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SMED
Swedish Environmental Emissions Data

Swedish BC emission inventory 2000-2012

Based on default information from the EMEP/EEA Air Pollutant Emission Inventory Guidebook (2013)

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SMED is short for Swedish Environmental Emissions Data, which is a collaboration between IVL Swedish Environmental Research Institute, SCB Statistics Sweden, SLU Swedish University of Agricultural Sciences, and SMHI Swedish Meteorological and Hydrological Institute. The work co-operation within SMED commenced during 2001 with the long-term aim of acquiring and developing expertise within emission statistics. Through a long-term contract for the Swedish Environmental Protection Agency extending until 2014, SMED is heavily involved in all work related to Sweden's international reporting obligations on emissions to air and water, waste and hazardous substances. A central objective of the SMED collaboration is to develop and operate national emission databases and offer related services to clients such as national, regional and local governmental authorities, air and water quality management districts, as well as industry. For more information visit SMED's website www.smed.se.

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Preface

This study has been commissioned by the Swedish Environmental Protection Agency and carried out by the Swedish Environmental Emissions Data (SMED) in 2014. It is part of the annual process to improve and strengthen the Swedish inventories of emissions to air for reporting to international regulations and conventions.

This study report has been prepared by Tina Skårman, Ingrid Mawdsley and Martin Jerksjö, IVL Swedish Environmental Institute, and Annika Gerner and Veronica Eklund Statistic Sweden (SCB).

Göteborg, May 2014

Tina Skårman

Abbreviations

NFR Code	Longname	Comment
1 A 1 a	1 A 1 a Public electricity and heat production	
1 A 1 b	1 A 1 b Petroleum refining	
1 A 1 c	1 A 1 c Manufacture of solid fuels and other energy industries	
1 A 2 a	1 A 2 a Stationary combustion in manufacturing industries and construction: Iron and steel	
1 A 2 b	1 A 2 b Stationary Combustion in manufacturing industries and construction: Non-ferrous metals	
1 A 2 c	1 A 2 c Stationary combustion in manufacturing industries and construction: Chemicals	
1 A 2 d	1 A 2 d Stationary combustion in manufacturing industries and construction: Pulp, Paper and Print	
1 A 2 e	1 A 2 e Stationary combustion in manufacturing industries and construction: Food processing, beverages and tobacco	
1 A 2 f i	1 A 2 f i Stationary combustion in manufacturing industries and construction: Other (Please specify in your IIR)	
1 A 2 f ii	1 A 2 f ii Mobile Combustion in manufacturing industries and construction: (Please specify in your IIR)	
1 A 3 a ii (i)	1 A 3 a ii (i) Civil aviation (Domestic, LTO)	
1 A 3 a i (i)	1 A 3 a i (i) International aviation (LTO)	
1 A 3 b i	1 A 3 b i Road transport: Passenger cars	
1 A 3 b ii	1 A 3 b ii Road transport:Light duty vehicles	
1 A 3 b iii	1 A 3 b iii Road transport:, Heavy duty vehicles	
1 A 3 b iv	1 A 3 b iv Road transport: Mopeds & motorcycles	
1 A 3 b v	1 A 3 b v Road transport: Gasoline evaporation	
1 A 3 b vi	1 A 3 b vi Road transport: Automobile tyre and brake wear	
1 A 3 b vii	1 A 3 b vii Road transport: Automobile road abrasion	
1 A 3 c	1 A 3 c Railways	
1 A 3 d i (ii)	1 A 3 d i (ii) International inland waterways	
1 A 3 d ii	1 A 3 d ii National navigation (Shipping)	

NFR Code	Longname	Comment
1 A 3 e	1 A 3 e Pipeline compressors	
1 A 4 a i	1 A 4 a i Commercial / institutional: Stationary	
1 A 4 a ii	1 A 4 a ii Commercial / institutional: Mobile	
1 A 4 b i	1 A 4 b i Residential: Stationary plants	
1 A 4 b ii	1 A 4 b ii Residential: Household and gardening (mobile)	
1 A 4 c i	1 A 4 c i Agriculture/Forestry/Fishing: Stationary	
1 A 4 c ii	1 A 4 c ii Agriculture/Forestry/Fishing: Off-road vehicles and other machinery	
1A 4 c iii	1A 4 c iii Agriculture/Forestry/Fishing: National fishing	
1 A 5 a	1 A 5 a Other stationary (including military)	
1 A 5 b	1 A 5 b Other, Mobile (including military, land based and recreational boats)	
1 B 1 a	1 B 1 a Fugitive emission from solid fuels: Coal mining and handling	
1 B 1 b	1 B 1 b Fugitive emission from solid fuels: Solid fuel transformation	
1 B 1 c	1 B 1 c Other fugitive emissions from solid fuels	
1 B 2 a i	1 B 2 a i Exploration, production, transport	
1 B 2 a iv	1 B 2 a iv Refining / storage	
1 B 2 a v	1 B 2 a v Distribution of oil products	
1 B 2 b	1 B 2 b Natural gas	
1 B 2 c	1 B 2 c Venting and flaring	
1 B 3	1 B 3 Other fugitive emissions from geothermal energy production , peat and other energy extraction not included in 1 B 2	
2 A 1	2 A 1 Cement production	
2 A 2	2 A 2 Lime production	
2 A 3	2 A 3 Limestone and dolomite use	
2 A 4	2 A 4 Soda ash production and use	
2 A 5	2 A 5 Asphalt roofing	
2 A 6	2 A 6 Road paving with asphalt	
2 A 7 a	2 A 7 a Quarrying and mining of minerals other than coal	
2 A 7 b	2 A 7 b Construction and demolition	
2 A 7 c	2A 7 c Storage, handling and transport of mineral products	
2 A 7 d	2 A 7 d Other Mineral products (Please specify the sources included/excluded in the notes column to the right)	

NFR Code	Longname	Comment
2 B 1	2 B 1 Ammonia production	
2 B 2	2 B 2 Nitric acid production	
2 B 3	2 B 3 Adipic acid production	
2 B 4	2 B 4 Carbide production	
2 B 5 a	2 B 5 a Other chemical industry (Please specify the sources included/excluded in the notes column to the right)	
2 B 5 b	2 B 5 b Storage, handling and transport of chemical products (Please specify the sources included/excluded in the notes column to the right)	
2 C 1	2 C 1 Iron and steel production	
2 C 2	2 C 2 Ferroalloys production	
2 C 3	2 C 3 Aluminum production	
2 C 5 a	2 C 5 a Copper production	
2 C 5 b	2 C 5 b Lead production	
2 C 5 c	2 C 5 c Nickel production	
2 C 5 d	2 C 5 d Zinc production	
2 C 5 e	2 C 5 e Other metal production (Please specify the sources included/excluded in the notes column to the right)	
2 C 5 f	2 C 5 f Storage, handling and transport of metal products (Please specify the sources included/excluded in the notes column to the right)	
2 D 1	2 D 1 Pulp and paper	
2 D 2	2 D 2 Food and drink	
2 D 3	2 D 3 Wood processing	
2 E	2 E Production of POPs	
2 F	2 F Consumption of POPs and heavy metals (e.g. electricial and scientific equipment)	
2 G	2 G Other production, consumption, storage, transportation or handling of bulk products (Please specify the sources included/excluded in the notes column to the right)	
3 A 1	3 A 1 Decorative coating application	
3 A 2	3 A 2 Industrial coating application	
3 A 3	3 A 3 Other coating application (Please specify the sources included/excluded in the notes column to the right)	
3 B 1	3 B 1 Degreasing	
3 B 2	3 B 2 Dry cleaning	
3 C	3 C Chemical products	

NFR Code	Longname	Comment
3 D 1	3 D 1 Printing	
3 D 2	3 D 2 Domestic solvent use including fungicides	
3 D 3	3 D 3 Other product use	
4 B 1 a	4 B 1 a Cattle dairy	
4 B 1 b	4 B 1 b Cattle non-dairy	
4 B 2	4 B 2 Buffalo	
4 B 3	4 B 3 Sheep	
4 B 4	4 B 4 Goats	
4 B 6	4 B 6 Horses	
4 B 7	4 B 7 Mules and asses	
4 B 8	4 B 8 Swine	
4 B 9 a	4 B 9 a Laying hens	
4 B 9 b	4 B 9 b Broilers	
4 B 9 c	4 B 9 c Turkeys	
4 B 9 d	4 B 9 d Other poultry	
4 B 13	4 B 13 Other	
4 D 1 a	4 D 1 a Synthetic N-fertilizers	
4 D 2 a	4 D 2 a Farm-level agricultural operations including storage, handling and transport of agricultural products	
4 D 2 b	4 D 2 b Off-farm storage, handling and transport of bulk agricultural products	
4 D 2 c	4 D 2 c N-excretion on pasture range and paddock unspecified (Please specify the sources included/excluded in the notes column to the right)	
4 F	4 F Field burning of agricultural wastes	
4 G	4 G Agriculture other(c)	
6 A	6 A Solid waste disposal on land	
6 B	6 B Waste-water handling	
6 C a	6 C a Clinical wasteincineration (d)	
6 C b	6 C b Industrial waste incineration (d)	
6 C c	6 C c Municipal waste incineration (d)	
6 C d	6 C d Cremation	
6 C e	6 C e Small scale waste burning	
6 D	6 D Other waste(e)	
7 A	7 A Other (included in national total for entire territory)	
1 A 3 a ii (ii)	1 A 3 a ii (ii) Civil aviation (Domestic, Cruise)	Not to be included in the national totals

NFR Code	Longname	Comment
1 A 3 a i (ii)	1 A 3 a i (ii) International aviation (Cruise)	Not to be included in the national totals
1 A 3 d i (i)	1 A 3 d i (i) International maritime navigation	Not to be included in the national totals
1 A 3	Transport (fuel used)	Not to be included in the national totals
7 B	7 B Other not included in nationaltotal of the entire territory (Please specify in notes and your IIR)	Not to be included in the national totals
11A	(11 08 Volcanoes)	Not to be included in the national totals
11 B	Forest fires	Not to be included in the national totals
11 C	Other natural emissions (Please specify in notes and your IIR)	Not to be included in the national totals

Summary

Sweden reports emissions to air annually to the UNECE Convention of Long-Range Transboundary Air Pollution (CLRTAP). Currently, PM (as $PM_{2.5}$), and from 2015 and onwards also black carbon (BC) as a voluntary reporting requirement from 2000, is included in the emission reporting program under CLRTAP. In 2013 the EMEP/EEA air pollutant emission inventory guidebook was updated with respect to, among other issues, BC methodological guidance, emission factors and reference material.

