WA-STE	1A2f	Industry - other	031600	4	IPCC (1997), Tier 1, Table 1-8, Industry, wastes
BIO-MASS	WOOD	1A1a	Electricity and heat pro-duction	010101 010102 010103 010104	0.8	Nielsen et al. (2010a)
				010203	4	IPCC (1997), Tier 1, Table 1-8, Energy industries, wood
		1A2 d-f	Industry	all	4	IPCC (1997), Tier 1, Table 1-8, Industry, wood
		1A4a	Commercial/ Institutional	020100	4	IPCC (1997), Tier 1, Table 1-8, Commercial, wood
		1A4b i	Residential	020200 020202	4	IPCC (1997), Tier 1, Table 1-8, Residential, wood
		1A4c i	Agriculture/ forestry	020300 020303	4	IPCC (1997), Tier 1, Table 1-8, Agriculture, wood
	STRAW	1A1a	Electricity and heat pro-duction	010101 010102 010103 010104	1.1	Nielsen et al. (2010a)
				010203	4	IPCC (1997), Tier 1, Table 1-8, Energy industries, other biomass
		1A4a	Commercial/ Institutional	020103	4	IPCC (1997), Tier 1, Table 1-8, Commercial, other biomass
		1A4b i	Residential	020200	4	IPCC (1997), Tier 1, Table 1-8, Residential, other biomass
		1A4c i	Agriculture/ forestry	020300 020302	4	IPCC (1997), Tier 1, Table 1-8, Agriculture, other biomass
	BIO OIL	1A1a	Electricity and heat pro-duction	010102	0.4	IPCC (1997), Tier 2, Table 1-15, Utility, distillate fuel oil
				010105	2.1	Assumed equal to gas oil. Based on Nielsen et al. (2010a)
				010202 010203	0.4	IPCC (1997), Tier 2, Table 1-15, Utility, distillate fuel oil
		1A4b i	Residential	020200	0.6	IPCC (1997), Tier 1, Table 1-8, Residential, oil
	BIOGAS	1A1a	Electricity and heat pro-duction	010101 010102	0.1	IPCC (1997), Tier 1, Table 1-8, Energy industries, natural gas
				010105	1.6	Nielsen et al. (2010a)
				010203	0.1	IPCC (1997), Tier 1, Table 1-8, Energy industries, natural gas
		1A2 e-f	Industry	Other	0.1	IPCC (1997), Tier 1, Table 1-8, Industry, natural gas
				Engines	1.6	Nielsen et al. (2010a)
		1A4a	Commercial/ Institutional	020100 020103	0.1	IPCC (1997), Tier 1, Table 1-8, Commercial, natural gas

Fuel group	Fuel	CRF source category	CRF source category	SNAP	Emission factor, g per GJ	Reference
				020105	1.6	Nielsen et al. (2010a)
		1A4c i	Agriculture/ forestry	020300	0.1	IPCC (1997), Tier 1, Table 1-8, Agriculture, natural gas
				020304	1.6	Nielsen et al. (2010a)
	BIO PROD GAS	1A1a	Electricity and heat production	010105	2.7	Nielsen et al. (2010a)
		1A4a	Commercial/ Institutional	020105	2.7	Nielsen et al. (2010a)

1) In Denmark, plants in Agriculture/forestry are similar to Commercial plants.

8.5 SO_2 emission factors

The SO_2 emission factors and references are shown in Table 48. Below the table further details about the references, additional references, and time series are discussed.

Table 48 SO_2 emission factors and references 2011.

Fuel type	Fuel	NFR	NFR_name	SNAP	Emission factor, g/GJ	Reference
SOLID	ANODE CARBON	1A2f	Industry - other	032000	574	Assumed equal to coal. DCE assumption.
	COAL	1A1a	Electricity and heat production	0101	9	DCE estimate based on data reported by plant owners to the electricity transmission company, Energinet.dk (Energinet.dk, 2012)
				0102	574	DCE calculation based on DEPA (2010c), DEA (2012a) and EMEP (2006)
		1A2a-f	Industry	03	574	DCE calculation based on DEPA (2010c), DEA (2012a) and EMEP (2006)
		1A4a	Commercial/Institutional	020100	574	DCE calculation based on DEPA (2010c), DEA (2012a) and EMEP (2006).
		1A4b i	Residential	020200	574	DCE calculation based on DEPA (2010c), DEA (2012a) and EMEP (2006)
		1A4c i	Agriculture/ forestry	0203	574	DCE calculation based on DEPA (2010c), DEA (2012a) and EMEP (2006)
	BROWN COAL BRI.	1A2f i	Industry - other	0308	574	Assumed equal to coal. DCE assumption.
		1A4a	Commercial/Institutional	0201	574	Assumed equal to coal. DCE assumption.
		1A4b	Residential	0202	574	Assumed equal to coal. DCE assumption.
		1A4c	Agriculture/ forestry	0203	574	Assumed equal to coal. DCE assumption.
	COKE OVEN COKE	1A2a-f	Industry	03	574	Assumed equal to coal. DCE assumption.
		1A4b i	Residential	020200	574	Assumed equal to coal. DCE assumption.
LIQUID	PETRO-LEUM COKE	1A1a	Electricity and heat production	0101	605	DCE calculation based on DEPA (2001b), DEA (2012a) and EMEP (2006).
		1A2a-f	Industry	03	605	DCE calculation based on DEPA (2001b), DEA (2012a) and EMEP (2006).
		1A4a	Commercial/ Institutional	020100	605	DCE calculation based on DEPA (2001b), DEA (2012a) and EMEP (2006).
		1A4b	Residential	020200	605	DCE calculation based on DEPA (2001b), DEA (2012a) and EMEP (2006).
	RESIDUAL OIL	1A1a	Electricity and heat production	0101	218	Unknown. See chapter 8.5.7.
				0102	344	DCE estimate based on EOF (2013) and DEA (2012a)
		1A1b	Petroleum refining	010306	537	DCE calculation based on plant specific data for year 2003.
		1A2a-f	Industry	03	344	DCE estimate based on EOF (2013) and DEA (2012a)

Fuel type	Fuel	NFR	NFR_name	SNAP	Emission factor, g/GJ	Reference
		1A4a	Commercial/ Institutional	0201	344	DCE estimate based on EOF (2013) and DEA (2012a)
		1A4b	Residential	0202	344	DCE estimate based on EOF (2013) and DEA (2012a)
		1A4c i	Agriculture/ forestry	0203	344	DCE estimate based on EOF (2013) and DEA (2012a)
	GAS OIL	1A1a	Electricity and heat production	all	23	DCE estimate based on DEPA (1998), Miljø- og planlægningsudvalget (1998) and DEA (2012a).
		1A1b	Petroleum refining	010306	23	DCE estimate based on DEPA (1998), Miljø- og planlægningsudvalget (1998) and DEA (2012a).
		1A2a-f	Industry	03	23	DCE estimate based on DEPA (1998), Miljø- og planlægningsudvalget (1998) and DEA (2012a).
		1A4a	Commercial/ Institutional	0201	23	DCE estimate based on DEPA (1998), Miljø- og planlægningsudvalget (1998) and DEA (2012a).
		1A4b i	Residential	0202	23	DCE estimate based on DEPA (1998), Miljø- og planlægningsudvalget (1998) and DEA (2012a).
		1A4c	Agriculture/forestry	0203	23	DCE estimate based on DEPA (1998), Miljø- og planlægningsudvalget (1998) and DEA (2012a).
	KERO-SENE	1A2f	Industry - other	03	5	DCE estimate based on Tønder (2004) and Shell (2013).
		1A4a	Commercial/ Institutional	0201	5	DCE estimate based on Tønder (2004) and Shell (2013).
		1A4b i	Residential	0202	5	DCE estimate based on Tønder (2004) and Shell (2013).
		1A4c i	Agriculture/ forestry	0203	5	DCE estimate based on Tønder (2004) and Shell (2013).
	ORIMUL-SION	1A1a	Electricity and heat production	0101	12	DCE estimate based on plant specific data.
	LPG	1A1a	Electricity and heat production	All	0.13	DCE estimate based on Augustesen (2003) and DEA (2012a).
		1A2a-f	Industry	03	0.13	DCE estimate based on Augustesen (2003) and DEA (2012a).
		1A4a	Commercial/ Institutional	0201	0.13	DCE estimate based on Augustesen (2003) and DEA (2012a).
		1A4b i	Residential	0202	0.13	DCE estimate based on Augustesen (2003) and DEA (2012a).
		1A4c i	Agriculture/ forestry	0203	0.13	DCE estimate based on Augustesen (2003) and DEA (2012a).
	REFINE-RY GAS	1A1b	Petroleum refining	0103	1	DCE estimate based on plant specific data for one plant, average value for 1995-2002.

Fuel type	Fuel	NFR	NFR_name	SNAP	Emission factor, g/GJ	Reference
GAS	NATURAL GAS	1A1a	Electricity and heat production	0101, 0102	0.3	Schmidt (2004)
		1A1c	Other energy industries	010504	0.3	Schmidt (2004)
		1A2a-f	Industry	03	0.3	Schmidt (2004)
		1A4a	Commercial/ Institutional	0201	0.3	Schmidt (2004)
		1A4b i	Residential	0202	0.3	Schmidt (2004)
		1A4c i	Agriculture/ forestry	0203	0.3	Schmidt (2004)
WASTE	WASTE	1A1a	Electricity and heat production	0101	8.3	Nielsen et al. (2010a)
				0102	15	DCE estimate based on plant specific data for four plants, 2009 data.
		1A2a-f	Industry	03	15	Assumed equal to district heating plants (DCE assumption).
		1A4a	Commercial/ Institutional	0201	15	Assumed equal to district heating plants (DCE assumption).
	INDU-STRIAL WASTE	1A2f	Industry - Other	031600	15	Assumed equal to waste. DCE assumption.
BIO-MASS	WOOD	1A1a	Electricity and heat production	0101	1.9	Nielsen et al. (2010a)
				0102	25	Serup et al. (1999); Christiansen et al. (1997)
		1A2a-f	Industry	All	25	Serup et al. (1999); Christiansen et al. (1997)
		1A4a	Commercial/ Institutional	0201	25	Serup et al. (1999); Christiansen et al. (1997)
		1A4b i	Residential	0202	25	Serup et al. (1999); Christiansen et al. (1997)
		1A4c i	Agriculture/ forestry	0203	25	Serup et al. (1999); Christiansen et al. (1997)
	STRAW	1A1a	Electricity and heat production	0101	49	Nielsen et al. (2010a)
				0102	130	Nikolaisen et al. (1998)
		1A4a	Commercial/Institutional	0201	130	Assumed equal to district heating plants. DCE assumption.
		1A4b i	Residential	0202	130	Assumed equal to district heating plants. DCE assumption.
		1A4c i	Agriculture/ forestry	0203	130	Assumed equal to district heating plants. DCE assumption.
	BIO OIL	1A1a	Electricity and heat production	0101	1	DCE estimate based on Folkecenter for Vedvarende Energi (2000) and DEA (2012a).
		1A2a-f	Industry	03	1	DCE estimate based on Folkecenter for Vedvarende Energi (2000) and DEA (2012a).
		1A4a	Commercial/ Institutional	0201	1	DCE estimate based on Folkecenter for Vedvarende Energi (2000) and DEA (2012a).

Fuel type	Fuel	NFR	NFR_name	SNAP	Emission factor, g/GJ	Reference
		1A4b i	Residential	0202	1	DCE estimate based on Folkecenter for Vedvarende Energi (2000) and DEA (2012a).
		1A4c	Agriculture/ forestry	0203	1	DCE estimate based on Folkecenter for Vedvarende Energi (2000) and DEA (2012a).
	BIOGAS	1A1a	Electricity and heat production	0101, not engines	25	DCE estimate based on Christiansen (2003), Hjort-Gregersen (1999) and DEA (2012a).
				Engines	19.2	Nielsen & Illerup (2003)
				0102	25	DCE estimate based on Christiansen (2003), Hjort-Gregersen (1999) and DEA (2012a).
		1A2a-f	Industry	03, not engines	25	DCE estimate based on Christiansen (2003), Hjort-Gregersen (1999) and DEA (2012a).
				03, engines	19.2	Nielsen & Illerup (2003)
		1A4a	Commercial/ Institutional	0201, not engines	25	DCE estimate based on Christiansen (2003), Hjort-Gregersen (1999) and DEA (2012a).
				020105	19.2	Nielsen & Illerup (2003)
		1A4c i	Agriculture/ forestry	0203, not engines	25	DCE estimate based on Christiansen (2003), Hjort-Gregersen (1999) and DEA (2012a).
				020304	19.2	Nielsen & Illerup (2003)
	BIO PROD GAS	1A1a	Electricity and heat production	010105	1.9	Assumed equal to wood. DCE assumption.
		1A2f	Industry - other	031305	1.9	Assumed equal to wood. DCE assumption.
		1A4a	Commercial/ Institutional	020105	1.9	Assumed equal to wood. DCE assumption.
		1A4c	Agriculture/ forestry	020304	1.9	Assumed equal to wood. DCE assumption.

8.5.1 Anode carbon

Anode carbon has been used in industrial plants since 2010. The SO_2 emission factor, 574 g/GJ, have been assumed equal to the SO_2 emission factor for coal combusted in industrial plants.

8.5.2 Coal, large power plants

Sector 1A1a, SNAP 0101

Data for SO_2 emission and fuel consumption for Danish power plants >25MW$_e$ are available for all plants for the years 1990 and onwards. In general, the plant specific data have been included in the emission inventories. For some years, a small part of the coal consumption has, however, been included as an area source. The SO_2 emission factor for coal has been estimated as an average value based on the annual reporting from the power plant operators to the electricity transmission company in Denmark, Energinet.dk[40].

From 2010 onwards, the emission factor is estimated based on a database query including power plants for which the coal consumption makes up more than 90 % of the total fuel consumption. All SO_2 emission from these plants is assumed to originate from the coal consumption.

For 2008-2009, the emission factor is based on emission data for power plants that are primarily fuelled by coal and the emission is assumed to originate from coal, residual oil, gas oil or biomass/waste.

For 1990-2007, the emission factor is based on the total SO_2 emission from all power plants divided by the fuel consumption of coal and residual oil. This methodology results in a small overestimation of the emission factor. From 2003 onwards, the fuel consumption data were stated in TJ.

The calculated time series for the SO_2 emission factor are shown in Table 49 below

Table 49 SO_2 emission factor for coal combusted in centralised power plants.

Year	SO_2 emission factor [g/GJ]
1990	506
1991	571
1992	454
1993	386
1994	343
1995	312
1996	420
1997	215
1998	263
1999	193
2000	64
2001	47
2002	45
2003	61
2004	42
2005	41
2006	37
2007	40
2008	26
2009	14
2010	10
2011	9

8.5.3 Coal, other plants

Sector 1A1a, 1A2a-f, 1A4a, 1A4b, 1A4c, SNAP 0102, 03, 02

According to Danish legislation, the maximum sulphur content of coal used in plants that are not large power plants is 0.9% (DEPA, 2010c). This value has been in force since 1989 (DEPA 1994; DEPA 1988, DEPA 2001b). The av-

[40] Eltra and Elkraft System in the beginning of the time series.

erage sulphur content has been assumed to be a little below the maximum – 0.8%.

The net calorific value (NCV) of coal used in other plants than power plants was 26.5 GJ/ton in 1991-2007 (DEA, 2012a). The NCV differed from this value in 1990 and in 2008 onwards. However, a NCV of 26.65 GJ/ton have been applied in the DCE estimate.

The sulphur retention in ash has been assumed to be 0.05 referring to the EMEP/Corinair Guidebook 2006[41] update (EMEP, 2006).

Based on these data the emission factor 574 g/GJ has been calculated (see below).

$$EMF_{SO2} = 10^6 \cdot ((2 \cdot C_s \cdot (1-\alpha_s)) / H_u)$$

$$EMF_{SO2} = 10^6 \cdot ((2 \cdot 0.8 \cdot 0.01 \cdot (1-0.05)) / 26.5) = 574 \text{ g/GJ}$$

The tier 1 emission factor in the 2009 update of the EMEP/EEA Guidebook is 820 g/GJ or 900 g/GJ depending on source category (EEA 2009).

Plant specific emission data are available for a large part of the coal consumption in the category. However, as a result of the large emission reductions for power plants and large industrial plants the SO_2 emission estimated based on the emission factor 574 g/GJ is considerable. An improved emission factor will be considered in future inventories.

8.5.4 Brown coal briquettes

Sector 1A2f, 1A4a, 1A4b, 1A4c, SNAP 03, 0201, 0202, 0203

The emission factors for brown coal briquettes have been assumed to be the same as for coal. The consumption of brown coal briquettes is below 0.2 PJ all years and below 0.03 % of the Danish fuel consumption.

8.5.5 Coke oven coke

Sector 1A2a-f, 1A4b, SNAP 03, 0202

The emission factors for coke oven coke have been assumed to be the same as for coal. The consumption of coke oven coke is below 1.4 PJ all years and below 0.3 % of the Danish fuel consumption.

8.5.6 Petroleum coke

Sector 1A1a, 1A2a-f, 1A4a, 1A4b, 1A4c, SNAP: All

The emission factor for petroleum coke (605 g/GJ) has been based on maximum sulphur content according to Danish legislation and on the lower heating value that is part of the Danish energy statistics.

The lower heating value for petroleum coke used in Denmark is 31.4 GJ/ton (DEA, 2012a).

[41] EMEP/Corinair Guidebook 2006 update, B111-22, Table 8.

According to Danish legislation, the sulphur content of petroleum coke should be below 1% in 2001 and onwards (DEPA, 2001b). In the years 1990 – 2000, the maximum sulphur content according to Danish legislation was 1.3% (DEPA, 1994; DEPA, 1988).

The sulphur retention in ash has been assumed to be 0.05 referring to EMEP (2006). It has been assumed that sulphur flue gas cleaning is not installed in plants combusting petroleum coke.

$EMF_{SO2} = 10^6 \cdot ((2 \cdot C_s \cdot (1-\alpha_s)) / H_u)$

1990-2000: $EMF_{SO2} = 10^6 \cdot ((2 \cdot 1.3 \cdot 0.01 \cdot (1-0.05)) / 31.4) = 787$ g/GJ

2001-2011: $EMF_{SO2} = 10^6 \cdot ((2 \cdot 1.0 \cdot 0.01 \cdot (1-0.05)) / 31.4) = 605$ g/GJ

8.5.7 Residual oil, large power plants

Sector 1A1a, SNAP 0101

Data for SO_2 emission and fuel consumption for Danish power plants >25MW$_e$ are available for all plants for the years 1990 and onwards. In general, the plant specific data have been included in the emission inventories. For some years, a small part of the residual oil consumption has, however, been included as an area source. The SO_2 emission factor for residual oil has been estimated as an average value based on the annual reporting from the power plant operators to the electricity transmission company in Denmark, Energinet.dk[42].

For 1990-2001, DCE has estimated the SO_2 emission factor for residual oil based on the sulphur content of the residual oil used in power plants >25MW$_e$. This information was part of the reporting from the power plant owners (Eltra & Elkraft System) to the Danish Energy Agency at that time. The lower heating value for residual oil refers to DEA (2012a). Sulphur retention in ash is not relevant for oil and sulphur flue gas cleaning has not been taken into account. The estimated emission factors are shown below.

The emission factors applied for 2002-2007 have been based on plant specific data for a few large power plant units combusting primarily residual oil. Data for this calculation refers to annual data from Eltra & Elkraft System.

For 2008 and onwards, the applied emission factor is 218 g/GJ. The reference of this value is unknown and in future inventories, the emission factor 100 g/GJ will be applied. This value is an average value of the plant specific data for 2008 and 2009. In general, plant specific data are available and thus the recalculation will be small.

[42] Eltra and Elkraft System in the beginning of the time series.

Table 50 Emission factors time series for residual oil used in power plants.

Year	Average sulphur content [%][1)]	Sulphur retention in ash [kg/kg]	Lower heating value [GJ/ton][2)]	Emission factor [g/GJ]
1990	0.9	0	40.4	446
1991	0.95	0	40.4	470
1992	0.99	0	40.4	490
1993	0.96	0	40.4	475
1994	3.16	0	40.4	543
1995	0.71	0	40.4	351
1996	0.83	0	40.7	408
1997	0.7	0	40.65	344
1998	0.75	0	40.65	369
1999	0.75	0	40.65	369
2000	0.82	0	40.65	403
2001	0.641	0	40.65	315
2002				290
2003				334
2004				349
2005				283
2006				308
2007				206
2008				218
2009				218
2010				218
2011				218

1. Eltra & Elkraft System annual reporting.

2. DEA (2012a).

3. Estimated based on plant specific data reported by plant operators to Energinet.dk (Previously Eltra & Elkraft System). Annual reporting.

8.5.8 Residual oil, refineries

Sector 1A1b, SNAP 010306

The refineries have been included in the Danish inventory as point sources with plant specific SO_2 emission data from 1994 onwards. Thus, the emission factor has only been applied for a small amount of residual oil.

The emission factor for 1994-2011 (537 g/GJ) has been estimated based on plant specific data for 2003 from the two refineries in operation in Denmark. It has been assumed that all SO_2 originate from residual oil.

The total emission from refinery furnaces 1990-1993 have been reported by Fenhann (1996). The emission factor for residual oil (798 g/GJ) has been estimated based on these data.

8.5.9 Residual oil, other plants

Sector 1A1a, 1A2a-f, 1A4a, 1A4b, 1A4c, SNAP 0102, 03, 0201, 0202, 0203

The legislative limit for sulphur content in residual oil sold in Denmark is 1% (DEPA, 2010c; DEPA, 2001b; DEPA, 1994).

However, the sulphur content of residual oil sold in Denmark has been somewhat lower in recent years; 0.75 % or 0.5% (EOF, 2013). According to

Danish Oil Industry Association, the average sulphur content has been 0.7% from 1997 to 2005 (EOF, 2003). The same sulphur content has been assumed for the years 2006-2011.

For the years 1990-1996, the legislative maximum sulphur content of 1% has been assumed by DCE.

The lower heating value for residual oil is 40.65 GJ/ton in 1997-2011 and 40.40 GJ/ton in 1990-1995 (DEA, 2012a).

The emission factors are estimated below:

$EMF_{SO2} = 10^6 \cdot (2 \cdot C_s / H_u)$

1990-1996: 495 g/GJ

1997-2011: 344 g/GJ

8.5.10 Gas oil

Sector 1A1a, 1A1b, 1A2a-f, 1A4a, 1A4b, 1A4c, SNAP: all

For the years 1995-2011, the emission factor is 23 g/GJ. This emission factor is based on a sulphur content of 0.05% and a lower heating value of 42.7 GJ/tonne.

The Danish legislation for gas oil requires sulphur content below 0.2% until 2008 (DEPA, 1994; DEPA, 2000; DEPA, 2001b; DEPA, 2010c) and below 0.1 % in 2008 onwards. The sulphur content has been lower than the 0.2% due to Danish tax laws (DEPA, 1998). According to the tax laws, the base sulphur content (no tax) for gas oil has been 0.05% since 1995.

The low average sulphur content for gas oil used in Denmark refers to a note from the parliamentary committee for environment (Miljø- og planlægningsudvalget, 1998). According to this reference, the oil sold in Denmark in 1998 had a sulphur content of 0.05% regardless of the legislative limit of 0.2% sulphur. The sulphur content of 0.05% has been confirmed by product data sheets from Q8, Shell and Statoil. The lower heating value for gas oil is 42.7 GJ/ton (DEA, 2012a).

For the years 1990-1994 the emission factor 94 g/GJ refers to Danish legislation (DEPA, 1994; DEPA, 1988) concerning sulphur content (0.2%) and the lower heating value 42.7 GJ/ton (DEA 2012a).

8.5.11 Kerosene

Sector 1A2f, 1A4a, 1A4b, 1A4c, SNAP: all

According to a product sheet from Shell (2013), the maximum sulphur content of kerosene is 0.05 %. However, this maximum sulphur content has been stated in the product sheets as it is the maximum sulphur content allowed to avoid sulphur taxes (DEPA, 1998). The actual sulphur content is somewhat lower. According to Tønder (2004), the sulphur content was approximately 95-107 mg S/litre. According to the product sheet from Shell (2013) the density of kerosene is 775-840 g/litre and thus the actual sulphur content is approximately 0.012 % sulphur.

The lower heating value 43.1 GJ/tonne refers to the product data sheet from Shell (2013).

The emission factor 5 g/GJ has been based on a sulphur content of 0.01% (Tønder, 2004) and the NCV 43.1 GJ/tonne (Shell, 2013).

8.5.12 Orimulsion

Sector 1A1a, SNAP 010101

Orimulsion has only been used in a single large power plant boiler in Denmark. This power plant boiler has been included in the inventories as a point source with plant specific SO_2 emission data included all years. Thus, the emission factors are only included for information.

The emission factors have been estimated based on the plant specific data from the power plant boiler combusting orimulsion. The plant specific SO_2 emission data refer to Eltra & Elkraft System (annual reporting) and the fuel consumption data refer to DEA (2012b). The emission factor is 149 g/GJ in 1995-1998 and 12 g/GJ in 2001-2004.

The use of orimulsion in Denmark ceased in 2005.

In 1996, the applied emission factor is 147 g/GJ. This will be corrected to 149 g/GJ in the next inventory.

8.5.13 LPG

Sector 1A1a, 1A1b, 1A2a-f, 1A4a, 1A4b, 1A4c, SNAP: all

The main part of the sulphur content in LPG originates from the added odorant (Krebs, 2003). The maximum sulphur content of LPG is 50 mg S/kg (Krebs, 2003). The added odorant is Ethylmercaptan (Augustesen, 2003). According to the Danish legislation concerning fuel gas, a minimum of 8.8 mg odorant/m^3 should be added if ethylmercaptan (C_2H_6S) is used (Gasreglementet, 2001). According to specifications from Statoil, a minimum of 12 mg odorant/m^3 is added (Augustesen, 2003). The S content in the odorant is 51.61% corresponding to a sulphur content of 12 0.5161=6.19 mg S/m^3. The weight of 1 m^3 propane is 1.96 kg/m^3, whereas the weight of butane is 2.59 kg/m^3. A 40 % propane / 60 % butane weights 2.34 kg/m^3. Thus, the sulphur content is at least 6.19/2.34=2.65 mg S/kg corresponding to 0.000265%.

The sulphur content of LPG is in the interval 0.000265% to 0.005%. DCE has assumed that the sulphur content is slightly above the specified minimum: 0.0003% S.

The lower heating value 46 GJ/ton refers to DEA (2012a) and the estimated emission factor is 0.13 g/GJ.

8.5.14 Refinery gas

Sector 1A1a, 1A1b, 1A2f, SNAP: all

The SO_2 emission from combustion of refinery gas in refinery furnaces has been included as a point source with plant specific SO_2 emission data in 1994 and onwards.

The emission factor (1 g/GJ) has been estimated by DCE based on plant specific emission data from a gas turbine only combusting refinery gas. The turbine is installed in a Danish refinery. Plant specific emission data for 1995-2002 have been included in the estimate. This emission factor has been applied for all technologies.

8.5.15 Natural gas

Sector 1A1a, 1A2a-f, 1A4a, 1A4b, 1A4c, SNAP: all

The sulphur content originates from the H_2S content of natural gas and from the added odorant (THT, C_4H_8S).

The Danish gas transmission company Energinet.dk states the H_2S content 3.2 mg/m_n^3 (Energinet.dk, 2013a). This corresponds to $3.2 \cdot 32/34 = 3.0$ mg S/m_n^3.

According to Energinet.dk, the added THT corresponds to 5.5 mg S/m_n^3 (Energinet.dk, 2013b).

Thus, the total sulphur content is 8.5 mg S/m_n^3.

The lower heating value in 2012 was 39.548 MJ/m_n^3 (Energinet.dk, 2013a).

DCE has estimated the SO_2 emission factor $8.5 \cdot 2/39.548 = 0.43$ mg SO_2/MJ or 0.43 g/GJ.

The emission factor has also been estimated for 2004 based on data from the former gas transmission company Gastra. In 2004, the H_2S content was 3.16 mg H_2S/m_n^3 (Gastra, 2005) and the THT content was 15 mg THT/m_n^3 (Gastra, 2005). The sulphur content in THT is 32/88. Based on these data the emission factor 0.42 g/GJ was estimated.

In future inventories, the emission factor 0.43 g/GJ will be applied for all years.

The emission factor that has is currently applied in the Danish inventories is 0.3 g/GJ. This emission factor has been applied for all years. The emission factor 0.3 g/GJ refers to an environmental report from Danish Gas Technology Centre (Schmidt, 2004).

The SO_2 emission from gas engines is somewhat higher due to the consumption of lube oil. This has not been taken into account in the Danish inventories so far but will be included in the next inventory.

8.5.16 Waste, CHP plants

Sector 1A1a, SNAP 0101

The emission factor for 2006 onwards is 8.3 g/GJ referring to Nielsen et al. (2010a). The emission factor is based on 43 emission measurements from 7 waste incineration plants representing 30 % of the waste consumption in CHP plants.

New emission limit values came into force for waste incineration plants in 2006 (DEPA, 2003). The SO_2 emission limit in the current legislation (DEPA 2012) is unchanged since 2006 (DEPA, 2003). Modifications of the plants are assumed to have taken place over several years prior to 2006 and a linear reduction of emission factor has been assumed between 2003 and 2006.

The emission factor for the years 2000-2003 refers to another Danish study (Nielsen & Illerup, 2003) that included emission measurements from 16 waste incineration plants (19 units) representing more than 70% of the waste consumption in CHP plants in the year 2000.

The flue gas cleaning systems in CHP waste incineration plants have been developed considerably during the last two decades. Thus, the emission factor applied for 2000 and onwards is not valid for the previous years.

The emission factors applied for the years 1990 and 1995 also refers to Nielsen & Illerup (2003). The estimates for 1990 and 1995, included in this report, were based on knowledge of flue gas cleaning systems of the plants in 1990 and 1995 (Illerup et al., 1999). Emission factors for plants with different flue gas cleaning systems were applied (Nielsen & Illerup, 2003). For plants with no flue gas cleaning, the sulphur content was assumed to be 0.24% (Risø, 2005) and the sulphur retention in ash was assumed to be 63% (Blinksbjerg, 1994) and thus the estimated emission factor was 169 g/GJ.

The estimated emission factors were 138 g/GJ in 1990 and 30 g/GJ in 1995. The emission factor time series between 1990 and 1995 and between 1995 and 2000 have been assumed linear (DCE assumption).

The emission factor time series are shown below.

Table 51 Emission factors for CHP waste incineration plants.

Year	Emission factor [g/GJ]
1990	138
1991	116
1992	95
1993	73
1994	52
1995	30
1996	29
1997	28
1998	26
1999	25
2000	24
2001	24
2002	24
2003	24
2004	19
2005	14
2006	8.3
2007	8.3
2008	8.3
2009	8.3
2010	8.3
2011	8.3

8.5.17 Waste, district heating and other plants

Sector 1A1a, 1A2a-f, 1A4a, SNAP 0102, 03, 0201

The emission factor 15 g/GJ that have been applied since 2007 refer to plant specific data for 2009. The estimate was based on plant specific data for 4 units without power production. However, the accurate result of the plant specific data is 14 g/GJ and this emission factor will be applied in future inventories. The emission limit value (DEPA, 2011) corresponds to 26 g/GJ.

DCE has estimated the emission factor for the year 2000 based on plant specific fuel consumption data in year 2000 (DEA, 2012b) and on SO_2 emission data (annual environmental reports 2001) for each of the 5 non-power producing plants. The estimated emission factor is 67 g/GJ.

Table 52 Waste incineration plants without power production, 2000.

Fuel consumption [GJ]	SO_2 emission [ton]	SO_2 emission factor [g/GJ]
1440233	96.42	67

The emission factor for 1990 has been estimated by DCE based on:

- Technology applied in 1990 (Illerup et al., 1999)
- Fuel consumption for each technology (Illerup et al., 1999)
- Emission factors for each sulphur flue gas cleaning technology in the year 2000 (Nielsen & Illerup, 2003).
- An emission factor for plants with no flue gas cleaning estimated by DCE. The estimated emission factor was 169 g/GJ. The sulphur content was assumed to be 0.24 % (Risø, 2005) and the sulphur retention in ash was assumed to be 63% (Blinksbjerg, 1994).

The estimated emission factor for 1990 is 138 g/GJ[43]. The emission factor time series between 1990 and 2000 have been assumed linear (DCE assumption).

Table 53 Emission factors for waste incineration plants without power production, 1990.

Flue gas cleaning [1)]	Waste combustion 1990[2)] [tonne]	SO_2 emission factor[3)] [g/GJ]	Consumption x emission factor 1990 [tonne g/GJ]
No sulphur cleaning	1327760	169	224391440
ESP WET	30700	50.5	1550350
SD (CYK) FB	148430	10.3	1528829
Other WET	12000	26.6	319200
Other DRY	156900	20.6	3232140
Total	1675790		231021959
			Emission factor 1990 [g/GJ]: 138

1. WET: wet flue gas cleaning. SD: semidry flue gas cleaning. DRY: dry flue gas cleaning. ESP: electrostatic precipitator. FB: fabric filter. CYK: cyclone.
2. Illerup et al. (1999).
3. Nielsen & Illerup (2003).