The aim of this study was to develop as complete an inventory of Sweden's BC emissions as possible based on the existing $PM_{2.5}$ inventory and information available in the EMEP/EEA guidebook 2013 (EEA, 2013).

The Swedish BC inventory has been based on the submission 2014 $PM_{2.5}$ inventory together with BC emission factors expressed as percentages of the $PM_{2.5}$ emissions, as available in the EMEP/EEA air pollutant emission inventory guidebook 2013 (EEA, 2013). The inventory includes emissions from year 2000 and onward.

The result of the Swedish BC inventory shows that the total emission of BC in Sweden was nearly 4.2 ktonnes in 2012 and that approximately 95% of BC emissions originated from the energy sector. The predominant source within the energy sector is small scale combustion, i.e. residential biomass combustion. Other important sources are stationary combustion in pulp, paper and print industries, off-road vehicles and other machinery, and road traffic.

There are large uncertainties in estimated BC emissions from residential biomass combustion linked to the issue of emission measurement methods for deriving emission factors for $PM_{2.5}$, as well as uncertainty due to insufficient knowledge of activity data (e.g. populations of different combustion technologies). This means that the absolute values for estimated BC-emissions should be used with caution.

Background

Black carbon (BC) is emitted from incomplete combustion of fuels, along with particular matter (PM), as well as carbon monoxide (CO) and volatile organic compounds (VOC). The emitted particles include BC but also organic carbon (OC). OC, in contrary to BC, has a cooling effect on the climate.

BC, together with methane (CH_4) and tropospheric ozone (O_3), is considered a short-lived climate pollutant (SLCP). These substances have a short residence time in the atmosphere (weeks to months) compared to for instance carbon dioxide, which has an average residence time in the atmosphere for several decades. Hydrofluorocarbons (HFCs) are also counted as SLCP, although they have longer retention times compared to the compounds mentioned above (SMHI, 2014).

In May 2012 a revised Gothenburg Protocol under the UNECE Convention on Long Range Transboundary Air Pollution (CLRTAP) was adopted. The revised protocol includes a ceiling for national emissions of particulate matter ($PM_{2.5}$ i.e. particles with an aerodynamic diameter <2.5 µm) and for SO_2, NO_X, NH_3 and NMVOC. BC (or soot) is a component of emitted $PM_{2.5}$. In the amended protocol text, a general recommendation is given that sources with the largest emitted fractions of BC should be prioritised when implementing emission reduction actions for $PM_{2.5}$. The revised Gothenburg protocol implies that Sweden should reduce the national emissions of $PM_{2.5}$ by 19% between 2005 and 2020.

Currently PM (as $PM_{2.5}$), and from submission 2015 also BC as a voluntary reporting requirement from emission year 2000 and onward, are included in the emission reporting program under CLRTAP. Generally there are substantial uncertainties associated with reported emission inventories of $PM_{2.5}$. In 2013 the EMEP/EEA air pollutant emission inventory guidebook was updated with respect to, among other issues, BC methodological guidance, emission factors and reference material. The guidebook states that the same emission control techniques that limit emissions of PM will also reduce emissions of BC. However, measurement data that address the abatement efficiencies for BC are limited. This means that in general it is assumed that the BC emissions can be reduced proportionally to the PM emissions and, in particular, $PM_{2.5}$ emissions. Consequently, for inventory development purposes, the BC emission factors are expressed as fractions of the $PM_{2.5}$ emissions (EEA, 2013).

The development of the guidebook reflects the incorporation of BC within the 2012 amendment of the Gothenburg Protocol to the LRTAP Convention. The amended protocol, which is the first international air pollution policy specifically including BC as a short-lived climate forcer, encourages the future reporting of BC emission inventories and projections. An improved understanding of Europe's BC emissions will encourage a wider view to be taken on environmental issues — that air pollution, the health of humans and ecosystems, and climate change are all connected (EEA, 2013).

In 2013 the Swedish presidency of the Nordic Council of Ministers proposed a project ("Improved Nordic emission inventories of Short-Lived Climate Pollutants, SLCPs") primarily aiming at improving the knowledge regarding BC. The project is planned for a period of three years and all five Nordic countries participate and contribute actively to the work. The project is in the phase of finalisation of a background analysis which includes screening of earlier work, identification of knowledge gaps and recommendations for prioritising measurements. One main conclusion thus far is that the most important source of PM in the Nordic countries is residential biomass combustion and that the current emission reporting of $PM_{2.5}$ (and BC) from that activity is not comparable between the Nordic countries. One of the reasons for this is that emission factors (EFs) for $PM_{2.5}$ based on different measurement standards (hot flue gases or diluted) give different results. The Swedish EFs for $PM_{2.5}$ from residential biomass combustion are based on hot flue gas measurements and they are generally lower than in other Nordic countries, which base their EFs on diluted sampling. It should be pointed out that neither method is considered to be "wrong", since both are existing measurement standards (Kindbom et al., unpublished).

Project objectives

The project aims to develop as complete an inventory of Sweden's BC emissions as possible, based on the existing $PM_{2.5}$ inventory and information available in the EMEP/EEA air pollutant emission inventory guidebook 2013.

Prerequisites and uncertainties

The default BC emission factors given in the EMEP/EEA Air Emission Inventory Guidebook are presented as percentage of $PM_{2.5}$ (EEA, 2013) and consequently the developed Swedish BC-inventory has been derived from the national $PM_{2.5}$ inventory. The BC-inventory is based on the best available collected information. However, use of default BC fractions of $PM_{2.5}$ emissions leads to uncertainties in the BC inventory for all source categories. In this study it has not been possible to assess the magnitude of such uncertainties. However, as described below, $PM_{2.5}$ emissions from small scale combustion are more uncertain compared to other source categories.

Swedish $PM_{2.5}$ inventory

The total emissions of $PM_{2.5}$ were approximately 27 ktonnes in 2012. The energy (including transport) sector is the largest source of $PM_{2.5}$ emission accounting for about 78% of the national total in 2012. Biomass combustion in residential heating and road traffic are the predominating sources of $PM_{2.5}$ within the energy sector (SEPA, 2014a).

Emissions of $PM_{2.5}$ from residential wood combustion are calculated using biomass fuel consumption for heating residences on three combustion technologies – boilers, stoves and open fire places – and national emission factors (SEPA, 2014a). In submission 2014 residential biomass combustion was the most uncertain activity within the Swedish $PM_{2.5}$ inventory, contributing about 85% of the variance in national total $PM_{2.5}$ emissions 2012 (SEPA, 2014b).

Uncertainty about the level of PM from residential biomass combustion

Emission inventories for PM, and especially for some of the specific sources, such as residential biomass combustion, are generally regarded as rather uncertain. This is partly due to difficulties in correctly estimating the activity data, but mostly due to a high variability in reported emission factors. The emission factors are a result of e.g. technical characteristics in the source and fuel quality, but are also strongly dependent on combustions practices, as inefficient and incomplete combustion gives higher emissions of PM than under efficient combustion conditions (e.g. Todorovic et al., 2007).

Different measurement methods

Emission factors for PM from residential biomass combustion are based on different measurement standards in different countries. There are two fundamentally different measurement methods for emissions of particulate matter, in the hot flue gases or in a dilution tunnel at a lower temperature (e.g. Nussbaumer et al 2008, Kindbom et al 2014). Measurements by sampling using dilution generally gives higher results than those from sampling in the flue gas channel, due to additional condensation of organic compounds on particles in the lowered temperature in the dilution tunnel (e.g. Gaegauf et al., 2011, Jokiniemi et al., 2008, Ryde and Johansson, 2007).

The choice of sampling methodology may also give rise to different results regarding the BC content of the measured particles. Jokiniemi et al. (2008) found that the fraction of BC in sampled PM is higher if measurements are performed in hot flue gases. After dilution and condensation of gaseous substances, the BC fraction will be lower due to condensation of other gaseous organic substances, yielding a higher total mass of PM, while the mass of BC does not increase.

The emission factors for residential plants burning wood in the EMEP/EEA Guidebook take into account the whole combustion cycle, and are based on diluted sampling measurements. The Swedish emission factors for residential combustion of biomass (Paulrud et al., 2006) are based on in-stack measurements, which thus are expected to give lower results for PM than if sampling in a dilution tunnel would have been used.

A comparative study of the sampling methods showed that the emission factors for PM found when using a dilution tunnel are between 2.5 and 10 times higher than when only taking into account the solid particles measured directly in the chimney (Nussbaumer et al., 2008). This range is also reported by Bäfver (2008).

Based on the discussion above it is very important to emphasize that the Swedish $PM_{2.5}$ emission factors for residential wood combustion is lower compared to the emission factors given in the EMEP/EEA guidebook.

Methodology

The Swedish BC inventory has been based on the submission 2014 $PM_{2.5}$ inventory and on BC default emission factors, expressed as a percentage of $PM_{2.5}$ emissions, as available in the EMEP/EEA air pollutant emission inventory guidebook 2013 (EEA, 2013). It is regarded as good practice to use national information, if available, in developing an inventory. However, default emission factors from the guidebook can be used if national information is lacking. The inventory includes emissions from year 2000 and onward. The BC EFs (as percentages of $PM_{2.5}$) that are used in this inventory are listed with the corresponding activity in Annex 1, together with the applied level of Tier and the 95% confidence interval for the years 2012 and 2000.

Energy

Power plants and industry

BC emissions were estimated according to the EMEP/EEA guidebook (EEA, 2013) throughout the sectors 1.A.1 Energy industries and 1.A.2 Combustion in manufacturing industries and construction. All emission factors that were used within these two sectors are presented as a percentage of $PM_{2.5}$ in EEA (2013). BC emission factors have been calculated by multiplication of the fraction with the $PM_{2.5}$ emission factors used in the submission 2014 of the Swedish emission inventory. The emission factors and fractions are sometimes given for specific fuels, e.g. hard coal or residual oil, and other times for fuel groups, e.g. liquid fuels or biomass. There are no emission factors or BC fractions provided for “other fuels” such as waste. For these fuels, the BC fractions given for hard coal or solid fuels are used together with the $PM_{2.5}$ emission factors used for these fuels in the Swedish emission inventory. Activity data is available on plant level (except for small enterprises and the construction industry), which enables the modifications described below.

All emissions are calculated as BC emission factor × activity data (TJ) with a few exceptions:

- Emissions from coke ovens (the major part of NFR 1A1c) are not estimated. The emissions reported in NFR 1A1c represent combustion emissions from other manufacturers of solid fuels, e.g. nuclear fuels, and are calculated using emission factors and BC fractions that are valid for NFR 1A2.

- Emissions from the largest plants in NFR 1A2a are calculated using BC fractions of $PM_{2.5}$ as given by EEA (2013) for NFR 1A2. As the emission factors are presented according to type of fuel, the composition of fuel used was calculated and used together with the appropriate emission factor on the total $PM_{2.5}$ emissions. LPG and heating oil were in this inventory considered liquid fuels and coke oven and furnace gases were considered solid fuels.
- Combustion emissions of particulate matter, NO_x and SO_2 from cement manufacturing plants (part of NFR 1.A.2.f.i) and one glass manufacturing plant are not reported in NFR 1.A.2.f.i in the Swedish inventory because these emissions are included in the process emissions reported for these plants. Hence, all BC emissions from these plants are included in NFR 2 and not reported in NFR 1.A.2.f.i.

Residential sector/small-scale combustion

BC emissions were estimated according to the EMEP/EEA guidebook (EEA, 2013) throughout the sector 1.A.4 Small scale combustion. All emission factors that were used within these two sectors are presented as a percentage of $PM_{2.5}$ in EEA (2013). Tier 2 emission factors were used for small scale combustion in the residential sector (NFR 1.A.4.b.i). Tier 1 emission factors were used for all fuels in NFR 1.A.4.a.i and 1.A.4.c.i and for liquid and gaseous fuels in the residential sector.

Off-road vehicles and other machinery

Emissions of greenhouse gases and air pollutants from off-road vehicles and other machinery are in Sweden estimated according to a nationally developed model (Fridell, 2008), following the Tier 3 methodology described in IPCCC (2006). The model has a “bottom-up” approach and calculates emissions based on population, annual working hours, load factor and emission factors. The emission factors are based on the limits given by the emission standards, but are corrected for e.g. yearly engine deterioration.

The model had, already before this study, been prepared for estimation of BC as a fraction of PM by vehicle type, engine power, fuel and emission standard. To estimate national BC emissions, BC fractions of the total exhaust PM from EEA (2013) were inserted into the model. Tier 1 data from EEA (2013) was used because the Tier 3 data did not add any more information compared to Tier 1. The Tier 1 data is in fact more detailed since it has differentiated emission factors for Stage IIIB machines with and without particulate filter, which is not the case for the Tier 3 emission factors.

Aviation

BC emissions were estimated according to Tier 1 and by using an average BC fraction of PM as recommended in the EMEP/EEA guidebook (EEA, 2013) for 1A3a Aviation. The guidebook recommends using the same average BC fraction for both Tier 1 and Tier 2, as there is not enough data available to propose different BC fractions of PM for different Tiers.

Emissions of particles from aviation are estimated using emission factors from EMEP/EEA Guidebook (2009) and activity data for delivered amounts of jet kerosene and aviation gasoline provided by Statistics Sweden.

Road transport

Emissions of BC from passenger cars, light commercial vehicles, heavy duty trucks and buses have been estimated by using national PM emissions as calculated by the road emission model HBEFA (HBEFA, 2013) together with BC fractions from EEA (2013). The $PM_{2.5}$ fraction of the total PM emissions was estimated to 90%. Since the BC fractions of $PM_{2.5}$ in the Guidebook are given by vehicle type and emission standard (Euro standard), emission data from HBEFA had to be extracted from the model at the same aggregate level, i.e. vehicle type and Euro standard.

Since HBEFA lacks PM emission factors for two-wheelers (mopeds and motor cycles) traffic activity from HBEFA was used together with $PM_{2.5}$emission factors from EEA (2013) to estimate $PM_{2.5}$ emissions. BC fractions were then applied to estimate the yearly BC emissions.

BC emission factors for the sub-code Automobile tyre and brake wear (NFR 1.A.3.b.vi) are presented by EEA (2013) as fractions of PM. Correspondence with the author of the chapter[1] clarified that either PM fraction can be used with the given BC fraction. Thus, the BC fractions were applied to $PM_{2.5}$ for two-wheelers, passenger cars, light duty vehicles and heavy duty vehicles, respectively, according to the EEA (2013) emission inventory guidebook. For NFR code 1 A 3 b vii - Automobile road abrasion - no BC emission factor was given in the EEA (2013) guidebook and thus notation key NE was used for this source.

Railways

BC emissions were estimated according to Tier 1 and by using the recommended BC fraction of PM in EMEP/EEA guidebook (EEA, 2013) for 1A3c Railways, which for railways engines on a Tier 1 level (1995

[1] Morten Winther (Danish Centre for Environment and Energy) e-mail correspondence May 6, 2014.

average engine technology levels) is the same BC fraction as for Euro I road vehicle engines.

Emissions of particles from railways were in submission 2014 estimated by using emission factors from EMEP/CORINAIR guidebook vol. 3, 8.8 and activity data for delivered amounts of jet kerosene and aviation gasoline from Statistics Sweden. These emission factors will be updated in submission 2015 with emission factors from EMEP/EEA guidebook 2013.

Navigation

BC emissions were estimated according to Tier 1 and by using different BC fractions of PM as specified in the EMEP/EEA guidebook (EEA, 2013) for 1A3d Navigation and for each fuel type.

It is recommended in the guidebook to use the BC fractions that are based on exhaust emission measurements made by Lack et al. (2009) and to distinguish only between fuel types. The main reason for choosing the data from Lack et al. (2009) is that this study is very comprehensive having measured the emissions from 211 commercial vessels (EEA, 2013).

Military

BC emissions from the Military consist of emissions from aviation, road traffic and navigation and were estimated according to the fractions of PM recommended in EMEP/EEA guidebook 2013 for each subsector.

Fishing

BC emissions were estimated according to Tier 1and the BC fractions of PM for diesel as specified in EMEP/EEA guidebook (EEA, 2013) for 1A3d Navigation.

Emissions of particles from Fishing are estimated using emission factors from the SMED report *Methodology for calculating emissions from ships* (Cooper et al., 2004), together with the consumption of diesel based on information from the Swedish Agency for Marine and Water management, and an assumption of an average consumption of diesel per kWh.

Fugitive emissions

Refining/storage

The given Tier 2 BC emission factor (EEA, 2013) for fluid catalytic cracking was applied to $PM_{2.5}$ emissions as reported in submission 2014 of the Swedish emission inventory.

Flaring

As there are no oil or gas extraction activities in Sweden, flaring occurs only at oil refineries and petrochemical industries. According to the guidelines of EEA (2013), section 1.B.2.c Venting and flaring, there is no BC fraction available for flaring at oil refineries. According to the guidelines, the BC emission factor can be expressed as a function of the volumetric heating value for flaring:

EFBC = 0.0578 (HV)-2.09

where EFBC is the BC emission factor [kg soot/103 m^3] and HV is the heating value of the flare gas [MJ/m^3].

In cases where the heating value is not known, it is recommended to use the BC fraction given for flaring in upstream oil and gas industry. This fraction has been used since volumetric heating values in most cases are not known for the flared gases; the amounts of flared gas are normally reported in tonnes and there is no information about the density.

Industrial processes

BC emissions were estimated according to the given emission factors in the EMEP/EEA guidebook (EEA, 2013) throughout the sector Industrial processes. Tier 1 or Tier 2 emission factors were used according to the information available.

All emission factors that were used within this sector were presented as a percentage of $PM_{2.5}$ in EEA (2013) and were applied directly to the reported $PM_{2.5}$ emissions in respective NFR code. In those NFR codes were $PM_{2.5}$ are not reported no BC emissions were introduced, and where $PM_{2.5}$ are reported as “Included Elsewhere” (IE), BC emissions are included in the same source code as $PM_{2.5}$ emissions. For those NFR codes where $PM_{2.5}$ emissions are reported, but no BC emission factors are listed in the EEA (2013), no BC emissions were included in the inventory.

For the non-ferrous metal industry, only BC emission factors for copper production are available from EEA (2013). Copper is however produced in conjunction with other non-ferrous metals in Sweden, and respective emissions cannot be separated. Thus, for those facilities where copper is produced, the BC emission factor is applied to the total reported $PM_{2.5}$ emissions irrespectively of which other metals are produced at the plant.

Similarly, EEA (2013) presents a BC emission factor for glass wool production, however none for other mineral wool production. Since glass wool and rock wool production is reported in the same NFR code in submission 2014 (a sub-code of 2.A.7.d), the BC emission factor is applied only to the $PM_{2.5}$ emissions from those facilities that are producing glass wool.

Solvent and product use

The only source of BC emissions included in the inventory in the sector Solvent and product use is tobacco smoking which is part of NFR 3.D.3.