Time series for the emission factor is shown below.

43 The emission factor happens to be equal to the factor for CHP plants. The reference is however not the same.

Table 54 Emission factors time series for non- power producing incineration plants.

Year	Emission factor [g/GJ]
1990	138
1991	131
1992	124
1993	117
1994	110
1995	103
1996	95
1997	88
1998	81
1999	74
2000	67
2001	60
2002	52
2003	45
2004	37
2005	30
2006	22
2007	15
2008	15
2009	15
2010	15
2011	15

The same emission factor time series have been assumed for industrial plants and commercial/institutional plants.

8.5.18 Industrial waste

Since the waste incinerated in the Danish cement production plant differs from waste incinerated in other plants a separate fuel category is applied. The emission factor for SO_2 has however been assumed equal to the emission factor for waste.

8.5.19 Wood, CHP plants

Sector 1A1a, SNAP 0101

The SO_2 emission factor for wood combusted in CHP plants, 1.9 g/GJ, refers to a Danish study (Nielsen et al., 2010a) that included 4 emission measurements from two plants. This emission factor has been applied for all years.

8.5.20 Wood, other plants

Sector 1A1a, 1A2a-f, 1A4a, 1A4b, 1A4c, SNAP 0102, 03, 0201, 0202, 0203

The emission factor refers to two reports, both in Danish: Serup et al. (1999) and Christiansen et al. (1997).

According to Serup et al. (1999), the emission factor is in the interval 5-30 g/GJ and a typical value is 15 g/GJ. According to Christiansen et al. (1997), the emission factor is in the interval 15-30 g/GJ.

Until now the emission factor 25 g/GJ has been applied all years.

The emission factor in the EMFP/EEA Guidebook (EEA, 2013) for biomass, small combustion is 11 g/GJ. This emission factor will be applied in future inventories.

8.5.21 Straw, CHP plants and power plants

Sector 1A1a, SNAP 0101

The SO_2 emission factor for straw combusted power plants and CHP plants (49 g/GJ) refers to a Danish study (Nielsen et al., 2010a) that included 15 emission measurements from five CHP plants combusting straw. The emission factor is also been applied for large power plants. However, plant specific SO_2 emission data are usually available for large power plants. The emission factor has been applied for all years.

8.5.22 Straw, other plants

Sector 1A1a, 1A2a-f, 1A4a, 1A4b, 1A4c, SNAP 0102, 03, 0201, 0202, 0203

The SO_2 emission factor (130 g/GJ) for straw combusted in plants that are not power producing refers to Nikolaisen et al. (1998). The reference states the typical value 130 g/GJ for district heating plants and the interval 100-170 g/GJ. The emission factor for small farmhouse boilers and other plants has been assumed to be the same (DCE assumption).

8.5.23 Bio oil

Sector 1A1a, 1A2a-f, 1A4a, 1A4b, 1A4c, SNAP: all

The sulphur content of rape oil is below 0.001% and typically 0.0005% (Folkecenter for Vedvarende Energi, 2000). The lower heating value is 37.6 GJ/ton (DEA, 2012a). Based on these data the estimated emission factor is 0.1-0.3 g/GJ. However, DCE has applied an emission factor that is somewhat higher – 1 g/GJ.

In future inventories, the emission factor 0.1 g/GJ will be applied.

8.5.24 Biogas, gas engines

Sector 1A1a, 1A2a-f, 1A4a, 1A4c, SNAP 010105, 030905, 020105, 020304

The SO_2 emission factor for biogas fuelled engines, 19.2 g/GJ, refers to a Danish study (Nielsen & Illerup, 2003) that included emission measurements on 5 biogas engines. Despite the limited number of emission measurements, the fuel consumption of the plants represented 11% of the biogas consumption in gas engines in year 2000.

8.5.25 Biogas, other plants

Sector 1A1a, 1A2a-f, 1A4a, 1A4c, SNAP: all that are not included above

The emission factor 25 g/GJ has been estimated based on a H_2S content of 200 ppm. The sulphur content refers to Christiansen (2003) and to Hjort-Gregersen (1999).

The density of H_2S is 1.521 kg/m^3.

The lower heating value of biogas is 23 MJ/m_n^3 (DEA, 2012a).

Based on these data DCE has estimated the SO_2 emission factor:

H_2S: $200 \cdot 1.521/23 = 13.2$ mg H_2S/MJ

S: $13.2 \cdot 32/34 = 12.4$ mg S/MJ
SO_2: $64/32 \cdot 12.4 =$ 25 mg SO_2/MJ

8.5.26 Biomass gasification gas

Biomass gasification gas is combusted in gas engines. The emission factor, 1.9 g/GJ, have been assumed equal to wood. The emission factor is probably overestimated.

8.6 NO_x emission factors

The NO_x emission factors and references are shown in Table 55. Below the table, further details about the references, additional references, and time series are discussed.

Table 55 NO_x emission factors and references 2011.

Fuel type	Fuel	NFR	NFR_name	SNAP	Emission factor, g/GJ	Reference
SOLID	ANODE CARBON	1A2f	Industry - other	032000	132	Assumed equal to coal. DCE assumption.
	COAL	1A1a	Electricity and heat production	0101	30	DCE estimate based on Energinet.dk (2012) and EU ETS (2012)
				0102	95	DEPA (2001a)
		1A2a-f	Industry	03	95	DEPA (2001a)
		1A2f	Industry, cement production	0316	95	DEPA (2001a)
		1A4a	Commercial/Institutional	020100	95	DEPA (2001a)
		1A4b i	Residential	020200	95	DEPA (2001a)
		1A4c i	Agriculture/ forestry	0203	95	DEPA (2001a)
	BROWN COAL BRI.	1A2f i	Industry - other	0308	95	Assumed equal to coal. DCE assumption.
		1A4a	Commercial/Institutional	0201	95	Assumed equal to coal. DCE assumption.
		1A4b	Residential	0202	95	Assumed equal to coal. DCE assumption.
		1A4c	Agriculture/ forestry	0203	95	Assumed equal to coal. DCE assumption.
	COKE OVEN COKE	1A2a-f	Industry	03	95	Assumed equal to coal. DCE assumption.
		1A4b i	Residential	020200	95	Assumed equal to coal. DCE assumption.
LIQUID	PETRO-LEUM COKE	1A1a	Electricity and heat production	0101	95	Assumed equal to coal. DCE assumption.
		1A2a-f	Industry	03	95	Assumed equal to coal. DCE assumption.
		1A4a	Commercial/ Institutional	020100	50	EMEP (2006)
		1A4b	Residential	020200	50	EMEP (2006)
		1A4c	Agriculture/ forestry	0203	50	EMEP (2006)
	RESIDUAL OIL	1A1a	Electricity and heat production	0101	138	DCE estimate based on Energinet.dk (2009); Energinet.dk (2010); Energinet.dk (2011): EU ETS (2009-2011)
				0102	142	DEPA (2001a)
		1A1b	Petroleum refining	010306	142	DEPA (2001a)

Fuel type	Fuel	NFR	NFR_name	SNAP	Emission factor, g/GJ	Reference
		1A2a-f	Industry	03	130	DEPA (1990)
		1A2e	Food processing, beverages and tobacco	030902, 030903	136	Nielsen et al. (2010a)
		1A4a	Commercial/ Institutional	0201	142	DEPA (2001a)
		1A4b	Residential	0202	142	DEPA (2001a)
		1A4c i	Agriculture/ forestry	0203	142	DEPA (2001a)
	GAS OIL	1A1a	Electricity and heat production	010100, 010101, 010102	249	DCE estimate based on plant specific data for 2003 (Eltra & Elkraft System, 2004; DEA, 2012b)
				010103 0102	65	DEPA (1990)
				010104	350	DCE estimate based on (Eltra & Elkraft System, 2001; DEA, 2012b)
				010105	942	Nielsen et al. (2010a)
		1A1b	Petroleum refining	010306	65	DEPA (1990)
		1A2a-f	Industry	03 (not engines)	65	DEPA (1990)
		1A2a-f	Industry	Engines	942	Nielsen et al. (2010a)
		1A4a	Commercial/ Institutional	0201	52	DEPA (2001a)
				020105	942	Nielsen et al. (2010a)
		1A4b i	Residential	0202	52	DEPA (2001a)
				020204	942	Nielsen et al. (2010a)
		1A4c	Agriculture/forestry	0203	52	DEPA (2001a)
				020304	942	Nielsen et al. (2010a)
	KERO-SENE	1A2f	Industry - other	03	50	EEA (2009)
		1A4a	Commercial/ Institutional	0201	50	EEA (2009)
		1A4b i	Residential	0202	50	EEA (2009)
		1A4c i	Agriculture/ forestry	0203	50	EEA (2009)
	ORIMUL-SION	1A1a	Electricity and heat production	0101	86 (in year 2004)	DCE estimate based on Eltra & Elkraft System (2005) and DEA (2012b).
	LPG	1A1a	Electricity and heat production	All	96	IPCC (1997)
		1A2a-f	Industry	03	96	IPCC (1997)
		1A4a	Commercial/ Institutional	0201	71	IPCC (1997)
		1A4b i	Residential	0202	47	IPCC (1997)
		1A4c i	Agriculture/ forestry	0203	71	IPCC (1997)
	REFIN-ERY GAS	1A1b	Petroleum refining	010304	170	DCE estimate based on plant specific data for a gas turbine in year 2000.
				010306	80	DCE estimate based on plant specific data for the years 2007 and 2008.
GAS	NATURAL GAS	1A1a	Electricity and heat production	010101, 010102	55	DEPA (2003b)
				010103	42	Larsen (2009)

Fuel type	Fuel	NFR	NFR_name	SNAP	Emission factor, g/GJ	Reference
				010104	48	Nielsen et al. (2010a)
				010105	135	Nielsen et al. (2010a)
				0102	42	Larsen (2009)
		1A1c	Other energy industries	010504	250	Kristensen (2004)
		1A2a-f	Industry	03	42	Larsen (2009)
				Engines	135	Nielsen et al. (2010a)
				Turbines	48	Nielsen et al. (2010a)
				030700	87	DCE estimate based on plant specific data for 11 clay production plants, EU ETS (2011-2012); DEPA (2012)
		1A4a	Commercial/ Institutional	0201	30	Larsen (2009); DEPA (2001a)
				Engines	135	Nielsen et al. (2010a)
		1A4b i	Residential	0202	30	Larsen (2009); DEPA (2001a)
				Engines	135	Nielsen et al. (2010a)
		1A4c i	Agriculture/ forestry	0203	30	Larsen (2009); DEPA (2001a)
				Engines	135	Nielsen et al. (2010a)
WASTE	WASTE	1A1a	Electricity and heat production	0101	102	Nielsen et al. (2010a)
				0102	164	DCE estimate based on plant specific data for year 2000.
		1A2a-f	Industry	03	164	DCE estimate based on plant specific data for district heating plants in year 2000.
		1A4a	Commercial/ Institutional	0201	164	DCE estimate based on plant specific data for district heating plants in year 2000.
	INDUS-TRIAL WASTE	1A2f	Industry - Other	031600	164	Assumed equal to waste. DCE assumption.
BIO-MASS	WOOD	1A1a	Electricity and heat production	0101	81	Nielsen et al. (2010a)
				0102	90	Serup et al. (1999)
		1A2a-f	Industry	All	90	Serup et al. (1999)
		1A4a	Commercial/ Institutional	0201	90	Serup et al. (1999)
		1A4b i	Residential	0202	120	IPCC (1997)
		1A4c i	Agriculture/ forestry	0203	90	Serup et al. (1999)
	STRAW	1A1a	Electricity and heat production	0101	125	Nielsen et al. (2010a)
				0102	90	Nikolaisen et al. (1998)
		1A2a-f	Industry	03	90	Nikolaisen et al. (1998)
		1A4a	Commercial/Institutional	0201	90	Assumed equal to district heating plants. DCE assumption.
		1A4b i	Residential	0202	90	Assumed equal to district heating plants. DCE assumption.
		1A4c i	Agriculture/ forestry	0203	90	Assumed equal to district heating plants. DCE assumption.
	BIO OIL	1A1a	Electricity and heat production	0101	249	Assumed equal to gas oil. DCE assumption.
				010105	700	Assumed equal to gas oil. DCE assumption.

Fuel type	Fuel	NFR	NFR_name	SNAP	Emission factor, g/GJ	Reference
				0102	65	Assumed equal to gas oil. DCE assumption.
		1A2a-f	Industry	03	65	Assumed equal to gas oil. DCE assumption.
				Engines	700	Assumed equal to gas oil. DCE assumption.
		1A4a	Commercial/ Institutional	020105	700	Assumed equal to gas oil. DCE assumption.
		1A4b i	Residential	0202	65	Assumed equal to gas oil. DCE assumption.
		1A4c	Agriculture/ forestry	020304	700	Assumed equal to gas oil. DCE assumption.
	BIOGAS	1A1a	Electricity and heat production	0101, not engines	28	DEPA (2001a)
				Engines	202	Nielsen et al. (2010a)
				0102	28	DEPA (2001a)
		1A2a-f	Industry	03, not engines	28	DEPA (2001a)
				03, engines	202	Nielsen et al. (2010a)
				030902	59	DEPA (1990); DEPA (1995)
		1A4a	Commercial/ Institutional	0201, not engines	28	DEPA (2001a)
				020105	202	Nielsen et al. (2010a)
		1A4c i	Agriculture/ forestry	0203, not engines	28	DEPA (2001a)
				020304	202	Nielsen et al. (2010a)
	BIO PROD GAS	1A1a	Electricity and heat production	010105	173	Nielsen et al. (2010a)
		1A2f	Industry - other	031305	173	Nielsen et al. (2010a)
		1A4a	Commercial/ Institutional	020105	173	Nielsen et al. (2010a)
		1A4c	Agriculture/ forestry	020304	173	Nielsen et al. (2010a)

8.6.1 Anode carbon

Anode carbon has been used in industrial plants since 2010. The NO_x emission factor, 95 g/GJ, have been assumed equal to the NO_x emission factor for coal combusted in industrial plants.

The emission factor for coal combusted in industrial plants will be changed and thus the emission factor for anode carbon will also be changed to 132 g/GJ.

8.6.2 Coal, large power plants

Sector 1A1a, SNAP 0101

Data for NO_x emission and the fuel consumption for Danish power plants >25MW$_e$ are available for all plants for the years 1990 and onwards. In general, the plant specific data have been included in the emission inventories.

For some years, a small part of the coal consumption has, however, been included as an area source. The NO_x emission factor for coal has been estimated as an average value based on the annual reporting from the power plant operators to the electricity transmission company in Denmark, Energinet.dk[44].

In 2010 onwards, the emission factor is estimated based on a database query including plant specific data for power plants for which the coal consumption makes up more than 90 % of the total fuel consumption. All NO_x emission from these plants is assumed to originate from the coal consumption.

For 2008-2009, the emission factor is based on plant specific emission data for power plants that are primarily fuelled by coal. The NO_x emissions from plants that are primarily fuelled by coal have been divided by the total fuel consumption of these plants.

For 1990-2007, the emission factor is based on the total NO_x emission from power plants (regardless of primary fuel category) divided by the total fuel consumption of the power plants. This emission factor has been applied for both coal and residual oil. From 2003 onwards, the fuel consumption data were stated in TJ.

The calculated time series for the NO_x emission factor is shown below.

Table 56 NO_x emission factors for coal, power plants.

Year	NO_x emission factor [g/GJ]
1990	342
1991	384
1992	294
1993	289
1994	267
1995	239
1996	250
1997	200
1998	177
1999	152
2000	129
2001	122
2002	130
2003	144
2004	131
2005	127
2006	109
2007	98
2008	59
2009	39
2010	30
2011	30

8.6.3 Coal, other plants

Sector 1A1a, 1A2a-f, 1A4a, 1A4b, 1A4c, SNAP 0102, 03, 02

The 2000-2011 emission factors for plants that do not produce power refer to Danish legislation (DEPA, 2001a). This is however only guidance notes and for some plants higher emission limits have been accepted in the environ-

[44] Eltra and Elkraft System in the beginning of the time series.

mental approval. The emission limit for 5-50 MW boilers is 95 g/GJ. The NO_x emission limit applies for plants approved in 2001 onwards, but DCE has applied the emission factor for year 2000 onwards.

For 1990-1992, the currently applied emission factor 200 g/GJ refers to Fenhann & Kilde (1994). DCE has assumed the same emission factor for 1993-1999.

The current legislation for 50-100 MW plants approved before 2013 is 104 g/GJ (DEPA, 2012b). Former legislation for large plants (DEPA, 1990) sets the emission limit 225 g/GJ for plants installed before 1992 and 69 g/GJ for plants installed after 1992. However, plants larger than 50 MW have in general been included in the inventory as point sources with plant specific NO_x emission data.