The BC emission factor for tobacco smoking is given as a percentage of $PM_{1.8}$ in the EMEP/EEA guidebook (EEA, 2013). However, since no data for $PM_{1.8}$ emissions is available and the BC emissions from this NFR code contribute only to an insignificant amount of total emissions from sector 2 and 3 (0.00006% in 2012), the $PM_{1.8}$ fraction was applied to reported $PM_{2.5}$ emissions.

For fireworks (included in NFR 3.D.3), $PM_{2.5}$ emissions are reported but BC emissions are not included in the inventory since this source is not described by EEA (2013). Reasonably, this source gives rise to BC emissions, however emissions are assumed to be very small.

Agriculture

There are no BC emissions occurring from the Agriculture sector, hence notation key “Not Applicable” (NA), or “Not Occurring” (NO) where the activity does not occur within the country, has been used. The category Field burning of agricultural waste does give rise to BC emissions; however this activity does not occur in Sweden.

Waste

Waste incineration

BC emissions from the only hazardous waste incineration plant in Sweden are included in the sub-sector Industrial waste incineration. The BC emission factor is taken from the EMEP/EEA guidebook (EEA, 2013) and applied directly to $PM_{2.5}$ emissions. As some municipal waste is also incinerated at the plant, these $PM_{2.5}$ emissions and thus also BC emissions, are included in the sub-sector Industrial waste incineration and notation key IE is used in the Municipal waste incineration code.

$PM_{2.5}$ emissions are also reported for Garden burning bonfires, however these types of fires are not described in the EMEP/EEA guidebook (EEA, 2013), hence notation key “Not Estimated” (NE) has been used for this source.

Results and discussion

The total emissions of BC were nearly 4.2 ktonnes in year 2012 (Figure 1), which corresponds to a reduction by about 14% since 2000. The largest source of emissions of BC is the energy sector (including transport). It contributed with approximately 95% of the emissions in 2012, followed by industrial processes which contributed with nearly 5%. The complete BC emission inventory is found in Appendix 2.

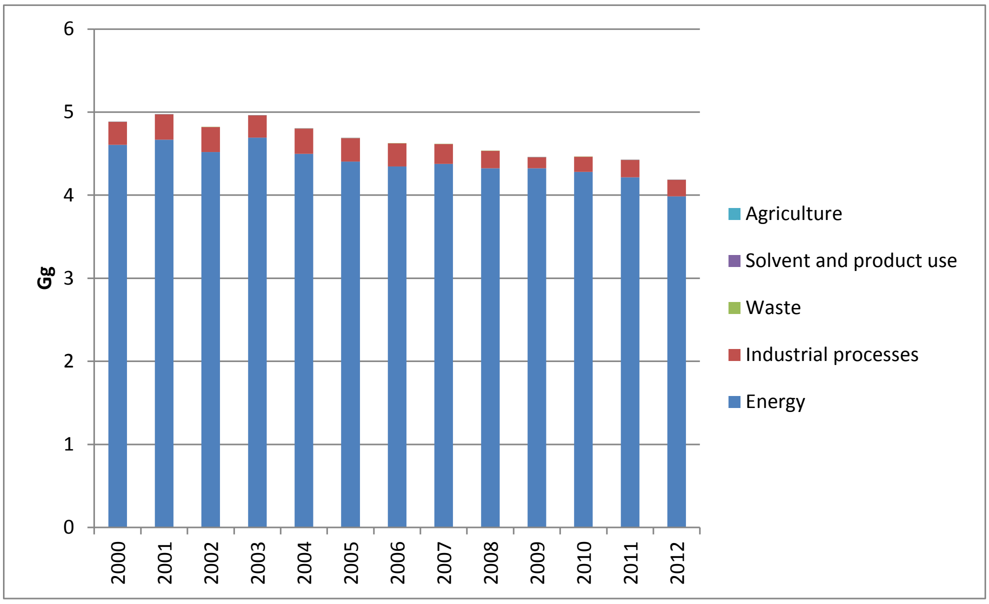

Figure 1. Emissions of BC, total and by sectors, 2000-2012 (Gg).

Energy

BC emissions from the energy sector were nearly 4.0 ktonnes in year 2012 (Figure 2), which equals an overall reduction of about 13% for the sector since 2000.

The predominant sources of BC within the energy sector in 2012 were small scale combustion (approximately 28%), energy other (approximately 20%, stationary combustion in pulp, paper and print manufacturing industries dominates), off-road mobile (approximately 19%, mobile combustion in manufacturing industries) and road traffic (approximately 18%, heavy duty vehicles dominates). It should be emphasised that the level of calculated emissions from residential biomass combustion in small scale combustion is uncertain (see chapter “Prerequisites and uncertainties” above). Different scenarios for BC from small-scale biomass combustion have been calculated in the CLEO-project (CLEO, 2014). One of the calculated scenarios is based on emission factors for $PM_{2.5}$ and BC fraction given in the EMEP/EEA guidebook for residential biomass combustion, where emission factors for $PM_{2.5}$ are based on diluted sampling. The scenario calculation results in a twice as high level of BC emissions from the activity of concern, in the order of 1.8 ktonnes, compared to approximately 0.8 ktonnes given in the current project.

The most significant changes in emission levels between 2000 and 2012 can be found in small scale combustion and road traffic. The BC emissions from small scale combustion have increased by about 48% since 2000, mainly due to colder winters during the end compared to the beginning of the period 2000-2012. BC emissions from road traffic were reduced by about 46% since 2000, due to the introduction of more stringent emission standards.

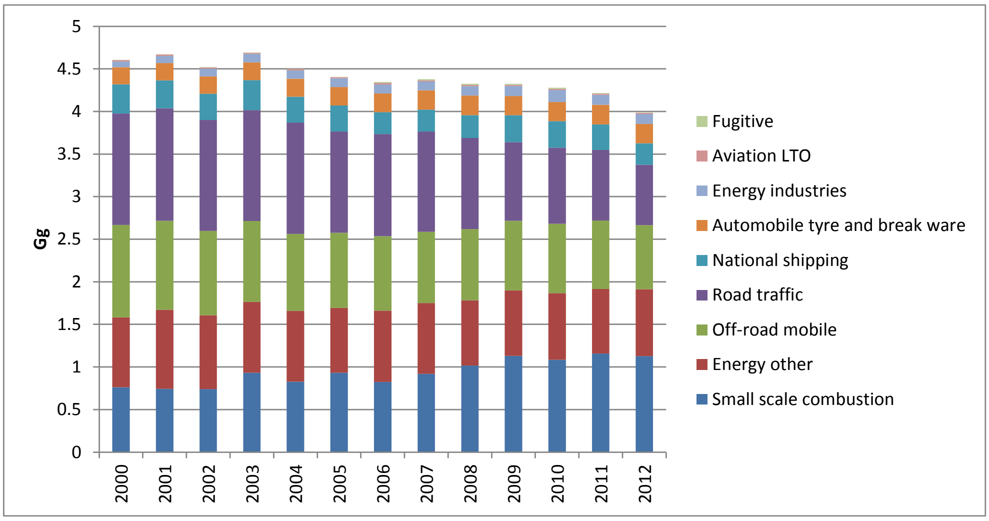

Figure 2. Emissions of BC, energy sector, 2000-2012 (Gg).

Industrial processes

Emissions of BC from industrial processes were nearly 0.2 ktonnes in year 2012 (Figure 3). This equals to a reduction of about 29% in the sector since 2000.

In 2012 the most predominant sources of BC within the industry sector were the metal industry (approximately 64%) and other industry, i.e. the pulp and paper industry (approximately 30%). Emissions from the metal industry have been reduced by about 19% since 2000, and the corresponding reduction for the pulp and paper industry was approximately 48%.

The decrease of emissions in years 2009 and 2010 was quite substantial. The reason for the low emissions is that during the autumn of 2008, an economic downturn began which was deepened during 2009 and affected especially the metal industry. The recession led to considerably reduced production in many industries, with reduced emissions in 2009 as a consequence. In 2010 most of the industries began to recover from the economic downturn.

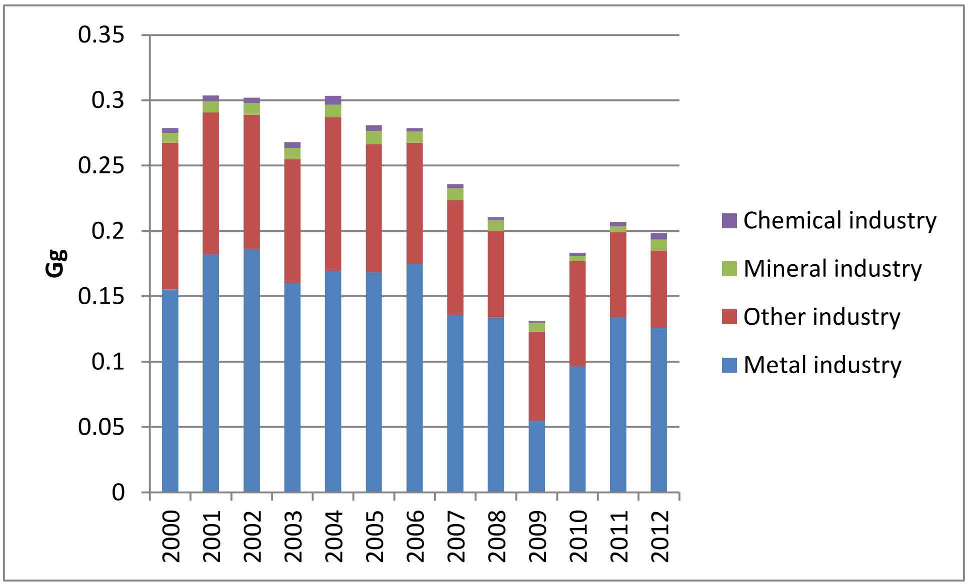

Figure 3. Emissions of BC from the industry sector, 2000-2012 (Gg).

Solvent and product use, Agriculture and Waste

Emissions of BC from the sectors solvent and product use, agriculture and waste were approximately 0.06 tonnes in year 2012 (Figure 4).

The predominant source of BC within these sectors in 2012 was waste incineration, which contributed with approximately 99% of the emissions. The only other contributing source was other product use (i.e. tobacco smoking). According to EMEP/EEA guidebook (2013) no emissions of BC are expected to occur from the agriculture sector.

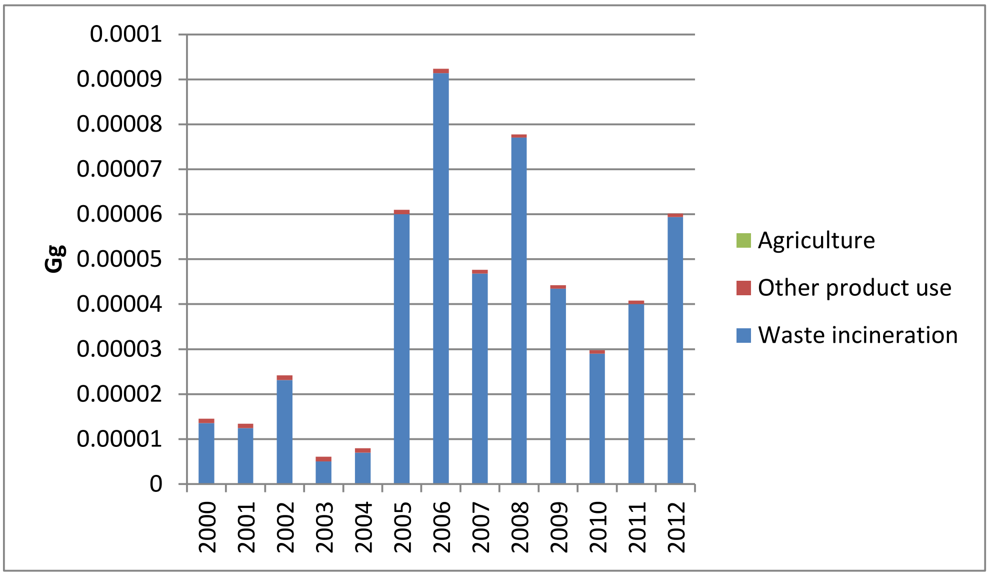

Figure 4. Emissions of BC from the solvent and product use, agriculture and waste sector, 2000-2012 (Gg).

International transport

Emissions from international transport (international shipping, civil aviation and international aviation) are not included in the total national emission according to the LRTAP reporting guidelines (ECE, 2014). In Figure 5 both the emissions of BC originating from international transport as well as the national total emissions of BC are presented. Emissions of BC from international transport were nearly 0.93 ktonnes in the year 2012 (Figure 5), which corresponds to an increase of about 18% since 2000.

The predominant source of BC in 2012 within the international transport category was international shipping, which contributed with approximately 93% of the reported emissions.

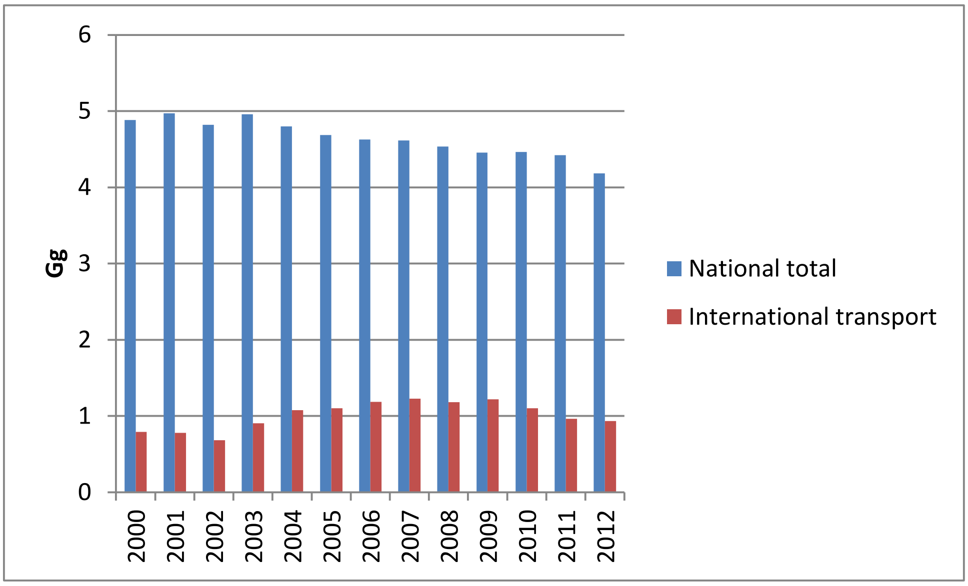

Figure 5. Emissions of BC, national total and international shipping, 2000-2012 (Gg).

Conclusions

The high level of uncertainty about the level of particulate emissions from small-scale biomass combustion linked to the issue of measurement methods and emission factors for $PM_{2.5}$ from residential biomass combustion, as well as uncertainty due to insufficient knowledge of the activity data (stocks of combustion technologies) implies that caution should be taken when using the absolute values for the estimated emissions in this study. Sweden uses in-stack measurements to derive national EFs, whereas many other European countries use emission factors based on the dilution tunnel. Compared with these countries, emissions of particles from small-scale combustion in Sweden can be considered to be underestimated.

In 2012, total emissions of BC in Sweden were nearly 4.2 ktonnes. This corresponds to a reduction by about 14% since year 2000. 95% of the BC emissions originate from the energy sector and consequently this is the predominant source of BC in Sweden.

According to the general recommendation given in the amended Gothenburg protocol text, the emission reduction actions for $PM_{2.5}$ should be prioritised for the sources with the largest emitted fractions of BC. The most important sources of BC for 2012 in the Swedish inventory are:

- Small scale combustion, including residential biomass combustion (approximately 27%)
- Energy other (approximately 19%, 1 A 2 d Stationary combustion in pulp, paper and print industries)
- Off-road mobile (approximately 18%)
- Road traffic (approximately 17%)

International transport, which is not included in the national totals, is the second largest source of BC within the Swedish inventory for 2012.

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Appendix 1

Table 1. Percentages of $PM_{2.5}$ used in the Swedish BC inventory for each activity, together with the used level of tier and 95% confidence interval for year 2012 and 2000. All BC-fractions are taken from the EMEP/EEA air pollutant emission inventory guidebook 2013 (EEA, 2013).

NFR Code	Sub-level	Tier	% of $PM_{2.5}$ 2012	Lower 95% conf. int. 2012	Upper 95% conf. int. 2012	% of $PM_{2.5}$ 2000	Lower 95% conf. int. 2000	Upper 95% conf. int. 2000	Reference
1 A 1 a	biomass	1	3.30%	1.60%	6.60%				1.A.1 Energy industries GB2013, Table 3_7
1 A 1 a	gas oil	1	33.50%	28.90%	38.00%				1.A.1 Energy industries GB2013, Table 3_6
1 A 1 a	residual oil	1	5.60%	0.22%	8.69%				1.A.1 Energy industries GB2013, Table 3_5
1 A 1 a	gaseous fuels	1	2.50%	1.00%	6.30%				1.A.1 Energy industries GB2013, Table 3_4
1 A 1 a	solid fuels and other fuels	1	2.20%	0.27%	8.08%				1.A.1 Energy industries GB2013, Table 3_2
1 A 1 b	refinery oil	2	5.60%	0.22%	8.69%				1.A.1 Energy industries GB2013, Table 4_4
1 A 1 b	natural gas	2	8.6%	4.3%	17.2%				1.A.1 Energy industries GB2013, Table 4_6
1 A 1 b	refinery gas	1	18.4%	5.2%	36.3%				1.A.1 Energy industries GB2013, Table 4_2

NFR Code	Sub-level	Tier	% of $PM_{2.5}$ 2012	Lower 95% conf. int. 2012	Upper 95% conf. int. 2012	% of $PM_{2.5}$ 2000	Lower 95% conf. int. 2000	Upper 95% conf. int. 2000	Reference
1 A 1 c	biomass	1	28.0%	11.0%	39.0%				1.A.2 Combustion in manufacturing industries and construction GB2013, Table 3_5
1 A 1 c	liquid fuels	1	56.0%	33.0%	78.0%				1.A.2 Combustion in manufacturing industries and construction GB2013, Table 3_4
1 A 2 a	biomass	1	28.0%	11.0%	39.0%				1.A.2 Combustion in manufacturing industries and construction GB2013, Table 3_5
1 A 2 a	gaseous fuels	1	4.0%	2.1%	7.0%				1.A.2 Combustion in manufacturing industries and construction GB2013, Table 3_3
1 A 2 a	liquid fuels	1	56.0%	33.0%	78.0%				1.A.2 Combustion in manufacturing industries and construction GB2013, Table 3_4
1 A 2 a	solid fuels and other fuels	1	6.4%	2.0%	26.0%				1.A.2 Combustion in manufacturing industries and construction GB2013, Table 3_2
1 A 2 b	biomass	1	28.0%	11.0%	39.0%				1.A.2 Combustion in manufacturing industries and construction GB2013, Table 3_5
1 A 2 b	gaseous fuels	1	4.0%	2.1%	7.0%				1.A.2 Combustion in manufacturing industries and construction GB2013, Table 3_3