The EMEP/EEA Guidebook (EEA, 2013) states the emission factors: 209 g/GJ for public electricity and heat production and 173 g/GJ for industrial plants.

An improved emission factor time series will be applied in future inventories. The consumption is largest for agricultural plants, food, beverage and tobacco industry and cement industry.

Plant specific data are available for the cement industry and the IEF was 199 g/GJ in 2011. The IEF is 732 g/GJ in year 2000 and 698 g/GJ in 1990. The emission factor 715 g/GJ will be applied for cement industry in future inventories for 1990-2000. For 2005, the IEF 580 g/GJ will be applied and for 2011, the IEF 199 g/GJ will be applied. A linear decline rate will be assumed between 2000-2005 and 2005-2011. In spite of the large change of emission factor, the estimated emission from cement industry will not change because plant specific data are available. However, the high but declining emission factors will now be reflected in the emission factor.

For 2011, plant specific data are available for one plant in the food, beverage and tobacco industry (with considerable coal consumption). The IEF was 132 g/GJ for this plant. This emission factor will be applied for all industrial plants (except cement production). The revised emission factor will be applied for all years.

The non-industrial consumption mainly takes place in agricultural plants and in 1990 also in district heating plants. The current emission factor referring to DEPA (2001a) will also be applied in future inventories.

The two revised emission factors will also be applied for brown coal briquettes and coke oven coke.

8.6.4 Brown coal briquettes

Sector 1A2f, 1A4a, 1A4b, 1A4c, SNAP 03, 0201, 0202, 0203

The emission factors for brown coal briquettes have been assumed to be the same as for coal. The consumption of brown coal briquettes is below 0.2 PJ all years and below 0.03 % of the Danish fuel consumption.

The emission factor will be revised when the emission factor for coal is revised.

8.6.5 Coke oven coke

Sector 1A2a-f and 1A4b, SNAP 03, 0202

The emission factors for coke oven coke have been assumed to be the same as for coal. The consumption of coke oven coke is below 1.4 PJ all years and below 0.3 % of the Danish fuel consumption.

The emission factor will be revised when the emission factor for coal is revised.

8.6.6 Petroleum coke, power plants and industry

Sector 1A1a, 1A2a-f, SNAP 0101, 03

DCE have assumed that the emission factor for petroleum coke combusted in power plants, district heating plants and industrial plants is the same as for coal combustion in district heating/industrial plants. This has been assumed for all years.

In the next inventory, the emission factor will be assumed equal to residual oil instead.

8.6.7 Petroleum coke, residential plants, commercial/institutional plants and plants in agriculture/forestry

Sector 1A4a, 1A4b, 1A4c, SNAP 0201, 0202, 0203

The emission factor for petroleum coke combusted in residential plants or other plants refers to the EMEP/Corinair Guidebook (EMEP, 2006)[45]. The NO_x emission factor 50 g/GJ for petroleum coke combusted in non-industrial plants have been applied.

The emission factor has been revised in the latest update of the Guidebook. The emission factor will be changed to 51 g/GJ for residential plants in the next inventory referring to the tier 1 value for liquid fuels in the latest update of the EMEP/EEA Guidebook (EEA, 2013). The emission factor for commercial/institutional plants and plants in agriculture/forestry will be assumed equal to the emission factor for residential plants.

8.6.8 Residual oil, power plants

Sector 1A1a, SNAP 0101

The NO_x emission and the fuel consumption for Danish power plants >25MW_e are available for all plants for the years 1990 and onwards. In general, the plant specific data have been included in the emission inventories.

For some years, a small part of the residual oil consumption has, however, been included as an area source. The NO_x emission factor for residual oil has been estimated as an average value based on the plant specific data. The NO_x emission data refer to Energinet.dk[46] and the fuel consumption data refer to EU ETS or DEA.

[45] In Chapter 112, Table 5 the NO_x emission factor 50 g/GJ is stated for petroleum coke combusted in non-industrial plants.
[46] Eltra and Elkraft System in the beginning of the time series.

From 2008 onwards, the emission factor is estimated based on an average value for 2008, 2009 and 2010. The emission factor for each year is based on a database query that include plant specific data for power plants for which the residual oil consumption is more than 90 % of the total fuel consumption. All NO_x emission from these plants is assumed to originate from the residual oil consumption. NO_x emission data refer to Energinet.dk (2009), Energinet.dk (2010), and Energinet.dk (2011). Fuel consumption data refer to EU ETS (2009-2011). The emission factor 138 g/GJ is the average for the years 2008, 2009 and 2010.

For 1990-2007, the emission factor is based on the total NO_x emission from power plants (regardless of primary fuel category) divided by the total fuel consumption of the power plants. This emission factor has been applied for both coal and residual oil. From 2003 onwards, the fuel consumption data were stated in TJ.

The calculated time series for the NO_x emission factor are shown below.

Table 57 NO_x emission factors for coal, power plants.

Year	NO_x emission factor [g/GJ]
1990	342
1991	384
1992	294
1993	289
1994	267
1995	239
1996	250
1997	200
1998	177
1999	152
2000	129
2001	122
2002	130
2003	144
2004	131
2005	127
2006	109
2007	98
2008	138
2009	138
2010	138
2011	138

8.6.9 Residual oil, industrial plants

Sector 1A2a-f, SNAP 03

The NO_x emission factor for residual oil combusted in industrial plants refers to Danish legislation.

Table 58 gives an overview of emission limits values and other emission factors for industrial plants combusting residual oil.

Table 58 Emission factors for industrial plants combusting residual oil.

Technology	Emission factor (/limit)	Reference
Boilers 2-50 MW	142 g/GJ	DEPA (2001a)[1)]
Boilers > 50 MW installed before 1992	130 g/GJ	DEPA (1990)[2)]
Boilers > 50 MW installed after 1992	65 g/GJ	DEPA (1990)[2)], DEPA (1995)
CHP plants, residual oil fuelled steam turbine	136 g/GJ	Nielsen et al. (2010a)
IEF for two plants in the food and tobacco industry, 2011	129 g/GJ	DCE estimate (2013)
IEF for the cement industry	199 g/GJ	DCE estimate (2013)
Heavy fuel oil for public electricity and heat production	215 g/GJ	EEA (2009)
Industry, oil	200 g/GJ	IPCC (1997)

1) The emission of NO_x from 2-50 MW boilers should be below 300 mg/m_n^3 (ref. 10% O_2) (DEPA, 2001a) corresponding to 142 g/GJ. Residual oil should not be combusted in boilers < 2 MW in Denmark (DEPA, 2001a).

2) The NO_x emission from boilers > 50 MW should be below 450 mg/m_n^3 (ref. 3% O_2) (DEPA, 1990) corresponding to 130 g/GJ. The emission from plants installed after 1992 should be below 225 mg/m_n^3 (ref. 3% O_2) (DEPA, 1990) corresponding to 65 g/GJ. A later update of the legislation (DEPA, 1995) confirms the same emission limits for residual oil.

In 2011, more than 90 % of the industrial consumption of residual oil was used in the food and tobacco industry. The consumption is also considerable in the cement industry. Plants in both sectors are included as point sources with plant specific data in the Danish emission inventory for 2011. The IEF for two plants in the food and tobacco industry 2011 is 129 g/GJ. The IEF for cement is 199 g/GJ in 2011.

The current emission factor 130 g/GJ refers to DEPA (1990), however for food and tobacco industry the emission factor 136 g/GJ refer to Nielsen et al. (2010a).

In future inventories, the same emission factor will be applied for all industrial plants. The current emission level is close to both Nielsen et al. (2010a) and to the IEF (129 g/GJ) based on plant specific data for two plants in the food and tobacco industry in 2011. The emission factor 129 g/GJ will be applied because this emission factor covers a large part of the consumption.

8.6.10 Residual oil, other plants

Sector 1A1a, 1A1b, 1A4a, 1A4b, 1A4c, SNAP 0102, 010306, 0201, 0202, 0203

Residual oil combusted in plants that are neither power plants nor industrial plants has been assumed to be boilers < 50MW. Thus, the plants have to meet Danish emission limit 142 g/GJ (DEPA, 2001a).

The EMEP/EEA Guidebook (EEA, 2009) states the emission factor 100 g/GJ for small combustion, non-residential plants. The IPCC Guidelines (IPCC, 1997) states the emission factor 100 g/GJ for other sectors and 200 g/GJ for energy industries. Thus, the legislative emission limit seems to be a reasonable choice.

Currently, the emission factor for refinery furnaces has been assumed to be the same (DCE assumption). However, in future inventories the IPCC default emission factor 200 g/GJ will be applied.

8.6.11 Gas oil, power plants

Sector 1A1a, SNAP 010100, 010101, 010102

The emission factor 249 g/GJ has been estimated by DCE based on plant specific emission data for 2003 (Eltra & Elkraft System, 2004) and fuel consumption data from DEA (2012b). The estimate was based on emission data from two power plant boilers that only combusted gas oil. This emission factor has been applied all years.

Based on plant specific data, DCE has estimated the emission factor for 2011 to 114 g/GJ. In the next inventory, this emission factor will be applied and a linear decrease since 2003 will be assumed.

Gas oil consumption adds up to less than 1% of the fuel consumption in power plants in 1990-2011[47].

8.6.12 Gas oil, gas turbines

Sector 1A1a, 1A2a-f, SNAP 010104, 030604, 030904

The emission factor for gas turbines combusting gas oil (350 g/GJ) has been estimated by DCE based on plant specific emission data from power plant gas turbines in year 2000 (Eltra & Elkraft System, 2001) and fuel consumption data from DEA (2012b). The emission factor has been applied for all years.

In 2011, the emission factor for a gas oil fuelled turbine was 146 g/GJ. A large part of the gas oil combusted in gas turbines is used in gas turbines that are primarily fuelled by natural gas. A large part of the consumption was in public power production plants.

The IPCC Reference Manual (IPCC, 1997) states the emission factor 300 g/GJ for gas oil combustion in gas turbines. The EMEP/EEA Guidebook (EEA, 2009) states the emission factor 398 g/GJ. These values verify the Danish emission factor.

The current emission limit value for gas oil fuelled gas turbines is 65 g/GJ (DEPA, 2012b). This limit is, however, not valid for turbines in plants with a thermal input above 50 MW or with less than 500 operating hours per year.

8.6.13 Gas oil, stationary engines

Sector 1A1a, 1A2a-f, 1A4a, 1A4b, 1A4c, SNAP 010105, 031205, 031305, 032005, 020105, 020204, 020304

The emission factor for gas oil combusted in stationary engines (942 g/GJ) refers to a Danish emission measurement project for CHP plants (Nielsen et al., 2010a). This emission factor has been applied for year 2000 onwards.

The EMEP/EEA Guidebook (EEA, 2009) that states the emission factor 1450 g/GJ. This emission factor has been applied for the year 1990. A linear decrease has been assumed between 1990 and 2000.

The emission limit is 178 g/GJ for existing engines (DEPA, 2012b). However, the limit value is not valid for engines with less than 500 operating hours per year.

[47] Except in 2009 (1.1 %)

8.6.14 Gas oil, small power plant boilers, district heating plants and industrial boilers

Sector 1A1a, 1A1b, 1A2a-f, SNAP 010103, 0102, 0301

The main part of the gas oil consumption is in district heating plants. Most of the district heating boilers are installed before 2003.

The current emission limit for existing 50-100 MW plants is 130 g/GJ (DEPA, 2012b[48]). The former legislation (DEPA, 2003b) included the same emission limit for plants installed before 2003. The legislation from 1990 (DEPA, 1990) also included this emission limit for boilers installed before 1992, but for boilers installed after 1992 the emission limit equals 65 g/GJ.

For 5- 50 MW boilers the emission limit is 52 g/GJ or 118 g/GJ depending on installation year (DEPA, 2001a).

The EMEP/EEA Guidebook (EEA, 2009) states the emission factors 180 g/GJ for other liquid fuels in energy industries or 100 g/GJ for other liquid fuels, small combustion. The IPCC Guidelines (IPCC, 1997) states the emission factor 200 g/GJ for energy industries and industry. Thus, these two references suggest higher emission factors than the current emission factor.

The emission factor applied for 1997 onwards (65 g/GJ) refers to DEPA (1990).

In future inventories, the emission factor will be revised to 130 g/GJ for all years referring to DEPA (2012b), DEPA (2003b) and DEPA (1990).

For 1990, the emission factor 100 g/GJ has been applied. This emission factor refers to Fenhann & Kilde (1994). The emission factors applied for 1991-1996 have been assumed to follow a constant decrease rate (DCE assumption).

8.6.15 Gas oil, residential plants, commercial/institutional plants, and plants in agriculture/forestry

Sector 1A4a, 1A4b, 1A4c, SNAP 0201, 0202, 0203

Residential plants, commercial and institutional plants and plants in agriculture/forestry are all small plants. The emission limit for 120 kW - 50 MW boilers is 52 g/GJ for plants installed after 2001 and 118 g/GJ for plants installed before 2001 (DEPA, 2001a).

The EMEP/EEA Guidebook (EEA, 2009) states the emission factors 68 g/GJ for residential plants, 100 g/GJ for commercial/institutional plants, 70 g/GJ for residential boilers. IPCC Guidelines (IPCC, 1997) states the tier 1 emission factor 100 g/GJ for residential or commercial/institutional plants and the tier 2 emission factor 65 g/GJ for distillate oil combusted in residential or commercial plants. These values confirm an emission level close to the emission limit in Denmark.

The applied emission factor 52 g/GJ refers to DEPA (2001a). DCE has assumed the same emission factor for residential plants, commercial/institutional plants and plants in agriculture/forestry. The same emission factor has been applied all years.

[48] Implements the EU Directive on Industrial Emissions

8.6.16 Kerosene

Sector 1A2f, 1A4a, 1A4b, 1A4c, SNAP 0301, 0201, 0202, 0203

The emission factor for kerosene, 50 g/GJ, refers to the EMEP/EEA Guidebook (EEA, 2009). The emission factor for residential stoves has been applied.

8.6.17 Orimulsion

Sector 1A1a, SNAP 010101

Orimulsion has only been used in a single large power plant boiler in Denmark. This power plant boiler has been included in the inventories as a point source with plant specific NO_x emission data included all years. Thus, the emission factors that are stated in the area source emission factor time series are only included for information.

The emission factors have been estimated based on plant specific data. The plant specific NO_x emission data refer to Eltra & Elkraft System (annual reporting) and the fuel consumption data refer to DEA (2012b) and the similar DEA data reported in former years. The use of orimulsion in Denmark ceased in 2005.

8.6.18 LPG

Sector 1A1a, 1A1b,1A2a-f, 1A4a, 1A4b, 1A4c, SNAP: all

The emission factors applied for LPG refer to the IPCC Guidelines (IPCC, 1997). The applied tier 2 emission factors are:

- 96 g/GJ for combustion in energy and transformation industry or in industrial plants
- 71 g/GJ for combustion in commercial and institutional plants and in agriculture/forestry
- 47 g/GJ for residential plants

The same emission factors have been applied for all years.

8.6.19 Refinery gas, gas turbine

Sector 1A1b, SNAP 010300, 010304

The applied emission factor for refinery gas combusted in gas turbines (170 g/GJ) refers to plant specific data in year 2000. The only refinery gas fuelled gas turbine in operation in Denmark has, however, been included as a point source with plant specific emission data since 1994.

8.6.20 Refinery gas, other

Sector 1A1b, 1A2f, SNAP 010306, 032000

The refineries have been included as point sources with plant specific emission factors in the Danish inventory since 1994.

The emission factor 80 g/GJ applied for refinery gas combusted in other units than gas turbines is an implied emission factor estimated by DCE based on plant specific data for emission and fuel consumption for the two refineries in year 2007 and 2008.

Based on plant specific data for 2011, the implied emission factor 94 g/GJ have been estimated[49]. For 1994, the implied emission factor 83 g/GJ have been estimated. In future inventories, the implied emission factors for 1994 will be applied for 1990-2008 and the implied emission factor for 2011 will be applied for 2009 onwards.

8.6.21 Natural gas, power plants

Sector 1A1a, SNAP 010101, 010102

In general, plant specific data are available for natural gas fuelled power plants.

The emission factor for 2008 onwards refers to Danish legislation for large combustion plants (DEPA, 2003b). The emission factor 55 g/GJ applies for 50- 500 MW_{th} plants installed before 2003. Emission limit values in the latest legislation from DEPA (2012b) have not been implemented in the inventory because the new limit value 28 g/GJ is only valid from 2016 for existing plants.