NFR Code	Sub-level	Tier	% of $PM_{2.5}$ 2012	Lower 95% conf. int. 2012	Upper 95% conf. int. 2012	% of $PM_{2.5}$ 2000	Lower 95% conf. int. 2000	Upper 95% conf. int. 2000	Reference
1 A 2 b	liquid fuels	1	56.0%	33.0%	78.0%				1.A.2 Combustion in manufacturing industries and construction GB2013, Table 3_4
1 A 2 b	solid fuels and other fuels	1	6.4%	2.0%	26.0%				1.A.2 Combustion in manufacturing industries and construction GB2013, Table 3_2
1 A 2 c	biomass	1	28.0%	11.0%	39.0%				1.A.2 Combustion in manufacturing industries and construction GB2013, Table 3_5
1 A 2 c	gaseous fuels	1	4.0%	2.1%	7.0%				1.A.2 Combustion in manufacturing industries and construction GB2013, Table 3_3
1 A 2 c	liquid fuels	1	56.0%	33.0%	78.0%				1.A.2 Combustion in manufacturing industries and construction GB2013, Table 3_4
1 A 2 c	solid fuels and other fuels	1	6.4%	2.0%	26.0%				1.A.2 Combustion in manufacturing industries and construction GB2013, Table 3_2
1 A 2 d	biomass	1	28.0%	11.0%	39.0%				1.A.2 Combustion in manufacturing industries and construction GB2013, Table 3_5
1 A 2 d	gaseous fuels	1	4.0%	2.1%	7.0%				1.A.2 Combustion in manufacturing industries and construction GB2013, Table 3_3

NFR Code	Sub-level	Tier	% of $PM_{2.5}$ 2012	Lower 95% conf. int. 2012	Upper 95% conf. int. 2012	% of $PM_{2.5}$ 2000	Lower 95% conf. int. 2000	Upper 95% conf. int. 2000	Reference
1 A 2 d	liquid fuels	1	56.0%	33.0%	78.0%				1.A.2 Combustion in manufacturing industries and construction GB2013, Table 3_4
1 A 2 d	solid fuels and other fuels	1	6.4%	2.0%	26.0%				1.A.2 Combustion in manufacturing industries and construction GB2013, Table 3_2
1 A 2 e	biomass	1	28.0%	11.0%	39.0%				1.A.2 Combustion in manufacturing industries and construction GB2013, Table 3_5
1 A 2 e	gaseous fuels	1	4.0%	2.1%	7.0%				1.A.2 Combustion in manufacturing industries and construction GB2013, Table 3_3
1 A 2 e	liquid fuels	1	56.0%	33.0%	78.0%				1.A.2 Combustion in manufacturing industries and construction GB2013, Table 3_4
1 A 2 e	solid fuels and other fuels	1	6.4%	2.0%	26.0%				1.A.2 Combustion in manufacturing industries and construction GB2013, Table 3_2
1 A 2 f i	biomass	1	28.0%	11.0%	39.0%				1.A.2 Combustion in manufacturing industries and construction GB2013, Table 3_5
1 A 2 f i	gaseous fuels	1	4.0%	2.1%	7.0%				1.A.2 Combustion in manufacturing industries and construction GB2013, Table 3_3

NFR Code	Sub-level	Tier	% of $PM_{2.5}$ 2012	Lower 95% conf. int. 2012	Upper 95% conf. int. 2012	% of $PM_{2.5}$ 2000	Lower 95% conf. int. 2000	Upper 95% conf. int. 2000	Reference
1 A 2 f i	liquid fuels	1	56.0%	33.0%	78.0%				1.A.2 Combustion in manufacturing industries and construction GB2013, Table 3_4
1 A 2 f i	solid fuels and other fuels	1	6.4%	2.0%	26.0%				1.A.2 Combustion in manufacturing industries and construction GB2013, Table 3_2
1 A 2 f ii	liquid fuels	1	78%	68%	88%	61%	53%	70%	Non-road mobile sources machinery, Appendix D, Table D.1, GB2013
1 A 3 a ii (i)		1	48%	-	-				1.A.3.a Aviation_GB2013: Table C2
1 A 3 a i (i)		1	48%	-	-				1.A.3.a Aviation_GB2013: Table C2
1 A 3 b i			64%	58%	70%	55%	48%	62%	Passenger cars, light commercial trucks, heavy-duty vehicles including buses and motorcycles, GB2013
1 A 3 b ii			75%	70%	80%	61%	55%	67%	Passenger cars, light commercial trucks, heavy-duty vehicles including buses and motorcycles, GB2013
1 A 3 b iii			70%	56%	84%	58%	47%	70%	Passenger cars, light commercial trucks, heavy-duty vehicles including buses and motorcycles, GB2013

NFR Code	Sub-level	Tier	% of $PM_{2.5}$ 2012	Lower 95% conf. int. 2012	Upper 95% conf. int. 2012	% of $PM_{2.5}$ 2000	Lower 95% conf. int. 2000	Upper 95% conf. int. 2000	Reference
1 A 3 b iv			20%	10%	30%	14%	7%	21%	Passenger cars, light commercial trucks, heavy-duty vehicles including buses and motorcycles, GB2013
1 A 3 b v		NA	-	-	-				
1 A 3 b vi	Two-wheelers		12%						Winther, 2012
1 A 3 b vi	Passenger cars		10%						Winther, 2013
1 A 3 b vi	Light-duty trucks		10%						Winther, 2014
1 A 3 b vi	Heavy-duty vehicles		10%						Winther, 2015
1 A 3 b vii		NE	-	-	-				
1 A 3 c		1	65%	52%	78%				1.A.3.c Railways GB2013: Table A1
1 A 3 d i (ii)		NO	-	-	-				
1 A 3 d ii		1	11%	9%	13.2%	16%	13%	19%	1.A.3.d Navigation_Shipping_GB2013: See Conclusion. Lack et al. (2009)
1 A 3 e	liquid fuels	1	65%	58%	71%	60%	54%	67%	Non-road mobile sources machinery, Appendix D, Table D.1, GB2013
1 A 4 a i	biomass	1	28.0%	11.0%	39.0%				1.A.4 Small combustion GB2013, table 3_10

NFR Code	Sub-level	Tier	% of $PM_{2.5}$ 2012	Lower 95% conf. int. 2012	Upper 95% conf. int. 2012	% of $PM_{2.5}$ 2000	Lower 95% conf. int. 2000	Upper 95% conf. int. 2000	Reference
1 A 4 a i	gaseous fuels	1	4.0%	2.1%	7.0%				1.A.4 Small combustion GB2013, table 3_8
1 A 4 a i	liquid fuels	1	56.0%	33.0%	78.0%				1.A.4 Small combustion GB2013, table 3_9
1 A 4 a ii	liquid fuels		IE	IE	IE	IE	IE	IE	
1 A 4 b i	Fireplaces burning wood	2	7.0%	2.0%	18.0%				1.A.4 Small combustion GB2013, table 3_14
1 A 4 b i	Conventional stoves burning wood and similar wood waste	2	10.0%	2.0%	20.0%				1.A.4 Small combustion GB2013, table 3_17
1 A 4 b i	Conventional boilers < 50 kW burning wood and similar wood waste	2	16.0%	5.0%	30.0%				1.A.4 Small combustion GB2013, table 3_18
1 A 4 b i	Pellet stoves and boilers burning wood pellets	2	15.0%	6.0%	39.0%				1.A.4 Small combustion GB2013, table 3_25

NFR Code	Sub-level	Tier	% of $PM_{2.5}$ 2012	Lower 95% conf. int. 2012	Upper 95% conf. int. 2012	% of $PM_{2.5}$ 2000	Lower 95% conf. int. 2000	Upper 95% conf. int. 2000	Reference
1 A 4 b i	Liquid Fuels	1	8.5%	4.8%	17.0%				1.A.4 Small combustion GB2013, table 3_5
1 A 4 b i	Gaseous fuels	1	5.4%	2.7%	11.0%				1.A.4 Small combustion GB2013, table 3_4
1 A 4 b ii	liquid fuels	1	16%	13%	20%	23%	19%	27%	Non-road mobile sources machinery, Appendix D, Table D.1, GB2013
1 A 4 c i	biomass	1	28.0%	11.0%	39.0%				1.A.4 Small combustion GB2013, table 3_10
1 A 4 c i	gaseous fuels	1	4.0%	2.1%	7.0%				1.A.4 Small combustion GB2013, table 3_8
1 A 4 c i	liquid fuels	1	56.0%	33.0%	78.0%				1.A.4 Small combustion GB2013, table 3_9
1 A 4 c i	hard coal	1	6.4%	2.0%	26.0%				1.A.4 Small combustion GB2013, table 3_7
1 A 4 c ii	liquid fuels	1	62%	54%	69%	55%	49%	62%	Non-road mobile sources machinery, Appendix D, Table D.1, GB2013
1A 4 c iii		1	55%	44%	66%				1.A.3.d Navigation_Shipping_GB2013: See Conclusion. Lack et al. (2009)
1 A 5 a		NO	-	-	-				

NFR Code	Sub-level	Tier	% of $PM_{2.5}$ 2012	Lower 95% conf. int. 2012	Upper 95% conf. int. 2012	% of $PM_{2.5}$ 2000	Lower 95% conf. int. 2000	Upper 95% conf. int. 2000	Reference
1 A 5 b			52%	47%	57%	52%	46%	58%	1.A.3.d Navigation_Shipping_GB2013: See Conclusion. Lack et al. (2009) 1.A.3.b Vägtrafik: Passenger cars, light commercial trucks, heavy-duty vehicles including buses and motorcycles, GB2013 1.A.3.a Aviation_GB2013: Table C2
1 B 1 a		NO	-	-	-				
1 B 1 b		NA	-	-	-				
1 B 1 c		NA	-	-	-				
1 B 2 a i		NO	-	-	-				
1 B 2 a iv	Catalytic cracker	1	0.13%	0.05%	0.20%				Mean value of EFs from Olmez et al. (1988), Cooper et al. (1987) and Chow et al. (2004). The emission factor for BC relates to PM2.5 emissions after abatement in the external stack whereas the PM2.5 emission factor is related to emission levels before such abatement.
1 B 2 a v		NA	-	-	-				
1 B 2 b		NO	-	-	-				

NFR Code	Sub-level	Tier	% of $PM_{2.5}$ 2012	Lower 95% conf. int. 2012	Upper 95% conf. int. 2012	% of $PM_{2.5}$ 2000	Lower 95% conf. int. 2000	Upper 95% conf. int. 2000	Reference
1 B 2 c		1	24.0%	2.4%	240.0%				1.B.2.c Venting and flaring GB2013 ,Table 3_4
1 B 3		NO	-	-	-				
2 A 1		1	3%	1.50%	6%				US EPA (2011, file no.: 91127)
2 A 2		1	0.46%	0.23%	0.92%				Chow et al. (2011)
2 A 3		IE	IE	IE	IE				
2 A 4		NA	-	-	-				
2 A 5		1	0.01%	0.01%	0.03%				US EPA (2011 file no.: 91148)
2 A 6		NE	-	-	-				
2 A 7 a		NA	-	-	-				
2 A 7 b		NA	-	-	-				
2 A 7 c		NA	-	-	-				
2 A 7 d	Glass production	2	0.06%	0.03%	0.12%				US EPA (2011, file no.: 91143)
2 A 7 d	Glass wool production	2	2.00%	1.00%	4.00%				US EPA (2011, file no.: 91142)
2 B 1		NO	-	-	-				
2 B 2		NA	-	-	-				
2 B 3		NO	-	-	-				

NFR Code	Sub-level	Tier	% of $PM_{2.5}$ 2012	Lower 95% conf. int. 2012	Upper 95% conf. int. 2012	% of $PM_{2.5}$ 2000	Lower 95% conf. int. 2000	Upper 95% conf. int. 2000	Reference
2 B 4		1	1.80%	0.90%	3.60%				US EPA (2011, file no.: 91124)
2 B 5 a		NE	-	-	-				
2 B 5 b		NE	-	-	-				
2 C 1	Steel	2	0.36%	0.18%	0.72%				US EPA (2011, file no.: 91153)
2 C 1	Pig iron	2	2.40%	0.09%	0.34%				Kupiainen & Klimont (2004)
2 C 1	Sinter and pellets	2	0.17%	0.09%	0.34%				US EPA (2011, file no.: 91139)
2 C 2		1	10%	5%	20%				US EPA (2011b, file no.: 91151)
2 C 3		2	2.30%	1.20%	4.60%				US EPA (2011, file no.: 91137).
2 C 5 a		IE	IE	IE	IE				
2 C 5 b		NE	-	-	-				
2 C 5 c		NE	-	-	-				
2 C 5 d		NE	-	-	-				
2 C 5 e		1	0.10%	0.05%	0.20%				US EPA (2011, file no.: 91158)
2 C 5 f		NE	-	-	-				
2 D 1		2	2.60%	1.30%	5.20%				US EPA (2011, file no.: 900152.5)
2 D 2		NA	-	-	-				
2 D 3		NE	-	-	-				
2 E		NA	-	-	-				

NFR Code	Sub-level	Tier	% of $PM_{2.5}$ 2012	Lower 95% conf. int. 2012	Upper 95% conf. int. 2012	% of $PM_{2.5}$ 2000	Lower 95% conf. int. 2000	Upper 95% conf. int. 2000	Reference
2 F		NA	-	-	-				
2 G		NO	-	-	-				
3 A 1		NA	-	-	-				
3 A 2		NA	-	-	-				
3 A 3		NA	-	-	-				
3 B 1		NA	-	-	-				
3 B 2		NA	-	-	-				
3 C		NA	-	-	-				
3 D 1		NE	-	-	-				
3 D 2		NA	-	-	-				
3 D 3	Tobacco smoking	2	0.45%	0.30%	0.67%				Schauer et al., 1998. It is assumed that EC equals BC for tobacco smoking
4 B 1 a		NA	-	-	-				
4 B 1 b		NA	-	-	-				
4 B 2		NO	-	-	-				
4 B 3		NA	-	-	-				
4 B 4		NA	-	-	-				
4 B 6		NA	-	-	-				

NFR Code	Sub-level	Tier	% of $PM_{2.5}$ 2012	Lower 95% conf. int. 2012	Upper 95% conf. int. 2012	% of $PM_{2.5}$ 2000	Lower 95% conf. int. 2000	Upper 95% conf. int. 2000	Reference
4 B 7		NO	-	-	-				
4 B 8		NA	-	-	-				
4 B 9 a		NA	-	-	-				
4 B 9 b		NA	-	-	-				
4 B 9 c		NA	-	-	-				
4 B 9 d		NA	-	-	-				
4 B 13		NA	-	-	-				
4 D 1 a		NA	-	-	-				
4 D 2 a		NA	-	-	-				
4 D 2 b		NA	-	-	-				
4 D 2 c		NA	-	-	-				
4 F		NO	-	-	-				
4 G		NO	-	-	-				
6 A		NA	-	-	-				
6 B		NA	-	-	-				
6 C a		NE	-	-	-				
6 C b		1	3.50%	1.80%	7%				Olmez et al. (1988)
6 C c		IE	IE	IE	IE				

NFR Code	Sub-level	Tier	% of $PM_{2.5}$ 2012	Lower 95% conf. int. 2012	Upper 95% conf. int. 2012	% of $PM_{2.5}$ 2000	Lower 95% conf. int. 2000	Upper 95% conf. int. 2000	Reference
6 C d		NE	-	-	-				
6 C e		NE	-	-	-				
6 D		NE	-	-	-				
7 A		NO	-	-	-				
1 A 3 a ii (ii)		1	48%	-	-				1.A.3.a Aviation_GB2013: Table C2
1 A 3 a i (ii)		1	48%	-	-				1.A.3.a Aviation_GB2013: Table C2
1 A 3 d i (i)		1	12%	10%	15%	13%	10%	15%	1.A.3.d Navigation_Shipping_GB2013: See Conclusion. Lack et al. (2009)
1 A 3									
7 B									
11A									
11 B									
11 C									

Appendix 2

Table 2. The Swedish BC emission inventory in Gg for 2000-2012.

NFR Code	2000 (Gg)	2001 (Gg)	2002 (Gg)	2003 (Gg)	2004 (Gg)	2005 (Gg)	2006 (Gg)	2007 (Gg)	2008 (Gg)	2009 (Gg)	2010 (Gg)	2011 (Gg)	2012 (Gg)
1 A 1 a	0.066893	0.083284	0.090534	0.100543	0.096947	0.101468	0.105206	0.101671	0.109775	0.11967	0.141773	0.116339	0.118516
1 A 1 b	0.029297	0.029972	0.029773	0.028739	0.028699	0.031244	0.03013	0.026871	0.031997	0.032599	0.032541	0.030902	0.034974
1 A 1 c	1.04E-05	1.11E-05	1.28E-05	1.69E-05	1.7E-05	1.72E-05	0.000282	0.000318	0.000261	0.000321	0.000329	0.000377	0.000251
1 A 2 a	0.024394	0.023561	0.023301	0.0267	0.026429	0.023875	0.024593	0.025237	0.021188	0.017978	0.020285	0.018797	0.029795
1 A 2 b	0.00242	0.001461	0.001612	0.001506	0.001124	0.001284	0.001163	0.001	0.000813	0.000941	0.001407	0.000801	0.000824
1 A 2 c	0.041576	0.056136	0.049885	0.044651	0.023533	0.022352	0.019752	0.020951	0.017669	0.017941	0.019867	0.019508	0.018731
1 A 2 d	0.292216	0.367	0.32183	0.295493	0.295064	0.292112	0.304375	0.291156	0.301087	0.297579	0.315145	0.291739	0.289203
1 A 2 e	0.018532	0.019614	0.019306	0.024112	0.020802	0.018423	0.018767	0.015018	0.016334	0.016766	0.016969	0.013077	0.012137
1 A 2 f i	0.217966	0.244323	0.227764	0.216713	0.204548	0.182094	0.236837	0.205895	0.174382	0.161604	0.179687	0.165434	0.160719
1 A 2 f ii	0.541053	0.524541	0.493468	0.466699	0.433914	0.430984	0.432724	0.411281	0.417332	0.407944	0.410363	0.409748	0.382167
1 A 3 a ii (i)	0.007585	0.00741	0.007	0.006531	0.006569	0.00706	0.008396	0.005188	0.005137	0.004846	0.004766	0.005103	0.004901

NFR Code	2000 (Gg)	2001 (Gg)	2002 (Gg)	2003 (Gg)	2004 (Gg)	2005 (Gg)	2006 (Gg)	2007 (Gg)	2008 (Gg)	2009 (Gg)	2010 (Gg)	2011 (Gg)	2012 (Gg)
1 A 3 a i (i)	0.008854	0.008636	0.007741	0.007452	0.007975	0.008666	0.00903	0.008747	0.009155	0.007988	0.008357	0.009086	0.008855
1 A 3 b i	0.37	0.37	0.36	0.35	0.35	0.34	0.36	0.36	0.35	0.32	0.31	0.27	0.24
1 A 3 b ii	0.26	0.34	0.37	0.41	0.44	0.34	0.36	0.36	0.33	0.30	0.29	0.28	0.24
1 A 3 b iii	0.67	0.61	0.56	0.53	0.51	0.50	0.48	0.45	0.38	0.30	0.29	0.27	0.23
1 A 3 b iv	0.0045	0.0050	0.0052	0.0057	0.0060	0.0059	0.0055	0.0063	0.0059	0.0056	0.0047	0.0042	0.0036
1 A 3 b v	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
1 A 3 b vi	0.202009	0.203918	0.204422	0.207657	0.212518	0.217057	0.221137	0.227846	0.229849	0.223762	0.225461	0.229642	0.227078
1 A 3 b vii	NE	NE	NE	NE	NE	NE	NE	NE	NE	NE	NE	NE	NE
1 A 3 c	0.071808	0.068419	0.065888	0.065346	0.063194	0.06156	0.065226	0.062612	0.063617	0.059532	0.057577	0.056617	0.056617
1 A 3 d i (ii)	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO
1 A 3 d ii	0.05459	0.053935	0.053888	0.069163	0.063204	0.060579	0.052402	0.04679	0.045529	0.066402	0.066255	0.061467	0.034765
1 A 3 e	0.123156	0.121359	0.118252	0.117209	0.115495	0.114552	0.114056	0.115167	0.118616	0.118364	0.119689	0.12197	0.120812