The emission factor for 2004-2007 also refers to DEPA (2003b). Until 2008, the emission limit for plants installed before 2003 is 97 g/GJ and this value have been applied.

The emission factor applied for 1990-2003 (115 g/GJ) has been estimated by DCE based on plant specific emission data for year 2000. Gas turbine plants were not included in the estimate.

8.6.22 Natural gas, gas turbines (and combined cycle plants)

Sector 1A1a, 1A2a-f, 1A4a, SNAP 010104, 030604, 030904, 031104, 031604, 020104

Gas turbines > 25MW_e have been included in the inventory as point sources with plant specific NO_x emission data.

The emission factor 48 g/GJ refers to Nielsen et al. (2010a). This emission measurement programme for decentralised CHP plants included estimation of emission factors for the years 2003-2006 and for 2007 onwards. The emission factor for 2007 onwards (48 g/GJ) have been applied in the inventory for the years 2007 onwards. The 2003-2006 emission factor (98 g/GJ) has been applied for 2005. The decline rate between 2005 and 2007 has been assumed linear.

The emission factor for year 2000 (124 g/GJ) refers to another Danish study (Nielsen & Illerup, 2003). This study included emission measurements from 17 gas turbine plants < 25MW_e. The emission measurements included in the estimate represented 67% of the natural gas consumption in gas turbines < 25 MW_e in 2000. The decline rate of the emission factor in 2000-2005 has been assumed linear.

[49] SNAP 010306, two refineries, all fuels included.

Emission factors for 1990 (161 g/GJ) and 1995 (141 g/GJ) was also included in Nielsen & Illerup (2003). The decline rate in 1990-1995 and 1995-2000 respectively, have been assumed linear.

8.6.23 Natural gas, off shore gas turbines

Sector 1A1c, SPAP 010504

The emission factor for off shore gas turbines, 250 g/GJ, refer to Kristensen (2004). The emission factor estimate is based on plant specific data. The estimate was performed by Danish Gas Technology Centre for a DEPA NO_x working group.

8.6.24 Natural gas, gas engines

Sector 1A1a, 1A2a-f, 1A4a, 1A4b, 1A4c, SNAP 010105, 03xx05, 020105, 020204, 020304

The emission factor for natural gas fuelled engines refers to Nielsen et al. (2010a). In this Danish emission measurement programme for CHP plants, emission factors for 2007 and 2003-2006 have been estimated. New emission limits were valid for existing engines from end 2006 (DEPA, 1998). The emission factor for 2007 (135 g/GJ) have been applied in the inventories for 2007 onwards. The emission factor based on emission measurements from 2003-2006 (143 g/GJ) have been applied for 2005. A linear decline rate has been assumed from 2005 to 2007.

The emission factor for year 2000 (168 g/GJ) refer to the full load emission factors estimated in the previous emission factor survey (Nielsen & Illerup, 2003) and the correction factors for start-up and shut-down developed in another project (Nielsen et al., 2008). The decline rate between year 2000 and 2005 have been assumed linear.

The emission factors for 1990 (176 g/GJ) and 1995 (194 g/GJ) also refer to Nielsen & Illerup (2003). Time series for 1990-1995 and 1995-2000 have been estimated assuming linear increase/decrease.

8.6.25 Natural gas, district heating boilers and industrial boilers

Sector 1A1a, 1A2a-f, SNAP 010103, 0102, 03xx00-03xx03

Boilers installed in district heating plants or industry and boilers < 50 MW_{th} installed in power plants are included in this category.

The emission factor (42 g/GJ) refers to a report from Danish Gas Technology Centre (Larsen 2009). The emission factor is the average of the emission interval for large boilers[50] (30-55 g/GJ).

The emission limit for 120 kW – 50 MW boilers is 29 g/GJ for boilers installed after 2001 and 57 g/GJ for boilers installed before 2001 (DEPA, 2001a). Almost all boilers in operation are installed before 2001 (Kristensen, 2005; Wit, 2005) and thus the emission factor is in agreement with the legislation.

[50] For forced draught gas burners. The interval for low NO_x burners is 12-17 g/GJ.

Improved emission factors for boilers will be estimated in an on-going project performed by Danish Gas Technology Centre.

8.6.26 Natural gas, non-metallic minerals

The emission factor for production of bricks and tiles is higher than the emission factor for other industrial combustion plants. Since this production is included in the industrial subsector non-metallic minerals, the emission factor for this category is higher (87 g/GJ).

The emission factor has been estimated based on plant specific data for 11 plants for years 2010 or 2011. Data for the estimate are based on EU ETS data for fuel consumption (EU ETS, 2011-2012) and NO_x emission data from annual environmental reports (DEPA, 2012a).

8.6.27 Natural gas, small boilers

Sector 1A4a, 1A4b, 1A4c, SNAP 020100, 020103, 020200, 020202, 020300

Small natural gas fuelled boilers that are either residential plants, commercial/institutional plants or plants in agriculture/forestry included in this category.

The emission factor applied for 1990 and onwards is 30 g/GJ. Several references have been taken into account. Larsen (2009) and DEPA (2001a) are the references for the applied emission factor.

- An environmental report from Danish Gas Technology Centre (Larsen, 2009) states the emission factor 19 g/GJ for condensing boilers in residential plants and 42 g/GJ for conventional boilers in residential plants.
- The emission limit value for 120 kW- 5 MW boilers installed after 2001 is 29 g/GJ (DEPA, 2001a). The emission limit for boilers installed before 2001 is 57 g/GJ.
- The IPCC Guidelines (IPCC, 1997) states the emission factor 47 g/GJ for residential boilers and 45 g/GJ for commercial boilers.
- The EMEP/EEA Guidebook (EEA, 2009) states the emission factor 70 g/GJ for small consumers and residential boilers.

Improved emission factors for boilers will be estimated in an on-going project performed by Danish Gas Technology Centre.

8.6.28 Waste, CHP plants

Sector 1A1a, SNAP 0101

The emission factor for 2006 onwards (102 g/GJ) refers to Nielsen et al. (2010a) that is a Danish measurement project for CHP plants. In 2006, 68 % of the waste was incinerated in plants installed with SNCR.

Most waste incineration plants report plant specific emission data. The implied emission factor for waste incineration plants was 100 g/GJ in 2011, and thus the emission data for 2011 confirm the current emission factor.

New emission limits for waste incineration plants were applicable from 2006 (DEPA, 2003a). The legislation includes two different emission limits for NO_x; 210 g/GJ for existing plants with a capacity of less than 6 tonnes/hour and 105 g/GJ for other plants.

The NO_x emission factor for year 2000 refers to an earlier Danish study (Nielsen & Illerup, 2003). The emission factor (124 g/GJ) has been applied for the inventories for year 2000-2003. A linear decline rate has been assumed for 2003-2006.

The first SNCR unit was installed in a waste incineration plant in 1998. The emission factor for 1990-1998 refers to the emission factor for plants without SNCR in Nielsen et al. (2010a). This emission factor might be underestimated since the combustion technology might also have been improved and contributed to the lower emission level.

8.6.29 Waste, other plants

Sector 1A1a, 1A2a-f, 1A4a, SNAP 0102, 03, 0201

The NO_x emission factor (164 g/GJ) applied for non-power producing plants (mainly district heating plants) has been estimated by DCE based on plant specific emission data from non-power producing plants in year 2000. The same emission factor has been applied for all years. In recent years, the main part of waste incineration plants that do not produce power has been replaced by power producing plants.

The current legislation for plants < 6 ton/hour is 210 g/GJ (DEPA, 2003a).

8.6.30 Industrial waste

Since the waste incinerated in the Danish cement production plant differs from waste incinerated in other plants a separate fuel category is applied. However, for NO_x plant specific emission data are available and the default emission factor (164 g/GJ) is not actually applied.

The value refer to value for waste incineration in non-power producing plants.

8.6.31 Wood, CHP plants and large power plants

Sector 1A1a, SNAP 0101

The NO_x emission factor for wood combusted in CHP plants (81 g/GJ) refers to Nielsen et al. (2010a). This emission factor is based on 5 emission measurements from 2 plants. The fuel consumption of the two plants represented 42% of the wood consumption in CHP plants in year 2006. The emission factor is applied for all years.

8.6.32 Wood, residential plants

Sector 1A4b, SNAP 0202

The emission factor for wood combustion in residential plants, 120 g/GJ, refers to the IPCC Guidelines (IPCC, 1997). The emission factor for conventional stoves has been applied. The default emission factor for residential wood combustion is 100 g/GJ.

The emission factors in the EMEP/EEA Guidebook (EEA, 2009) are between 70 g/GJ and 120 g/GJ depending on technology.

In future inventories, the technology specific emission factors in the 2013 update of the EMEP/EEA Guidebook (EEA, 2013) will be applied for estimating a time series for the emission factor. The emission factor will be lower than the current emission factor: 81 g/GJ in 2012.

8.6.33 Wood, other plants

Sector 1A1a, 1A2a-f, 1A4a, 1A4c, SNAP 0102, 03, 0201, 0203

The emission factor applied for wood combustion in district heating plants, industrial plants, commercial/institutional plants and plants in agriculture/forestry is 90 g/GJ referring to Serup et al. (1999). According to Setup et al. (1999), the emission factor for Danish district heating plants combusting wood is 40-140 g/GJ and the typical value is 90 g/GJ. This emission factor has been applied for 1999 onwards.

For 1990-1998, the emission factor is 130 g/GJ. This is a rough estimate based on Serup et al. (1999), DEPA (2001a) and Christensen (1997). The emission limit for 1-50 MW boilers combusting wood is 143 g/GJ (DEPA, 2001a). Christensen (1997) states the emission factor 55-230 g/GJ.

The IPCC Guidelines (IPCC, 1997) states the emission factor 100 g/GJ for district heating and industry. The emission factor stated in the 2013 update of the EMEP/EEA Guidebook (EEA, 2013) is 91 g/GJ.

In future inventories, the emission factor 90 g/GJ will be applied for all years referring to Serup et al. (1999) and EEA (2013).

8.6.34 Straw, CHP plants and large power plants

Sector 1A1a, SNAP 0101

The emission factor for wood combusted in CHP plants and power plants (125 g/GJ) refers to Nielsen et al. (2010a). This emission measurement programme included 14 datasets from 5 plants representing 83 % of the straw consumption in CHP plants[51] in 2006.

The emission factor has also been applied for combustion of straw in large power plants. However, plant specific NO_x emission data are usually available for large power plants.

The emission factor has been applied for all years.

8.6.35 Straw, other plants

Sector 1A1a, 1A2a-f, 1A4a, 1A4b, 1A4c, SNAP 0102, 03, 0201, 0202, 0203

The emission factor, 90 g/GJ, refers to Nikolaisen et al. (1998). According to Nikolaisen et al. (1998), the typical emission factor for Danish district heating plants combusting straw is 90 g/GJ with a typical interval of 40-150 g/GJ.

Due to lack of data from other non-power producing plants, the emission factor 90 g/GJ have been applied for these as well.

Data from EEA (2013) support the emission factor level. EEA (2013) states the emission factor 80 g/GJ for residential combustion of biomass and 91

[51] $< 25 MW_e$

g/GJ for biomass combustion in commercial/institutional/agricultural plants.

The emission factor has been applied for all years.

8.6.36 Bio oil

Sector 1A1a, 1A2a-f, 1A4a, 1A4b, 1A4c, SNAP all

The NO_x emission factors for bio oil have been assumed to be the same as for gas oil.

8.6.37 Biogas, gas engines

Sector 1A1a, 1A2e, 1A4a, 1A4c, SNAP 010105, 030905, 020105, 020304

The emission factor for 2006 onwards (202 g/GJ) refers to Nielsen et al. (2010a). The emission factor is based on emission measurements from 10 engines. A new emission limit (297 g/GJ) is valid for existing biogas engines from 2013 (DEPA, 2012c).

The emission factor for year 2000 (540 g/GJ) refers to an earlier Danish study (Nielsen & Illerup, 2003). This study included emission measurements on 15 gas engines. The emission measurements included in the estimate represented 21% of the biogas consumption in gas engines in year 2000. A linear decline rate of the emission factor has been assumed from year 2000 to year 2006.

Emission factors for 1990 (711 g/GJ) and 1995 (635 g/GJ) also refer to Nielsen & Illerup (2003). The decline rates in 1990-1995 and in 1995-2000 have been assumed constant.

8.6.38 Biogas, industrial boilers > 50 MW

Sector 1A2e, SNAP 030902

For industrial boilers > 50 MW the applied emission factor (59 g/GJ) refers to former Danish legislation for large boilers (DEPA, 1990; DEPA, 1995).

For boilers installed before 2003 the current emission limit is 79 g/GJ and the emission limit is 53 g/GJ for boilers approved in 2003 or later.

8.6.39 Biogas, other boilers

Sector 1A1a, 1A2a-f, 1A4a, 1A4c, SNAP 0102, 03, 0201, 0203

Boilers are in general < 50 MW and the emission factor refers to Danish legislation (DEPA, 2001a). The emission limit value for 120 kW – 50 MW is 28 g/GJ[52] (DEPA, 2001a) and this emission factor has been applied for all years.

8.6.40 Biomass gasification gas

Biomass gasification gas is combusted in gas engines. The emission factor, 173 g/GJ, refers to Nielsen et al. (2010a).

[52] In some cases the limit is 54 g/GJ for existing plants.

8.7 NMVOC emission factors

Emission factors for NMVOC are listed in Annex 4. The annex includes references and time series. The emission factors for NMVOC refer to:

- An emission measurement program for decentralised CHP plants (Nielsen et al., 2010a).
- The EMEP/EEA Guidebook (EEA, 2009).
- Aggregated emission factor based on the technology distribution for residential wood combustion and guidebook (EEA, 2009) emission factors. Technology distribution based on Nielsen & Hessberg (2011).
- DGC Danish Gas Technology Centre 2001, Naturgas – Energi og miljø (DGC, 2001).
- Gruijthuijsen L.v. & Jensen J.K., 2000. Energi- og miljøoversigt, Danish Gas Technology Centre 2000 (In Danish).

8.8 CO emission factors

Emission factors for CO are listed in Annex 4. The annex includes references and time series. The emission factors for CO refer to:

- The EMEP/EEA Guidebook (EEA, 2009) and the former update (EEA, 2007).
- IPCC Guidelines (IPCC, 1997)
- An emission measurement program for decentralised CHP plants (Nielsen et al., 2010a).
- Danish legislation (DEPA, 2001a)
- Aggregated emission factor based on the technology distribution for residential wood combustion and guidebook (EEA, 2009) emission factors. Technology distribution based on Nielsen & Hessberg (2011).
- DCE estimate based on annual environmental reports for Danish waste incineration plants without power production, year 2000.
- Nikolaisen et al. (1998)
- Jensen & Nielsen (1990)
- Bjerrum (2002)
- Sander (2002)
- Gruijthuijsen & Jensen (2000)

8.9 NH_3 emission factors

Emission factors have been included for residential wood combustion, residential straw combustion, waste incineration in public power production and residential combustion of coal and coke oven coke. The emission factor for waste incineration plants refers to a Danish emission measurement programme (Nielsen et al., 2010a) and all other emission factors refer to the EMEP/EEA Guidebook (EEA, 2009). Time series have not been estimated.

8.10 PM emission factors

Emission factors for PM and references for the emission factors are listed in Annex 4. The emission factors are based on:

- The TNO/CEPMEIP emission factor database (CEPMEIP, 2001).

In addition, a considerable number of country-specific factors referring to:

- Danish legislation:

  - DEPA (2001a), The Danish Environmental Protection Agency, Luftvejledningen (legislation from Danish Environmental Protection Agency).
  - DEPA (1990), The Danish Environmental Protection Agency, Bekendtgørelse 698 (legislation from Danish Environmental Protection Agency).
- Calculations based on plant-specific emission data from a considerable number of waste incineration plants.
- Aggregated emission factors for residential wood combustion based on technology distribution (Nielsen & Hessberg, 2011) and technology specific emission factors (EEA, 2009; DEPA, 2010b).
- Two emission measurement programs for decentralised CHP plants (Nielsen et al., 2010a; Nielsen & Illerup, 2003).
- An emission measurement program for large power plants (Livbjerg et al., 2001).
- Research leading to the first Danish PM emission inventory for stationary combustion (Nielsen et al., 2003)
- Additional personal communication concerning straw combustion in residential plants.

Emission factor time series have been estimated for residential wood combustion and waste incineration. All other emission factors have been considered constant in 2000-2011.

8.11 Heavy metal emission factors

Emission factors for 2011 for heavy metals (HM) are presented in Annex 4. The annex includes references and time series. The emission factors refer to:

- Two emission measurement programs carried out on Danish decentralised CHP plants (Nielsen et al., 2010a; Nielsen & Illerup, 2003).
- Implied Emission Factors for power plants based on plant specific data reported by the power plant owners.
- Research concerning heavy metal emission factors representative for Denmark (Illerup et al., 1999).
- A CONCAWE study (Denier van der Gon & Kuenen, 2010)
- Data for Danish natural gas (Gruijthuijsen (2001); Energinet.dk homepage)
- Emission factors without national reference all refer to EEA (2009).

Time series have been estimated for coal and for waste incineration. For all other sources, the same emission factors have been applied for 1990-2011.

A report documenting the heavy metal emission inventory in detail is published in 2013 (Nielsen et al., 2013c).

8.12 PAH emission factors

Emission factors 2011 for PAH are shown in Annex 4. The appendix includes references. The PAH emission factors refer to:

- Research carried out by TNO (Berdowski et al., 1995).
- Research carried out by Statistics Norway (Finstad et al., 2001).
- An emission measurement program performed on biomass fuelled plants. The project was carried out for the Danish Environmental Protection Agency (Jensen & Nielsen, 1996).

- Two emission measurement programs carried out on Danish decentralised CHP plants (Nielsen et al., 2010a; Nielsen & Illerup, 2003).
- Additional information from the gas sector (Jensen, 2001).

For residential wood combustion, country specific emission factors have been aggregated based on technology distribution in the sector (Nielsen & Hessberg, 2011) and technology specific emission factors (EEA, 2009; DEPA 2010b).

Emission factor time series have been estimated for residential wood combustion, natural gas fuelled engines, biogas fuelled engines and waste incineration plants. All other emission factors have been considered constant from 1990 to 2011. In general, emission factors for PAH are uncertain.

8.13 PCDD/F emission factors

Emission factors 2011 for PCDD/F are shown in Annex 4.

The emission factor for residential wood combustion refers to technology specific emission factors (EEA, 2009; DEPA, 2010b) and to updated technology distribution data (Nielsen & Hessberg, 2011).

The emission factors for decentralised CHP plants[53] refer to an emission measurement program for these plants (Nielsen et al., 2010a).

All other emission factors refer to research regarding PCDD/F emission carried out by NERI (now DCE) to prepare a new PCDD/F emission inventory (Henriksen et al., 2006).

Time series have been estimated for residential wood combustion and for incineration of waste. For all other sources, the same emission factors have been applied for 1990-2011.

8.14 HCB emission factors

Emission factors 2011 for HCB are shown in Annex 4. The emission factors for waste incineration plants, CHP plants combusting straw, biogas fuelled engines, gas oil fuelled engines and engines combusting biomass gasification gas refer to a Danish emission measurement programme for decentralised CHP plants (Nielsen et al., 2010a). All other HCB emission factors refer to the EMEP/EEA Guidebook (EEA, 2009). Time series have been estimated for waste incineration plants. All other emission factors have been considered constant in 1990-2011.

8.15 Technology specific emission factors for residential wood combustion, NMVOC and CO

For the pollutants NMVOC, CO, TSP, PM_{10}, $PM_{2.5}$, PCDD/F and PAH emission factors have been based on fuel consumption data and emission factors for 10 different technologies. Technology categories, emission factors and implied emission factors for 2011 are shown in Table 59. For other pollutants, time series have not been estimated and the emission factors are shown in Annex 4.

[53] Natural gas fuelled engines, biogas fuelled engines, gasoil fuelled engines, engines fuelled by biomass gasification gas, CHP plants combusting straw or wood and waste incineration plants.

Table 59 Technology specific mission factors for residential wood combustion.

Technology	NMVOC, g/GJ	CO, g/GJ	TSP, g/GJ	PM10, g/GJ	$PM_{2.5}$, g/GJ	PCDD/F, ng/GJ	Benzo(a)pyrene, mg/GJ	Benzo(b)fluoranthene, mg/GJ	Benzo(k)fluoranthene, mg/GJ	Indeno(1.2.3-c,d)pyrene, mg/GJ
Old stove	1200	6000	850	810	810	800	250	240	150	180
New stove	560	6000	850	810	810	800	250	240	150	180
Stove according to resent Danish legislation (DEPA, 2007)	250	3000	640	608	608	300	100	90	40	60
Eco labelled stove / new advanced stove	125	1500	250	240	240	150	50	45	20	30
Other stoves	1200	6000	900	860	850	800	250	240	150	180
Old boilers with hot water storage	400	4000	1000	950	900	500	130	200	100	80
Old boilers without hot water storage	400	4000	2000	1900	1800	500	130	200	100	80
New boilers with hot water storage	100	3000	150	142.5	135	300	40	14	8	6
New boilers without hot water storage	250	300	300	285	270	300	12	60	20	20
Pellet boilers	20	500	35	33	32	30	15	16	10	9
IEF residential wood combustion, 2011	343	3100	481	458	452	391	113	113	66	77

8.16 Implied emission factors

A considerable part of the emission data for waste incineration plants and large power plants are plant-specific. Thus, the area source emission factors do not necessarily represent average values for these plant categories. To attain a set of emission factors that expresses the average emission for power plants combusting coal and for waste incineration plants, implied emission factors have been calculated for these two plant categories. The implied emission factors are presented in Annex 11. The implied emission factors are calculated as total emission divided by total fuel consumption.

9 Uncertainty

Uncertainty estimates include uncertainty with regard to the total emission inventory as well as uncertainty with regard to trends. Uncertainties are reported annually for both greenhouse gases and for other pollutants.

9.1 Methodology

9.1.1 Greenhouse gases

The uncertainty for greenhouse gas emissions have been estimated according to the IPCC Good Practice Guidance (IPCC, 2000). The uncertainty has been estimated by two approaches; tier 1 and tier 2. Both approaches are further described in Nielsen et al. (2013a)[54].

The **tier 1** approach is based on a normal distribution and a confidence interval of 95 %.

The input data for the tier 1 approach are:

- Emission data for the base year and the latest year.
- Uncertainties for emission factors.
- Uncertainty for fuel consumption rates.

The emission source categories applied are listed in Table 60.

The **tier 2** approach is a Monte Carlo approach based on a lognormal distribution. The input data for the model is also based on 95 % confidence interval. The input data for the tier 2 approach are:

- Fuel consumption data for the base year and the latest year.
- Emission factors or implied emission factors (IEF) for the base year and the latest year.
- Uncertainties for emission factors for the base year and the latest year. If the same uncertainty is applied for both years, the data can be indicated as statistically dependent or independent.
- Uncertainties for fuel consumption rates in the base year and the latest year. If the same uncertainty is applied for both years, the data can be indicated as statistically dependent or independent.

The same emission source categories and emission data have been applied for both approaches. The separate uncertainty estimation for gas engine CH_4 emission and CH_4 emission from other plants does not follow the recommendations in the IPCC Good Practice Guidance. The disaggregation is applied, because in Denmark, the CH_4 emission from gas engines is much larger than the emission from other stationary combustion plants, and the CH_4 emission factor for gas engines is estimated with a much smaller uncertainty level than for other stationary combustion plants.

In general, the same uncertainty levels have been applied for both approaches. However, the tier 2 approach allows different uncertainty levels for 1990 and 2011 and this is relevant to a few uncertainties as discussed below. The 2011 uncertainty levels have been applied in the tier 1 approach.

[54] Chapter 1.7.

Most of the applied uncertainty estimates for activity rates and emission factors are default values from the IPCC Guidelines (IPCC, 1997) or aggregated by DCE based on the default values. Some of the uncertainty estimates are, however, based on national estimates.

In general, the uncertainty of the fuel consumption data has been assumed to be the same in 1990 and 2011 and the uncertainty has been assumed to be statistically independent. However, a considerable part of the residential wood consumption is non-traded and the uncertainty of biomass consumption has been assumed statistically dependent.

Fuel consumption data for waste are more uncertain for 1990 than for 2011. The uncertainty for biomass is higher in 2011 than in 1990 because a higher share of the biomass is combusted in residential plants in 2011.

For coal and refinery gas combustion, the uncertainty of the CO_2 emission factor is lower in 2011 than in 1990 due to availability of EU ETS data. Further, the CO_2 emission factor for the fossil part of waste is less uncertain for 2011 than for 1990.

The uncertainty of the CH_4 emission factors for gas engines have been assumed higher in 1990 than in 2011 due to the emission measurement programmes on which the emission factors in later years are based.

All other uncertainty levels for emission factors have been assumed equal in 1990 and 2011 and statistically dependent.

Table 60 Uncertainty rates for fuel consumption and emission factors, 2011.

IPCC Source category	Gas	Fuel consumption uncertainty, %		Emission factor uncertainty, %	
		1990	2011	1990	2011
Stationary Combustion, Coal, CO_2	CO_2	0.9[2)]	0.9[7)]	4[10)]	0.5[7)]
Stationary Combustion, brown coal briquettes, CO_2	CO_2	2.9[2)]	2.5[2)]	5[1)]	
Stationary Combustion, Coke[55], CO_2	CO_2	1.9[2)]	1.9[2)]	5[1)]	
Stationary Combustion, Fossil waste, CO_2	CO_2	10.0[2)]	5.0[2)]	20[5)]	10[5)]
Stationary Combustion, Petroleum coke, CO_2	CO_2	3.3[2)]	5.0[2)]	5[1)]	
Stationary Combustion, Residual oil, CO_2	CO_2	1.2[2)]	1.1[2)]	2[4)]	2[7)]
Stationary Combustion, Gas oil, CO_2	CO_2	2.9[2)]	2.4[2)]	4[10)]	
Stationary Combustion, Kerosene, CO_2	CO_2	3.0[2)]	1.9[2)]	5[1)]	
Stationary Combustion, LPG, CO_2	CO_2	1.7[2)]	1.6[2)]	5[1)]	
Stationary Combustion, Refinery gas, CO_2	CO_2	1.0[2)]	1.0[2)]	5[1)]	2[12)]
Stationary Combustion, Natural gas, CO_2	CO_2	1.2[2)]	1.0[2)]	0.4[8)]	
Stationary Combustion, SOLID, CH_4	CH_4	0.9[2)]	1.0[2)]	100[1)]	
Stationary Combustion, LIQUID, CH_4	CH_4	1.5[2)]	1.2[2)]	100[1)]	
Stationary Combustion, GAS, CH_4	CH_4	1.0[8)]	1.0[8)]	100[1)]	
Natural gas fuelled engines, GAS, CH_4	CH_4	1.0[9)]	1.0[9)]	10[11)]	2[3)]
Stationary Combustion, WASTE, CH_4	CH_4	10.0[5)]	5.0[5)]	100[1)]	
Stationary Combustion, BIOMASS, CH_4	CH_4	14.9[2)]	16.5[2)]	100[1)]	
Biogas fuelled engines, BIOMASS, CH_4	CH_4	6.8[2)]	3.9[2)]	20[11)]	10[11)]
Stationary Combustion, SOLID, N_2O	N_2O	0.9[2)]	1.0[2)]	400[6) 13)]	
Stationary Combustion, LIQUID, N_2O	N_2O	1.5[2)]	1.2[2)]	1000[1) 13)]	
Stationary Combustion, GAS, N_2O	N_2O	1.0[8)]	1.0[8)]	750[6) 13)]	
Stationary Combustion, WASTE, N_2O	N_2O	10.0[5)]	5.0[5)]	400[6) 13)]	
Stationary Combustion, BIOMASS, N_2O	N_2O	14.7[2)]	16.0[2)]	400[6) 13)]	

55 Including anodic carbon.

1) IPCC Good Practice Guidance, default value (IPCC, 2000).
2) Estimated by DCE based on default uncertainty levels in IPCC Good Practice Guidance, Table 2.6 (IPCC, 2000).
3) Jørgensen et al., (2010). Uncertainty data for NMVOC + CH_4.
4) Jensen & Lindroth (2002).
5) Estimated by DCE based on Astrup et al., (2012).
6) DCE, rough estimate based on a default value of 400 % when the emission factor is based on emission measurements from plants in Denmark.
7) Emission data based on EU ETS data.
8) Lindgren (2010). Personal communication, Tine Lindgren, Energinet.dk, e-mail 2010-03-16.
9) Equal to natural gas total. DCE assumption.
10) DCE assumption based on EU ETS data interval and IPCC Guidelines (IPCC, 1997) data interval.
11) DCE estimate based on Nielsen et al. (2010a).
12) DCE assumption based on the fact that data are based on EU ETS data.
13) With a truncation of twice the uncertainty rate. The truncation is relevant for the very large uncertainty rates for N_2O emission factors due to the log-normal distribution applied in the tier 2 model.

9.1.2 Other pollutants

According to the Good Practice Guidance for LRTAP Emission Inventories (Pulles & Aardenne, 2004) uncertainty estimates should be estimated and reported each year.

With regard to other pollutants, IPCC methodologies for uncertainty estimates have been adopted for the LRTAP Convention reporting activities (Pulles & Aardenne, 2004). The Danish uncertainty estimates are based on the simple Tier 1 approach.

The uncertainty estimates are based on emission data for the base year and year 2011 as well as on uncertainties for fuel consumption and emission factors for each of the main SNAP source categories. For particulate matter (PM), 2000 is considered to be the base year, but for all other pollutants, the base year is 1990. The applied uncertainties for activity rates and emission factors are default values referring to Pulles & Aardenne (2004). The uncertainty for PM is, however, estimated by DCE. The default uncertainties for emission factors are given in letter codes representing an uncertainty range. It has been assumed that the uncertainties were in the lower end of the range for all sources and pollutants. The applied uncertainties for emission factors are listed in Table 61. The uncertainty for fuel consumption in stationary combustion plants is assumed to be 2 %.

For heavy metals, an improved uncertainty estimate is included in Nielsen et al. (2013c).

Table 61 Uncertainty rates for emission factors, %.

SNAP source category	SO_2	NO_x	NMVOC	CO	PM	HM	PAH	HCB	PCDD/F	NH_3
01	10	20	50	20	50	100	100	1000	500	1000
02	20	50	50	50	500	1000	1000	1000	1000	1000
03	10	20	50	20	50	100	100	1000	1000	1000

9.2 Results of the uncertainty estimates for GHGs

The tier 1 uncertainty estimates for stationary combustion emission inventories are shown in Table 62. Detailed calculation sheets are provided in Annex 7. The tier 2 uncertainty estimates are shown in Table 63 and detailed results are provided in Annex 7.

The tier 1 uncertainty interval for greenhouse gas is estimated to be ±2.0 % and trend in greenhouse gas emission is -29.1 % ± 1.2 %-age points. The main sources of uncertainty for greenhouse gas emission 2011 are the N_2O emission from combustion of biomass, gaseous and solid fuels and CO_2 emission from fossil waste combustion. The main sources of uncertainty in the trend in greenhouse gas emission are the CO_2 emission from coal and fossil waste combustion and the N_2O emission from combustion of biomass and liquid fuels.

The tier 2 approach points out N_2O emission from combustion of biomass and gaseous fuels and CO_2 from fossil waste combustion as the main contributors to the total uncertainty for greenhouse gas emission from stationary combustion.

Table 62 Danish uncertainty estimates, tier 1 approach, 2011.

Pollutant	Uncertainty Total emission, %	Trend 1990-2011, %	Uncertainty trend, %-age points
GHG	± 2.0	-29.1	± 1.2
CO_2	± 0.9	-29.9	± 0.7
CH_4	± 35	+186	± 133
N_2O	± 254	+ 4	± 252
SO_2	± 7.7	-94	± 0.4
NO_x	± 17	-68	± 2.3
NMVOC	± 43	+ 14	± 7.2
CO	± 45	+ 5	± 2.7

Table 63 Danish uncertainty estimates, tier 2 approach, 2011.

Pollutant	Uncertainty of total emission, %		Trend 1990-2011, %	Uncertainty of trend, %-age points	
GHG	-1.3	2.1	-29.0	-2.8	2.8
CO_2	-0.9	0.9	-29.9	-2.7	2.7
CH_4	-21	50	+183	-16	28
N_2O	-73	214	+1.6	-163	114

The results are illustrated and compared in Figure 70. The uncertainties are in the same level for each pollutant. The emission data shown for the tier 1 approach are the CRF emission data. The tier 2 emission levels are median values based on the Monte Carlo approach.

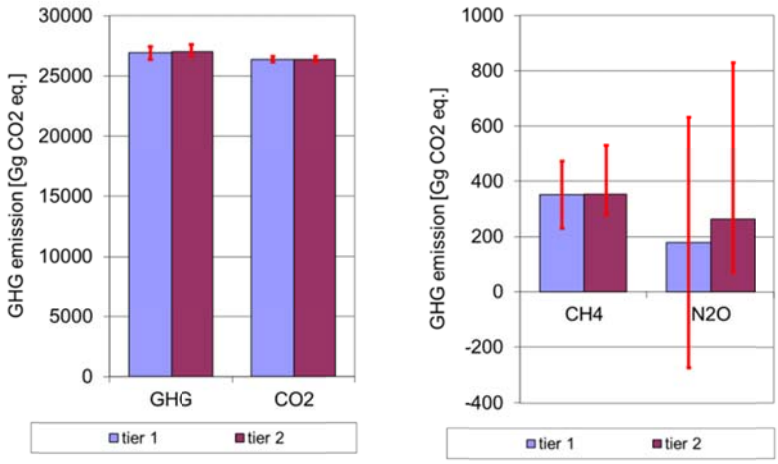


Figure 70 Uncertainty level, the two approaches are compared for 2011.

9.3 Results of the uncertainty estimates for other pollutants

The uncertainty estimates for stationary combustion emission inventories are shown in Table 64. Detailed calculation sheets are provided in Annex 7.

The total emission uncertainty is 7.7 % for SO_2, 17 % for NO_x, 43 % for NMVOC and 45 % for CO. For PM, heavy metals, HCB, PCDD/F and PAH the uncertainty is above 100 %. An improved uncertainty estimate for heavy metals is available in Nielsen et al. (2013c).

Table 64 Uncertainty estimates, tier 1 approach, 2011.

Pollutant	Uncertainty Total emission, %	Trend Uncertainty 1990-2011, Trend, %-age % points
SO_2	7.7	-94 ± 0.4
NO_x	17	-68 ± 2
NMVOC	43	+14 ± 7
CO	45	+5 ± 3
NH_3	931	+182 ± 268
TSP [1)]	469	+26 ± 44
PM_{10} [1)]	474	+27 ± 39
$PM_{2.5}$ [1)]	479	+30 ± 30
As	151	-79 ± 20
Cd	364	-86 ± 41
Cr	267	-92 ± 16
Cu	470	-80 ± 74
Hg	121	-88 ± 4
Ni	118	-89 ± 4
Pb	658	-83 ± 90
Se	101	-77 ± 6
Zn	732	-76 ± 138
HCB	729	-82 ± 54
PCDD/F	937	-62 ± 262
Benzo(b)fluoranthene	974	+102 ± 18
Benzo(k)fluoranthene	985	+115 ± 34
Benzo(a)pyrene	993	+111 ± 7
Indeno(1,2,3-c,d)pyrene	996	+79 ± 17

[1)] The base year for PM is year 2000.

10 QA/QC and verification

An updated quality manual for the Danish emission inventories has been published in 2013 (Nielsen et al., 2013d). The quality manual describes the concepts of quality work and definitions of sufficient quality, critical control points and a list of Point for Measuring (PM).

Documentation concerning verification of the Danish emission inventories has been published by Fauser et al. (2007). An updated verification report for the Danish emission inventories for GHGs is published in 2013 (Fauser et al., 2013).

The IPCC reference approach for CO_2 emission is an important verification of the CO_2 emission from the energy sector. The reference approach is reported each year.

Information on the Danish QA/QC plan is included in Nielsen et al. (2013a)[56]. Source specific QA/QC and PM's are shown below.

10.1 Verification – reference approach

In addition to the sector specific CO_2 emission inventories (the national approach), the CO_2 emission is also estimated using the reference approach described in the IPCC Guidelines (IPCC, 1997). The reference approach is based on data for fuel production, import, export and stock change. The CO_2 emission inventory based on the reference approach is reported to the Climate Convention and used for verification of the official data in the national approach.

Data for import, export and stock change used in the reference approach originate from the annual "basic data" table prepared by the Danish Energy Agency (DEA) and published on their home page (DEA 2012a). The fraction of carbon oxidised has been assumed to be 1.00. The carbon emission factors are default factors originating from the IPCC Guidelines (IPCC, 1997). The country-specific emission factors are not used in the reference approach, the approach being for the purposes of verification. The emission factor for fossil waste is, however, based on the emission factor applied in the national approach.

The Climate Convention reporting tables include a comparison of the national approach and the reference approach estimates. To make results comparable, the incineration of fossil waste and the corresponding CO_2 emission have been added in the reference approach. Furthermore, consumption for non-energy purposes is subtracted in the reference approach, because non-energy use of fuels is included in other sectors (Industrial processes and Solvent use) in the Danish national approach.

Three fuels are used for non-energy purposes: lubricants, bitumen and white spirit. The total consumption for non-energy purposes is relatively low – 12.4 PJ in 2011.

[56] Chapter 1.6.

The CO_2 emission from lube oil was 33 Gg in 2011 corresponding to 21 % of the CO_2 emission from lube oil consumption assuming full oxidation. This is in agreement with the IPCC Guideline methodology for lube oil emissions. Methodology and emission data for lube oil is shown in Nielsen et al. (2013a)[57].

The CO_2 emission from white spirit was 17 Gg in 2011 corresponding to 61 % of the CO_2 emission from white spirit assuming full oxidation. The CO_2 emission data for white spirit is shown in Nielsen et al. (2013a)[58].

The CO_2 emission from bitumen is included as part of the emission from the source sectors *2A5 Asphalt roofing* and *2A6 Road paving with asphalt*.

According to IPCC Good Practice Guidance (IPCC, 2000) the difference should be within 2 %. A comparison of the national approach and the reference approach is illustrated in Figure 71.

In 2011, the fuel consumption rates in the two approaches differ by 0.58 % and the CO_2 emission differs by 0.52 %. In the period 1990-2011, both the fuel consumption and the CO_2 emission differ by less than 2.0 %. The differences are below 1% for all years except 1998 and 2009.

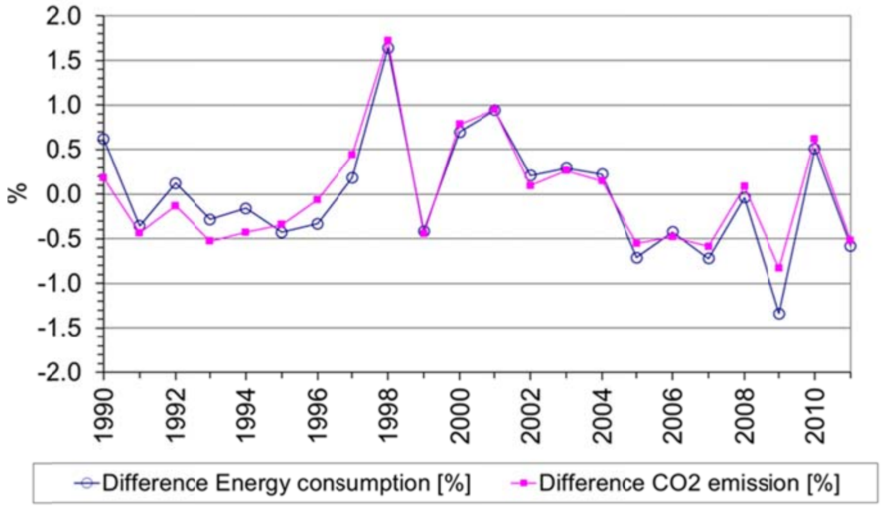


Figure 71 Comparison of the reference approach and the national approach.

The large differences in certain years, e.g. 1998 are due to high statistical differences in the Danish energy statistics in these years. This is illustrated in Figure 72.

[57] Chapter 4.8.
[58] Chapter 5, Table 5.4.

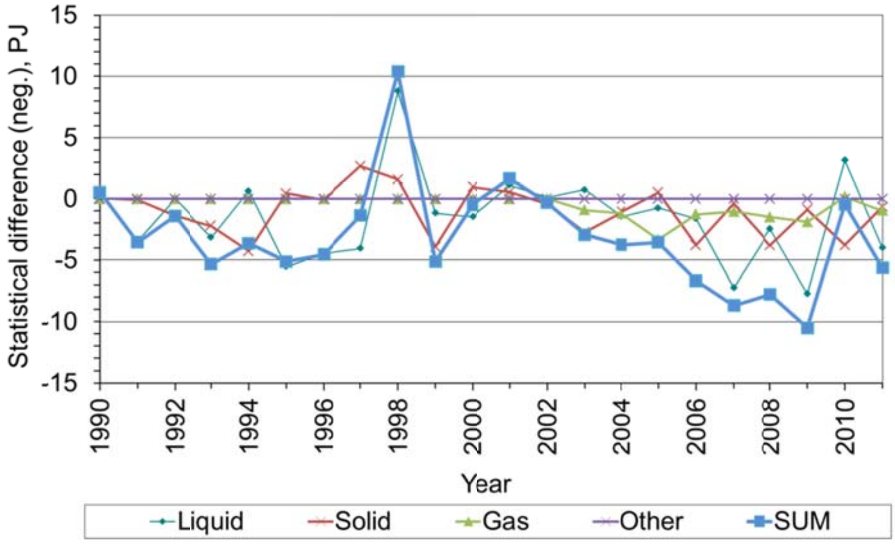


Figure 72 Statistical difference in the Danish energy statistics (DEA, 2012a).

10.2 National external review

The report has been reviewed by Vibeke Vestergaard Nielsen, DCE. Vibeke Vestergaard Nielsen was employed by the Danish Environmental Protection Agency until the beginning of 2013.

Most of the comments from Vibeke Vestergaard Nielsen have been implemented in this report. In addition, some improvements of emission factors will be implemented in the emission inventory reported in 2015.

The 2004, 2006 and 2009 updates of this report were reviewed by Jan Erik Johnsson from the Technical University of Denmark, Bo Sander from Elsam Engineering and Annemette Geertinger from FORCE Technology (Nielsen et al., 2004, Nielsen et al., 2006 and Nielsen et al., 2009).

The external review forms a vital part of the QA activities for the emission inventories for stationary combustion.

10.3 QA/QC

The quality manual describes the concepts of quality work and definitions of sufficient quality, critical control points and a list of Point for Measuring (PM).

10.3.1 Data storage, level 1

Table 65 lists the sector specific PMs for data storage level 1.

Table 65 List of PM, data storage level 1.

Level	CCP	Id	Description	Sectoral/general	Stationary combustion
Data Storage level 1	1. Accuracy	DS.1.1.1	General level of uncertainty for every dataset including the reasoning for the specific values.	Sectoral	Uncertainties are estimated and references given in Chapter 9.
	2. Comparability	DS1.2.1	Comparability of the emission factors/calculation parameters with data from international guidelines, and evaluation of major discrepancies.	Sectoral	In general, if national referenced emission factors differ considerably from IPCC Guideline / EMEP/EEA Guidebook values this is discussed in Chapter 8. This documentation is improved annually based on reviews. At CRF level, a project has been carried out comparing the Danish inventories with those of other countries (Fauser et al., 2007).
	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.	Sectoral	A list of external data are shown and discussed below.
	4.Consistency	DS.1.4.1	The original external data has to be archived with proper reference.	Sectoral	It is ensured that all external data are archived at DCE. Subsequent data processing takes place in other spreadsheets or databases. The datasets are archived annually in order to ensure that the basic data for a given report are always available in their original form.
	6.Robustness	DS.1.6.1	Explicit agreements between the external institution holding the data and DCE about the conditions of delivery	Sectoral	For stationary combustion, a data delivery agreement is made with the DEA. NERI (now DCE) and DEA have renewed the data delivery agreement in 2010. Most of the other external data sources are available due to legislatory requirements. See Table 66.
	7.Transparency	DS.1.7.1	Listing of all archived datasets and external contacts.	Sectoral	A list of external datasets and external contacts is shown in Table 66 below.

Table 66 List of external data sources.

Dataset	Description	AD or Emf.	Reference	Contact(s)	Data agreement/ Comment
Energiproducenttællingen.xls	Data set for all electricity and heat producing plants.	Activity data	The Danish Energy Agency (DEA)	Kaj Stærkind	Data agreement 2010.
Gas consumption for gas engines and gas turbines 1990-1994	Historical data set for gas engines and gas turbines.	Activity data	The Danish Energy Agency (DEA)	Peter Dal / Jane Rusbjerg (from 2013)	No data agreement. Historical data
Basic data (Grunddata.xls)	The Danish energy statistics. Data set applied for both the reference approach and the national approach.	Activity data	The Danish Energy Agency (DEA)	Peter Dal / Jane Rusbjerg (from 2013)	Data agreement 2010. However, the data set is also published as part of national energy statistics
Energy statistics for industrial subsectors	Disaggregation of the industrial fuel consumption. The data set have been applied for the first time in the inventory reported in 2012.	Activity data	The Danish Energy Agency (DEA)	Peter Dal / Jane Rusbjerg (from 2013)	Only informal data delivery agreement. The data set will be included in the next update of the data delivery agreement with DEA.
SO_2 & NO_x data, plants>25 MW_e	Annual emission data for all power plants > 25 MW_e. Includes information on methodology: measurements or emission factor.	Emissions	Energinet.dk	Christian F.B. Nielsen	No data agreement.
Emission factors	Emission factors stems from a large number of sources.	Emission factors	See chapter regarding emission factors		Some of the annually updated CO_2 emission factors are based on EU ETS data, see below. For the other emission factors no formal data delivery agreement.
Annual environmental reports / environmental data	Emissions from plants defined as large point sources	Emissions	Various plants		No data agreement necessary. Plants are obligated by law and data published on the Danish EPA homepage.
EU ETS data	Plant specific CO_2 emission factors	Emission factors and fuel consumption	The Danish Energy Agency (DEA)	Dorte Maimann Helen Falster	Plants are obligated by law. The availability of detailed information is part of the renewed data agreement with DEA.

Energiproducenttaellingen - statistic on fuel consumption from district heating and power plants (DEA)
The data set includes all plants producing power or district heating. The spreadsheet from DEA is listing fuel consumption of all plants included as large point sources in the emission inventory. The statistic on fuel consumption from district heating and power plants is regarded as complete and with no significant uncertainty since the plants are bound by law to report their fuel consumption and other information.

Gas consumption for gas engines and gas turbines 1990-1994 (DEA)
For the years 1990-1994, DEA has estimated consumption of natural gas and biogas in gas engines and gas turbines. DCE assesses that the estimation by the DEA are the best available data.

Basic data (DEA)
The Danish energy statistics. The spreadsheet from DEA is used for the CO_2 emission calculation in accordance with the IPCC reference approach and is also the first data set applied in the national approach. The data set is included in the data delivery agreement with DEA, but it is also published annually on DEA's homepage.

Energy statistics for industrial subsectors (DEA)
This data set has been applied for the first time in the inventory reported in 2012. The data includes disaggregation of the fuel consumption for industrial plants. The data set is estimated for the reporting to Eurostat. The data delivery agreement is informal at this time, but the dataset will be included in the next update of the agreement with DEA.

SO_2 and NO_x emission data from electricity producing plants > 25MW$_e$ (Energinet.dk)
Plants larger than 25 MW$_e$ are obligated to report emission data for SO_2 and NO_x to the DEA annually. Data are on production unit level and classified. The data on plant level are part of the plants annually environmental reports. DCE's QC of the data consists of a comparison with data from previous years and with data from the plants' annual environmental reports.

Emission factors
For specific references, see the Chapter 8 regarding emission factors. Some of the annually updated CO_2 emission factors are based on EU ETS data, se below.

Annual environmental reports (DEPA)
A large number of plants are obligated by law to report annual environmental data including emission data. DCE compares the data with those from previous years and large discrepancies are checked.

EU ETS data (DEA)
EU ETS data are information on fuel consumption, heating values, carbon content of fuel, oxidation factor and CO_2 emissions. DCE receives the verified reports for all plants which utilises a detailed estimation methodology. DCE's QC of the received data consists of comparing to calculation using standard emission factors as well as comparing reported values with those for previous years.

10.3.2 Data processing, level 1

Table 67 lists the sector specific PMs for data processing level 1.

Table 67 List of PM, data processing level 1.

Level	CCP	Id	Description	Sectoral / general	Stationary combustion
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.	Sectoral	Uncertainties are estimated and references given in Chapter 9.
	2.Comparability	DP.1.2.1	The methodologies have to follow the international guidelines suggested by UNFCCC and IPCC.	Sectoral	The methodological approach is consistent with international guidelines. An overview of tiers is given in Chapter 7.1.
	3.Completeness	DP.1.3.1	Identification of data gaps with regard to data sources that could improve quantitative knowledge.	Sectoral	The energy statistics is considered complete.
	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.	Sectoral	The two main methodological changes in the time series; implementation of Energiproducenttaellingen (plant specific fuel consumption data) from 1994 onwards and implementation of EU ETS data from 2006 onwards is discussed in Chapter 8.1.
	5.Correctness	DP.1.5.2	Verification of calculation results using time series	Sectoral	Time series for activity data on SNAP and CRF source category level are used to identify possible errors. Time series for emission factors and the emission from CRF subcategories are also examined.
		DP.1.5.3	Verification of calculation results using other measures	Sectoral	The IPCC reference approach validates the fuel consumption rates and CO_2 emission. Both differ less than 2.0 % (1990-2011). The reference approach is further discussed in Chapter 10.1.
	7.Transparency	DP.1.7.1	The calculation principle, the equations used and the assumptions made must be described.	Sectoral	This is included in Chapter 7.
		DP.1.7.2	Clear reference to dataset at Data Storage level 1	Sectoral	This is included in Chapter 7.
		DP.1.7.3	A manual log to collect information about recalculations.	Sectoral	-

10.3.3 Data storage, level 2

Table 68 lists the sector specific PM's for data storage level 2.

Table 68 List of PM, data storage level 2.

Level	CCP	Id	Description	Sectoral / general	Stationary combustion
Data Storage level 2	5.Correctness	DS.2.5.1	Check if a correct data import to level 2 has been made	Sectoral	To ensure a correct connection between data on level 2 and level 1, different controls are in place, e.g. control of sums and random tests.

10.3.4 Data storage level 4

Table 69 lists the sector specific PMs for data storage level 4.

Table 69 List of PM, data storage level 4.

Level	CCP	Id	Description	Sectoral / general	Stationary combustion
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.	Sectoral	Large dips/jumps in time series are discussed and explained in Chapter 3 and 4.

10.3.5 Other QC procedures

Some automated checks have been prepared for the emission databases:

- Check of units for fuel rate, emission factors and plant-specific emissions.
- Check of emission factors for large point sources. Emission factors for pollutants that are not plant-specific should be the same as those defined for area sources.
- Additional checks on database consistency.
- Emission factor references are included in this report (Chapter 8 and Annex 4).
- Annual environmental reports are kept for subsequent control of plant-specific emission data.
- QC checks of the country-specific emission factors have not been performed, but most factors are based on input from companies that have implemented some QA/QC work. The major power plant owner/operators in Denmark, DONG Energy and Vattenfall have obtained the ISO 14001 certification for their environmental management system and ISO 9001 certification for their quality management system[59]. The Danish Gas Technology Centre and Force Technology both run accredited laboratories for emission measurements.

The emission from each large point source is compared with the emission reported the previous year.

[59] http://www.dongenergy.com/DA/ansvarlighedsrapport/2006/Pages/page235c.html?page=7

11 Source specific recalculations and improvements

11.1 Recalculations for GHGs

Recalculations for stationary combustion 2010 are shown in Table 70. The main calculations are discussed below.

Table 70 Recalculations for stationary combustion, 2010.

	CO_2 , Gg CO_2	CH_4, Gg CO_2 eqv.	N_2O Gg CO_2 eqv.	CO_2 , %	CH_4, %	N_2O %
1.A.1. Energy Industries	19.46	1.46	0.85	0%	1%	1%
Liquid Fuels	36.60	0.01	0.06	2%	2%	2%
Solid Fuels	0.00	0.00	0.00	0%	0%	0%
Gaseous Fuels	-5.40	-0.18	0.00	0%	0%	0%
Biomass	75.73	1.63	0.85	1%	6%	2%
Other Fuels	-11.74	0.00	-0.05	-1%	-1%	-1%
a. Public Electricity and Heat Production	19.32	1.46	0.85	0%	1%	1%
Liquid Fuels	36.60	0.01	0.06	5%	6%	4%
Solid Fuels	0.00	0.00	0.00	0%	0%	0%
Gaseous Fuels	-5.54	-0.18	-0.01	0%	0%	0%
Biomass	75.73	1.63	0.85	1%	6%	2%
Other Fuels	-11.74	0.00	-0.05	-1%	-1%	-1%
b. Petroleum Refining	0.00	0.00	0.00	0%	0%	0%
Liquid Fuels	0.00	0.00	0.00	0%	0%	0%
Solid Fuels	0.00	0.00	0.00	0%	0%	0%
Gaseous Fuels	0.00	0.00	0.00	0%	0%	0%
Biomass	0.00	0.00	0.00	0%	0%	0%
Other Fuels	0.00	0.00	0.00	0%	0%	0%
c. Other Energy Industries	0.14	0.00	0.00	0%	0%	0%
Liquid Fuels	0.00	0.00	0.00	0%	0%	0%
Solid Fuels	0.00	0.00	0.00	0%	0%	0%
Gaseous Fuels	0.14	0.00	0.00	0%	0%	0%
Biomass	0.00	0.00	0.00	0%	0%	0%
Other Fuels	0.00	0.00	0.00	0%	0%	0%
1.A.2 Manufacturing Industries and Construction	-30.07	0.08	-1.79	-1%	1%	-5%
Liquid Fuels	-17.34	-0.01	-0.35	-1%	-1%	-2%
Solid Fuels	-12.73	-0.03	-0.06	-3%	-3%	-3%
Gaseous Fuels	-0.01	0.29	-0.64	0%	4%	-22%
Biomass	-55.45	-0.17	-0.75	-6%	-5%	-7%
Other Fuels	0.00	0.00	0.00	0%	0%	0%
a. Iron and steel	-0.12	0.00	0.00	0%	0%	-1%
Liquid Fuels	-0.04	0.00	0.00	-4%	-3%	-6%
Solid Fuels	0.00	0.00	0.00	0%	0%	0%
Gaseous Fuels	-0.08	0.00	0.00	0%	0%	0%
Biomass	0.00	0.00	0.00	0%	0%	0%
Other Fuels	0.00	0.00	0.00	0%	0%	0%
b. Non-ferrous metals	-0.13	0.00	0.00	-1%	-1%	-6%
Liquid Fuels	-0.12	0.00	0.00	-7%	-7%	-7%
Solid Fuels	0.00	0.00	0.00	0%	0%	0%
Gaseous Fuels	-0.01	0.00	0.00	0%	0%	0%
Biomass	0.00	0.00	0.00	0%	0%	0%

	CO_2 , Gg CO_2	CH_4, Gg CO_2 eqv.	N_2O Gg CO_2 eqv.	CO_2 , %	CH_4, %	N_2O %
Continued						
Other Fuels	0.00	0.00	0.00	0%	0%	0%
c. Chemicals	47.45	0.02	-0.01	32%	28%	-1%
Liquid Fuels	-1.84	0.00	-0.04	-7%	-7%	-7%
Solid Fuels	0.00	0.00	0.00	0%	0%	0%
Gaseous Fuels	49.29	0.03	0.03	40%	37%	8%
Biomass	0.00	0.00	0.00	0%	0%	0%
Other Fuels	0.00	0.00	0.00	0%	0%	0%
d. Pulp, paper and print	39.94	0.03	0.20	36%	5%	11%
Liquid Fuels	-0.52	0.00	-0.01	-6%	-5%	-7%
Solid Fuels	0.00	0.00	0.00	0%	0%	0%
Gaseous Fuels	40.46	0.03	0.21	40%	48%	384%
Biomass	0.00	0.00	0.00	0%	0%	0%
Other Fuels	0.00	0.00	0.00	0%	0%	0%
e. Food processing, beverages and tobacco	191.22	4.50	0.48	20%	590%	8%
Liquid Fuels	0.00	0.00	0.00	0%	0%	0%
Solid Fuels	0.00	0.00	0.00	0%	0%	0%
Gaseous Fuels	191.22	4.23	0.42	31%	1272%	56%
Biomass	19.98	0.27	0.06	96%	513%	58%
Other Fuels	0.00	0.00	0.00	0%	0%	0%
f. Other (please specify)(4)	-308.44	-4.46	-2.46	-10%	-36%	-8%
Cement production	0.00	0.00	0.00	0%	0%	0%
Liquid Fuels	0.00	0.00	0.00	0%	0%	0%
Solid Fuels	0.00	0.00	0.00	0%	0%	0%
Gaseous Fuels	0.00	0.00	0.00	0%	0%	0%
Biomass	0.00	0.00	0.00	0%	0%	0%
Other Fuels	0.00	0.00	0.00	0%	0%	0%
Non-road machinery	0.00	0.00	0.00	0%	0%	0%
Liquid Fuels	0.00	0.00	0.00	0%	0%	0%
Solid Fuels	0.00	0.00	0.00	0%	0%	0%
Gaseous Fuels	0.00	0.00	0.00	0%	0%	0%
Biomass	0.00	0.00	0.00	0%	0%	0%
Other Fuels	0.00	0.00	0.00	0%	0%	0%
Other non-specified	0.00	0.00	0.00	0%	0%	0%
Liquid Fuels	-14.82	-0.01	-0.29	-21%	-18%	-26%
Solid Fuels	-12.73	-0.03	-0.06	-9%	-10%	-10%
Gaseous Fuels	-281.49	-4.10	-1.30	-27%	-54%	-74%
Biomass	-75.42	-0.43	-0.81	-11%	-19%	-10%
Other Fuels	0.00	0.00	0.00	0%	0%	0%
1.A.4 Other Sectors	-43.88	1.78	-0.31	-1%	1%	0%
Liquid Fuels	24.26	0.00	0.15	1%	0%	0%
Solid Fuels	13.01	0.03	0.06	14%	7%	14%
Gaseous Fuels	-95.72	0.28	-1.13	-3%	1%	-10%
Biomass	18.84	1.35	0.40	0%	1%	1%
Other Fuels	14.57	0.11	0.22	525%	525%	525%
a. Commercial/Institutional	-54.17	0.94	-0.50	-5%	5%	-4%
Liquid Fuels	11.40	0.00	0.02	3%	0%	2%
Solid Fuels	0.00	0.00	0.00	0%	0%	0%
Gaseous Fuels	-80.14	0.20	-1.02	-11%	2%	-12%
Biomass	26.88	0.63	0.28	13%	12%	18%
Other Fuels	14.57	0.11	0.22	525%	525%	525%
b. Residential	-3.31	0.12	0.04	0%	0%	0%
Liquid Fuels	4.18	0.00	0.01	0%	0%	0%

	CO_2 , Gg CO_2	CH_4, Gg CO_2 eqv.	N_2O Gg CO_2 eqv.	CO_2 , %	CH_4, %	N_2O %
Continued						
Solid Fuels	0.00	0.00	0.00	0%	0%	0%
Gaseous Fuels	-7.49	-0.02	0.00	0%	0%	0%
Biomass	2.55	0.15	0.03	0%	0%	0%
Other Fuels	0.00	0.00	0.00	0%	0%	0%
c. Agriculture/forestry/fisheries	13.60	0.71	0.16	1%	2%	0%
Liquid Fuels	8.68	0.00	0.12	0%	0%	0%
Solid Fuels	13.01	0.03	0.06	15%	15%	15%
Gaseous Fuels	-8.09	0.11	-0.11	-5%	1%	-7%
Biomass	-10.60	0.58	0.09	-3%	3%	3%
Other Fuels	0.00	0.00	0.00	0%	0%	0%

For stationary combustion plants, the emission estimates for the years 1990-2010 have been updated according to the latest energy statistics published by the Danish Energy Agency. The update included both end use and transformation sectors as well as a source category update.

In response to a recommendation during the EU ESD review in May-August of 2012, a recalculation was made regarding LPG use. In previous inventory, submissions the LPG use in road transport was calculated bottom-up in the Danish road transport model. However, the difference between the bottom-up calculated LPG use and the official energy statistics was not handled. In the 2013 submission, the residual LPG use has been allocated to stationary combustion in residential plants. The allocation has been done in dialogue with the Danish Energy Agency. In general, the change in emission is very small. For most years, this has meant an increase in the reported emissions, but for some years in the early part of the time series the emissions have decreased.

The disaggregation of emissions in 1A2 Manufacturing industries and construction has been recalculated based on further improvements to the methodology that was implemented in the 2012 submission. This has caused a reallocation of emissions from industrial plants. The main change being that less emission are allocated to *1A2f Other* and that emissions reported for especially *1A2c Chemicals*, *1A2d Pulp, paper and print* and *1A2e Food processing, beverages and tobacco* have increased.

A recalculation for stationary combustion was done as a consequence of the recalculation described for national navigation. An additional amount of fuel oil was allocated to stationary combustion in manufacturing industries and stationary combustion in agriculture and forestry.

The fossil energy fraction for waste has been coordinated between DEA and DCE.

11.2 Recalculations for non-GHGs

Recalculations of emissions of non-GHGs include a few additional improvements.

A reallocation of emissions has been made from *1A1a Public Electricity and Heat Production* to *1A4a Commercial/Institutional*. This is caused by a different categorization of some combustion plants.

The reported SO_2 emission from 1A1b in 2005-2010 is lower than last year due to reallocation of emissions from refineries.

Recalculations for stationary combustion as a whole are shown in Table 71.

Table 71 Recalculations for stationary combustion, emissions reported in 2013 compared to emissions reported in 2012.

	1990	1995	2000	2005	2006	2007	2008	2009	2010
					Percent				
SO_2	100.0	100.0	100.0	99.8	99.8	99.0	99.6	99.4	99.6
NO_x	100.1	100.2	100.0	100.0	100.2	100.4	100.5	100.6	100.8
NMVOC	100.0	99.9	100.0	100.0	99.9	99.9	99.8	99.9	100.1
CO	100.0	100.0	100.0	100.1	100.0	100.0	100.0	100.0	100.3
TSP			100.0	100.0	100.0	100.0	100.0	100.0	100.1
PM_{10}			100.0	100.0	100.0	100.0	100.0	100.0	100.1
$PM_{2.5}$			100.0	100.0	100.0	100.0	100.0	100.0	100.1
NH_3	100.0	100.0	100.0	99.9	100.0	100.0	100.0	100.0	100.0
As	100.0	100.0	100.0	100.0	99.9	100.0	99.9	99.9	99.8
Cd	100.0	100.0	100.0	100.0	99.9	100.0	99.9	100.0	100.0
Cr	100.0	100.0	100.0	100.0	99.7	100.0	99.8	100.0	100.2
Cu	100.0	100.0	100.0	100.0	99.7	100.0	99.8	100.0	100.0
Hg	100.0	100.0	100.0	100.0	99.9	100.0	99.9	100.0	100.0
Ni	100.0	100.0	100.0	100.0	100.0	100.0	99.9	99.7	100.0
Pb	100.0	100.0	100.0	100.0	99.5	100.0	99.6	100.0	100.1
Se	100.0	100.0	100.0	100.0	99.8	100.0	99.9	100.0	100.0
Zn	100.0	100.0	100.0	100.0	99.7	100.0	99.7	100.0	99.8
HCB	100.0	99.9	99.8	99.7	99.6	99.7	99.7	99.3	99.9
PCDD/F	100.0	100.0	100.2	99.9	99.8	100.0	99.9	100.2	100.4
Benzo(a)pyrene	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0
Benzo(b)fluoranthene	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0
Benzo(k)fluoranthene	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0
Indeno(123cd)pyrene	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0

12 Source specific planned improvements

A number of improvements are planned for the stationary combustion emission inventories:

- The reporting of, and references for, the applied emission factors will be further developed in future inventories.
- Additional analysis of the time series for industrial subsectors in Chapter 5.
- Data for imported natural gas will be improved.
- The CO_2 emission factor for petroleum coke will be changed based on EU ETS data.
- Some emission factors for SO_2 and NO_x will be changed as discussed in Chapter 0 and Chapter 8.6.
- The inventory for HCB will be improved.
- An inventory for PCB will be included.
- Improved uncertainty estimate. The current uncertainty estimates are based on SNAP main categories and default uncertainties. The source categories will be changed to NFR categories and country specific uncertainty estimates included for some of the main emission sources.
- Plant specific CO_2 emission data will be included when waste incineration is included in the EU ETS from 2013.

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DANISH EMISSION INVENTORIES FOR STATIONARY COMBUSTION PLANTS

Inventories until 2011

Emission inventories for stationary combustion plants are presented and the methodologies and assumptions used for the inventories are described. The pollutants considered are SO_2, NO_x, NMVOC, CH_4, CO, CO_2, N_2O, NH_3, particulate matter, heavy metals, PCDD/F, HCB and PAH. The CO_2 emission in 2011 was 30 % lower than in 1990. However, fluctuations in the emission level are large as a result of electricity import/export. The emission of CH_4 has increased due to increased use of lean-burn gas engines in combined heating and power (CHP) plants. In recent years, the emission has declined. This is due to liberalisation of the Danish electricity market, which means that the fuel consumption in gas engines has decreased. The N_2O emission was higher in 2011 than in 1990 but the fluctuations in the time series are significant. A considerable decrease of the SO_2, NO_x and heavy metal emissions is mainly a result of decreased emissions from large power plants and waste incineration plants. The combustion of wood in residential plants has increased considerably until 2007 resulting in increased emission of PAH and particulate matter. The emission of NMVOC has increased since 1990 as a result of both the increased combustion of wood in residential plants and the increased emission from lean-burn gas engines. The PCDD/F emission decreased since 1990 due to flue gas cleaning on waste incineration plants.

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