NFR Code	2000 (Gg)	2001 (Gg)	2002 (Gg)	2003 (Gg)	2004 (Gg)	2005 (Gg)	2006 (Gg)	2007 (Gg)	2008 (Gg)	2009 (Gg)	2010 (Gg)	2011 (Gg)	2012 (Gg)
1 A 4 a i	0.069788	0.064197	0.074205	0.075499	0.114145	0.077099	0.087358	0.130081	0.081438	0.103692	0.076795	0.095975	0.117637
1 A 4 a ii	IE	IE	IE	IE	IE	IE	IE	IE	IE	IE	IE	IE	IE
1 A 4 b i	0.744704	0.725208	0.718574	0.834869	0.728768	0.773945	0.661636	0.709652	0.758704	0.860837	0.816622	0.823657	0.795486
1 A 4 b ii	0.061897	0.060577	0.058795	0.061906	0.064638	0.058725	0.053097	0.052682	0.053894	0.046749	0.038543	0.036983	0.03327
1 A 4 c i	0.018766	0.018566	0.021228	0.096972	0.098851	0.157732	0.162592	0.210023	0.259092	0.270023	0.268162	0.334058	0.333251
1 A 4 c ii	0.386313	0.375268	0.35391	0.340676	0.327785	0.317443	0.309667	0.296538	0.29509	0.291699	0.298116	0.29101	0.271073
1A 4 c iii	0.28769	0.27215	0.25431	0.28442	0.23888	0.24568	0.20489	0.21044	0.22389	0.25111	0.24345	0.23969	0.21563
1 A 5 a	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO
1 A 5 b	0.023033	0.016091	0.018785	0.016379	0.014548	0.01277	0.013586	0.012214	0.008732	0.010833	0.008521	0.00896	0.008165
1 B 1 a	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO
1 B 1 b	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
1 B 1 c	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
1 B 2 a i	NO	NO	NO	NO	NO	2.49E-07	0.01042	0.010734	0.012158	0.010554	0.012891	0.006021	5.41E-05

NFR Code	2000 (Gg)	2001 (Gg)	2002 (Gg)	2003 (Gg)	2004 (Gg)	2005 (Gg)	2006 (Gg)	2007 (Gg)	2008 (Gg)	2009 (Gg)	2010 (Gg)	2011 (Gg)	2012 (Gg)
1 B 2 a iv	3.98E-05	3.65E-05	3.98E-05	3.26E-05	4.98E-05	4.75E-05	4.86E-05	4.09E-05	5.3E-05	3.74E-05	6.94E-05	2.26E-05	5.8E-05
1 B 2 a v	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
1 B 2 b	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO
1 B 2 c	0.000758	0.000754	0.000974	0.001002	0.000527	0.000822	0.001789	0.001102	0.000574	0.00067	0.000708	0.000602	0.000655
1 B 3	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO
2 A 1	0.005438	0.006113	0.007003	0.006787	0.008009	0.008381	0.006936	0.00736	0.006483	0.005439	0.002703	0.002919	0.007003
2 A 2	0.001132	0.001031	0.000849	0.000875	0.00075	0.000816	0.000728	0.000982	0.000781	0.000498	0.000553	0.00058	0.000482
2 A 3	IE	IE	IE	IE	IE	IE	IE	IE	IE	IE	IE	IE	IE
2 A 4	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
2 A 5	3.76E-08	3.88E-08	3.84E-08	3.73E-08	3.94E-08	4.1E-08	3.87E-08	3.94E-08	3.87E-08	3.27E-08	3.29E-08	3.27E-08	3.31E-08
2 A 6	NE	NE	NE	NE	NE	NE	NE	NE	NE	NE	NE	NE	NE
2 A 7 a	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
2 A 7 b	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
2 A 7 c	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
2 A 7 d	0.000817	0.001236	0.000952	0.000988	0.000841	0.000782	0.000888	0.000959	0.000829	0.000932	0.000767	0.000821	0.000791
2 B 1	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO

NFR Code	2000 (Gg)	2001 (Gg)	2002 (Gg)	2003 (Gg)	2004 (Gg)	2005 (Gg)	2006 (Gg)	2007 (Gg)	2008 (Gg)	2009 (Gg)	2010 (Gg)	2011 (Gg)	2012 (Gg)
2 B 2	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
2 B 3	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO
2 B 4	0.003629	0.00445	0.004205	0.004239	0.006745	0.004383	0.002691	0.003383	0.002608	0.001478	0.002376	0.003362	0.004926
2 B 5 a	NE	NE	NE	NE	NE	NE	NE	NE	NE	NE	NE	NE	NE
2 B 5 b	NE	NE	NE	NE	NE	NE	NE	NE	NE	NE	NE	NE	NE
2 C 1	0.145231	0.173934	0.176822	0.151312	0.158897	0.158644	0.16356	0.12486	0.121773	0.051956	0.091751	0.127101	0.12085
2 C 2	0.007575	0.006375	0.0066	0.006	0.00765	0.0069	0.006225	0.006587	0.008409	0.001725	0.003379	0.005307	0.003914
2 C 3	0.002371	0.001883	0.002621	0.002748	0.002749	0.002985	0.004987	0.004083	0.003588	0.001028	0.001403	0.001463	0.001135
2 C 5 a	IE	IE	IE	IE	IE	IE	IE	IE	IE	IE	IE	IE	IE
2 C 5 b	NE	NE	NE	NE	NE	NE	NE	NE	NE	NE	NE	NE	NE
2 C 5 c	NE	NE	NE	NE	NE	NE	NE	NE	NE	NE	NE	NE	NE
2 C 5 d	NE	NE	NE	NE	NE	NE	NE	NE	NE	NE	NE	NE	NE
2 C 5 e	4.79E-05	4.68E-05	3.48E-05	3.5E-05	3.34E-05	2.79E-05	3.23E-05	4.15E-05	2.72E-05	2.68E-05	3.1E-05	2.92E-05	3.2E-05
2 C 5 f	NE	NE	NE	NE	NE	NE	NE	NE	NE	NE	NE	NE	NE
2 D 1	0.112374	0.108557	0.102921	0.09489	0.117671	0.097898	0.0927	0.087805	0.066178	0.068212	0.080343	0.06537	0.059068
2 D 2	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
2 D 3	NE	NE	NE	NE	NE	NE	NE	NE	NE	NE	NE	NE	NE

NFR Code	2000 (Gg)	2001 (Gg)	2002 (Gg)	2003 (Gg)	2004 (Gg)	2005 (Gg)	2006 (Gg)	2007 (Gg)	2008 (Gg)	2009 (Gg)	2010 (Gg)	2011 (Gg)	2012 (Gg)
2 E	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
2 F	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
2 G	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO
3 A 1	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
3 A 2	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
3 A 3	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
3 B 1	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
3 B 2	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
3 C	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
3 D 1	NE	NE	NE	NE	NE	NE	NE	NE	NE	NE	NE	NE	NE
3 D 2	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
3 D 3	1.01E-06	1.03E-06	1.05E-06	1.02E-06	9.79E-07	1.03E-06	9.72E-07	8.79E-07	7.49E-07	7.79E-07	7.78E-07	7.95E-07	7.48E-07
4 B 1 a	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
4 B 1 b	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
4 B 2	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO
4 B 3	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
4 B 4	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
4 B 6	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA

NFR Code	2000 (Gg)	2001 (Gg)	2002 (Gg)	2003 (Gg)	2004 (Gg)	2005 (Gg)	2006 (Gg)	2007 (Gg)	2008 (Gg)	2009 (Gg)	2010 (Gg)	2011 (Gg)	2012 (Gg)
4 B 7	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO
4 B 8	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
4 B 9 a	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
4 B 9 b	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
4 B 9 c	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
4 B 9 d	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
4 B 13	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
4 D 1 a	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
4 D 2 a	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
4 D 2 b	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
4 D 2 c	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
4 F	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO
4 G	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO
6 A	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
6 B	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
6 C a	NE	NE	NE	NE	NE	NE	NE	NE	NE	NE	NE	NE	NE
6 C b	1.35E-05	1.24E-05	2.32E-05	5.04E-06	6.99E-06	6E-05	9.14E-05	4.68E-05	7.7E-05	4.35E-05	2.9E-05	4E-05	5.94E-05

NFR Code	2000 (Gg)	2001 (Gg)	2002 (Gg)	2003 (Gg)	2004 (Gg)	2005 (Gg)	2006 (Gg)	2007 (Gg)	2008 (Gg)	2009 (Gg)	2010 (Gg)	2011 (Gg)	2012 (Gg)
6 C c	IE	IE	IE	IE	IE	IE	IE	IE	IE	IE	IE	IE	IE
6 C d	NE	NE	NE	NE	NE	NE	NE	NE	NE	NE	NE	NE	NE
6 C e	NE	NE	NE	NE	NE	NE	NE	NE	NE	NE	NE	NE	NE
6 D	NE	NE	NE	NE	NE	NE	NE	NE	NE	NE	NE	NE	NE
7 A	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO
1 A 3 a ii (ii)	0.015358	0.01463	0.014095	0.013782	0.015957	0.015927	0.014898	0.014559	0.014141	0.011918	0.011582	0.012515	0.012537
1 A 3 a i (ii)	0.054756	0.052929	0.045497	0.044303	0.050182	0.054472	0.056467	0.062185	0.069919	0.059395	0.060034	0.06439	0.061583
1 A 3 d i (i)	0.722269	0.710664	0.622974	0.848863	1.012203	1.031016	1.112858	1.149726	1.098402	1.149337	1.031517	0.886826	0.85866
1 A 3	NE	NE	NE	NE	NE	NE	NE	NE	NE	NE	NE	NE	NE
7 B	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO
11A	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO
11 B	NE	NE	NE	NE	NE	NE	NE	NE	NE	NE	NE	NE	NE
11 C	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO