REPORT

Short Lived Climate Pollutants - method development for emission inventories of Black Carbon

Identifying gaps and reducing uncertainties

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Title and subtitle of the report

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Identifying gaps and reducing uncertainties

Summary

For important Swedish emission sources of Black Carbon (BC) a literature review of emission factors for $PM_{2.5}$ and of the BC content in emitted $PM_{2.5}$ is presented and discussed. Example calculations of emissions of $PM_{2.5}$ and of BC for stationary biomass combustion and for mobile diesel combustion are made based on the different sets of emission factors reviewed. Uncertainties and the importance of sampling methodology for PM measurements are discussed. Gaps of knowledge and further work needed for improved emission inventories of PM and BC are identified.

Keyword

Black Carbon, BC, $PM_{2.5}$, emission factors, emission inventory

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Summary

There is an increasing attention and interest in the role of Black Carbon (BC) in climate change and the possibilities to slow down the on-going temperature increase by reducing emissions of BC and other so called Short Lived Climate Pollutants (SLCP). Reduced emissions of SLCP, and in particular BC, will give a more rapid response in climate change in comparison to reducing CO_2 emissions, due to the shorter life time of these species in the atmosphere. Furthermore, BC is a component of emitted particulate matter (PM), and recently national reduction targets for emissions of $PM_{2.5}$ in 2020 were included in the amended CLRTAP Gothenburg protocol, agreed in May 2012. 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 $PM_{2.5}$.

Currently $PM_{2.5}$, but not BC, is included in the emission reporting program under the UNECE Convention on Long Range Transboundary Air Pollution (CLRTAP). The national Swedish inventory of $PM_{2.5}$, and other air pollutants, is performed and reported on an annual basis.

The current project builds on present knowledge and established structures regarding emission inventory work and the aim is to improve earlier preliminary estimates of total Swedish BC emissions, which for 2005 were estimated to 5.1 kton. Available estimates of BC emissions for Sweden indicate that stationary biomass combustion and emissions from diesel vehicles and machinery are the most important sources, together contributing in the order of 75-80% of national BC emissions. As the emissions of BC are calculated as a fuel- and technology specific fraction of emitted $PM_{2.5}$, the quality and accuracy of the $PM_{2.5}$ emission estimates are crucial for reliable estimates of BC emissions.

This study includes and presents, for important Swedish BC sources, the results of a literature review of emission factors and emissions of $PM_{2.5}$ and of published data on the BC content in $PM_{2.5}$. Example calculations of emissions of $PM_{2.5}$ and of BC for stationary biomass combustion and for mobile diesel combustion are made based on the different sets of emission factors reviewed.

The review of emission factors for $PM_{2.5}$ for stationary biomass combustion shows that the emission factors are highly variable, particularly for residential sources. The variability is due to operational factors but importantly also due to the sampling method applied for the PM emission measurements that are used in developing emission factors. The differences in emissions of PM between hot flue gas measurements and measurements performed after cooling of the flue gases in a dilution tunnel have been reported to be between 2-10 times. This of course also affects the subsequent estimates of BC as a fraction of $PM_{2.5}$.

A comparison of emission factors for $PM_{2.5}$ and for BC between the Swedish national factors, factors from the EMEP/EEA Air Pollutant Emission Inventory Guidebook and from IIASA shows large differences, especially for small scale biomass combustion. The Swedish emission factors are based on hot flue gas measurements, which give lower results,

while the emission factor data in the EMEP/EEA Guidebook generally are based on measurements in dilution tunnel, resulting in higher numbers.

Example calculations of Swedish emissions, using different sets of $PM_{2.5}$ and BC factors for stationary biomass combustion and for diesel vehicles and machinery, show that this can result in substantially different estimates. For stationary biomass combustion the differences are most pronounced for residential/small scale technologies, but also for power plants. For mobile diesel combustion the estimated BC emissions can differ about a factor of 2 for heavy duty vehicles and for off-road vehicles and machinery depending on choice of factors.

The review of available emission factors for $PM_{2.5}$ and BC, as well as the differences in the examples calculated for Swedish emissions, show that further work is needed to assess the representativeness of published factors for Swedish conditions, in order that a future national total emission inventory of BC will be as accurate and with as low uncertainty as possible. Reliable source specific emission data for BC are essential as background information when assessing and prioritising sources for implementing emission reduction actions.

Contents

Introduction

There is an increasing attention and interest in the role of Black Carbon (BC) in climate change and the possibilities to slow down the on-going temperature increase by reducing emissions of BC and other so called Short Lived Climate Pollutants (SLCP). Reduced emissions of SLCP, and in particular BC, will give a more rapid response in climate change in comparison to reducing CO_2 emissions due to the shorter life time of these species in the atmosphere. For the same reason, emission reductions of SLCP can also have a regional effect on climate change. For sensitive regions such as the Arctic, reducing BC emissions is thus an attractive policy option. In order to assess and understand the contribution from BC to a changing climate in the Arctic, a sound basis of knowledge regarding emissions of BC in Northern countries is essential. It is important to understand the magnitude and sources of origin of emissions of BC, as policy support when priorities regarding measures to abate climate change need to be weighed against each other.

Black Carbon is a component of emitted particulate matter (PM). Accurate emission inventories of PM are thus an important basis for estimating emissions of BC and other components of PM. A better understanding of PM composition is also essential for the assessment of climate benefits of emission reduction actions since PM also can have a cooling effect on the climate.

Currently PM (as $PM_{2.5}$ i.e. particles with an aerodynamic diameter <2.5 μm), but not BC, is included in the emission reporting program under the UNECE Convention on Long Range Transboundary Air Pollution (CLRTAP). The national Swedish inventory is performed and reported on an annual basis and covers several air pollutants from various anthropogenic sources (IIR and IIR Annexes, Swedish EPA, 2012). Generally there are substantial uncertainties associated with reported emission inventories of PM.

Recently national reduction targets for emissions of $PM_{2.5}$ in 2020 were included in the amended Gothenburg protocol, agreed in May 2012. 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 $PM_{2.5}$.

In 2011 a preliminary estimate of the national Swedish emissions of BC for 2005 was presented by Hansson et al, (2011). In this report it was concluded that further efforts are needed to reduce the uncertainty surrounding the national emission estimates of PM, including BC and other components. A better understanding of the present and future contribution from different individual sources to the emissions of $PM_{2.5}$ and BC is necessary as background information and a basis for policy development and recommendations for mitigation efforts.

In the current project the aim is to improve the preliminary estimates of source specific emissions of BC in Sweden. A review of current emission inventories of PM is provided and possibilities and actions to improve the inventories and reduce the uncertainty are discussed. The project builds on present knowledge and established structures regarding emission inventory work, where IVL as part of the SMED consortium (www.smed.se) annually compiles the national emission inventory of air pollutants and climate gases for reporting to international conventions.

The following tasks are included in this study:

- Review and evaluation of the emission factors and emissions of $PM_{2.5}$ for important Swedish sources by revisiting available material in order to develop more detailed emission factors and identify gaps of knowledge.
- Investigation of the fractions of BC in emitted PM from important Swedish sources by assessment of available information through in depth literature review.
- Recalculation of the Swedish national emissions of $PM_{2.5}$ and BC from important sources by using e.g. updated emission factors and uncertainty information

Available estimates of Black Carbon for Sweden

Emissions of BC can be calculated based on specific emission factors for black carbon, or based on emission inventories of PM, where BC constitutes a fraction of the emitted PM. The fractions are different for different types of emission sources and also depend on e.g. the efficiency of combustion. In a recently reported project financed by the Swedish EPA, "Black carbon – Possibilities to reduce emissions and potential effects" by Hansson et al (2011), preliminary data on BC emissions in Sweden in 2005 were compiled, calculated based on information on general fractions of BC in $PM_{2.5}$ as compiled by IIASA (Kupiainen and Klimont, 2004 and 2007). The preliminary results showed that biomass burning and combustion of diesel in mobile sources were important sources for emissions of BC. For biomass, combustion of wood logs in residential boilers was the single largest source. The largest BC sources from diesel combustion were non-road vehicles and machinery and heavy duty vehicles in road traffic (Figure 1 and Table 1). The key sources presented in Figure 1 are defined as the sources, ranked from largest to smallest contribution, which sum up to 95% of the total national emissions.

The International Institute for Applied System Analysis (IIASA) has continued its work on BC and has provided updated information on fractions of BC in $PM_{2.5}$ and also calculated emissions for Sweden (Klimont, 2012). The key sources from the recent IIASA calculations are included in Figure 1. The definitions of source categories are not always directly comparable between the national official reporting of emissions and that used in the IIASA modelling. In the figure the source categories have been aggregated to provide an as close as possible comparison of the estimated emission.

According to both the Swedish and the IIASA 2012 estimates diesel combustion in mobile sources and biomass combustion in stationary sources are large sources of BC, together contributing >75% of national total BC-emissions. A comparison of the contributions from the main groups of sources (Table 2) show that non-road mobile sources is larger according to the IIASA calculations while residential small scale biomass combustion is smaller than those calculated in Hansson et. al. The estimated total national emissions of BC are 5.1 and 6.3 ktonnes of BC, from Hansson et al. and IIASA (Klimont, 2012), respectively.

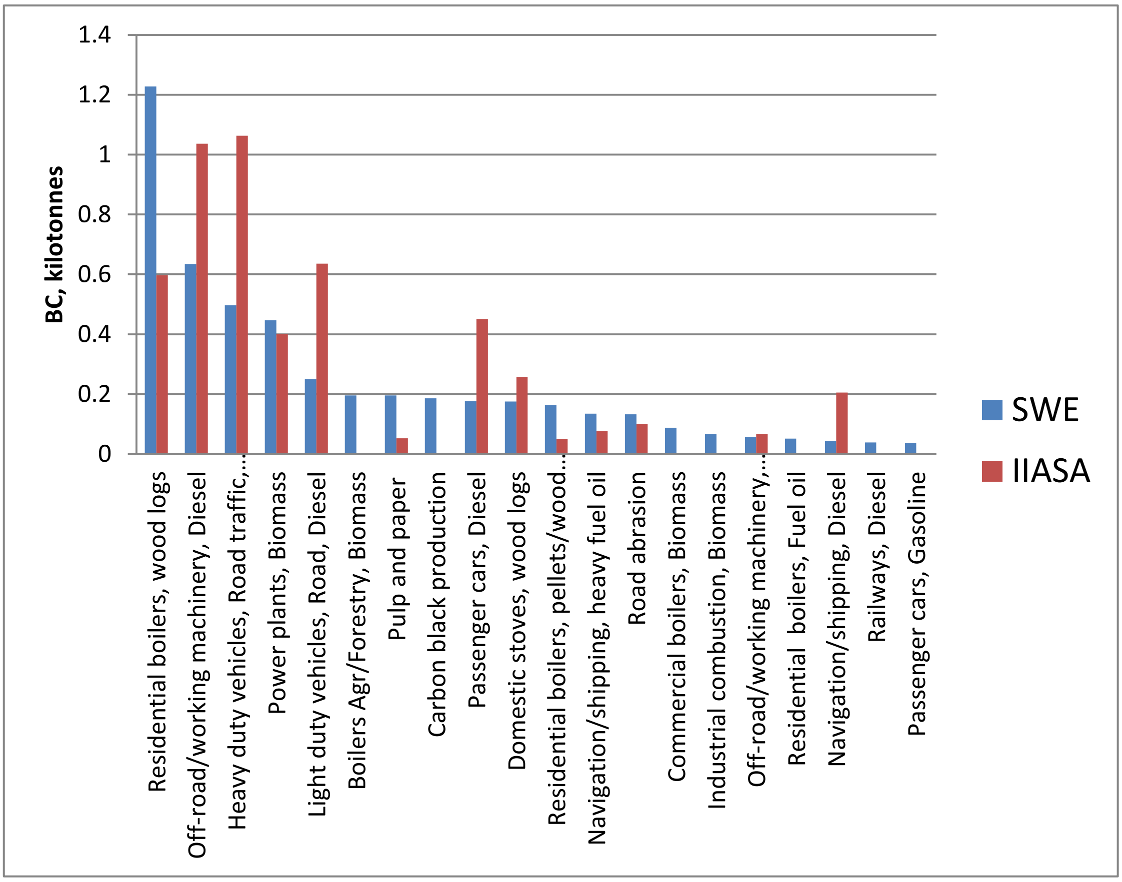

Figure 1 BC key sources in Sweden, 2005, from Hansson et al, (2011) and derived from IIASA (Klimont, 2012).

Table 1 BC key sources in Sweden, 2005 (Hansson et al, 2011)

	BC (kton)		BC (kton)
Total national emissions	**5.1**	***Non-road mobile sources***	***0.91***
Residential sector/small-scale combustion	***1.90***	Off-road/working machinery, Diesel	0.64
Residential boilers, biomass	1.39*	Navigation/shipping, heavy fuel oil	0.13
Boilers Agr/Forestry, Biomass	0.20	Off-road/working machinery, Gasoline	0.06
Domestic stoves, wood logs	0.18	Railways, Diesel	0.04
Commercial boilers, Biomass	0.09	Fishing, Diesel	0.02
Residential boilers, Fuel oil	0.05	Navigation/shipping, Diesel	0.02
Power plants and industry	***0.91***	***Road transport***	***1.09***
Power plants, Biomass	0.45	Heavy duty vehicles, Road traffic Diesel	0.50
Pulp and paper	0.20	Light duty vehicles, Road, Diesel	0.25
Carbon black production	0.19	Passenger cars, Diesel	0.18
Industrial combustion, Biomass	0.07	Road abrasion	0.13
		Passenger cars, Gasoline	0.04

* wood logs contribute 1.23 kton and pellets/wood chips 0.16 kton BC

Table 2 Comparison of BC emission source contribution in Sweden in 2005 as calculated in Hansson et al (2011) and derived from IIASA estimates (Klimont, 2012).

	Swedish estimates	IIASA estimates
	BC (kton)	BC (kton)
Residential sector/small-scale combustion	1.9	1.1
Power plants and industry	0.9	0.5
Non-road mobile sources	0.9	1.5
Road transport	1.1	2.8
Other	0.3	0.4
Total National BC	5.1	6.3

The first technology based global inventory of BC emissions by Bond et al (2004) presents estimated emissions of BC for different world regions for 1994. In Table 3 Abrahamsson et al (2010) have derived shares of the Nordic BC emissions as estimates for Sweden, based on the global inventory by Bond et al (2004). The rough sum of national BC emissions thus estimated for Sweden for 1994 is 12.5 kton.

The total estimates for Sweden for 2005, 5.1 kton, can be regarded to agree fairly well with those derived from Bond et al., considering the more than 10 years difference.

Table 3 Emissions of black carbon for 1994, for different sectors in the Arctic countries (kton/year). (derived from Bond et al, 2004, presented in Abrahamsson et al, 2010). The last column shows the calculated Swedish fraction of total estimated Nordic emissions.

Sector\ Countries Gg/year	North Ame	Russia	Nordic	Swed frac of Nordic emissions
Ag Burn	15,27	8,86	0	0
Industry	17,3	12	3,27	0,52
Open Burn	100,8	80,6	0,28	0,50
Power Gen.	2,99	1,26	0,05	0,20
Residential Biofuel	35,85	27,8	5,63	0,54
Residential Coal	20,17	12,3	0,09	0,00
Residential Other	3,73	0,56	0,29	0,41
Road Transport	228,1	30	13,25	0,35
Off-road transport	117,7	27	11,92	0,24
Total	**541,91**	**200,38**	**34,78**	**0,36**

Emissions of $PM_{2.5}$

The importance of reliable $PM_{2.5}$ inventories for estimating BC emissions

Different methods can be used to obtain emission estimates of BC, either from specific emission factors for BC or by applying estimated BC fractions to existing $PM_{2.5}$ or PM_{10} emission inventories. Due to lack of specific BC emission factors for most sources, the emissions of BC on a national scale needs to be based on reported emissions of $PM_{2.5}$, covering all relevant sources. The accuracy, representativeness and uncertainties of the emissions of $PM_{2.5}$ will thus directly influence the resulting estimated emissions of BC. An advantage of using estimated PM emissions to derive BC, as opposed to by specific emission factors, is that the estimates of PM and BC will be consistent.

In the Task Force on Emission Inventories and Projections, TFEIP, under UNECE CLRTAP, discussions have started regarding methodologies for estimating national and source specific BC emissions. At its latest meeting in May 2012, the TFEIP noted the progress of BC emission estimates from a number of countries, and included an item in the TFEIP workplan to assess the information that is currently available. Presently the EMEP/EEA Air Emission Inventory Guidebook (EEA, 2009) is under revision regarding updated information on emission factors for $PM_{2.5}$ and inclusion of information regarding BC. This work is planned to be finalised by a formal endorsement by the EMEP Steering Body in December 2013. Before that, the revised chapters were circulated for comments and review to TFEIP members during October 2012, and are scheduled to be discussed and endorsed by the TFEIP in May 2013 after revisions following the review. This material will provide a harmonised and general basis for comparable BC emission inventories between countries in the LRTAP Convention. It is however necessary to have a good knowledge on the specific characteristics of national sources in order to assess the representativeness of the more general guidance in the Emission Inventory Guidebook.

In this present work emission factors for $PM_{2.5}$ as well as the share of BC in the emitted $PM_{2.5}$, were taken from the draft Guidebook circulated for review in October 2012. Some information in the Guidebook may be updated following comments and additional information during the review process.

Measurement methodologies for PM emissions from small scale biomass combustion

Emission inventories of PM, and especially of some of the specific sources, such as small-scale 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). Another very important factor is the sampling methodology employed for PM emission measurements when the results are used as the basis for deriving emission factors.

In Europe there are several national standards and methods for sampling of PM concentrations from small scale biomass combustion. They can be divided into two main groups (Ryde and Johansson, 2007):

- Sampling in the hot flue gases in the chimney (above the flue gas dew point)
- Sampling in a dilution tunnel (below the flue gas dew point)

There are advantages and disadvantages with both sampling methods. Measurements in the chimney require less instrumentation since no dilution tunnel is needed. Sampling in a dilution tunnel on the other hand gives results more similar to the conditions when the flue gas reaches the ambient air.

General emission factors, valid on the national scale, should be derived based on representative emission measurements. The different standards for sampling emissions of particles may however heavily affect the measured particle concentration and hence the calculation of emission factors. In principle, particles are sampled on filters or impactors which are then weighed for a gravimetrical determination of the PM mass. Different gas sampling inlet configurations are used to separate particles with different aerodynamical mass (e.g. $PM_{2.5}$ or PM_{10}). The fraction of BC can be determined using optical instruments or other specific detection devices.

The purpose of a dilution tunnel is to simulate what happens to the flue gas when it reaches the ambient air, and the flue gas is diluted and cooled with large amounts of ambient-tempered air prior to sampling. Measurements by sampling using a dilution tunnel 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 difference between the two sampling methods is not constant, and the differences increase with increasingly poor and inefficient combustion conditions (Ryde and Johansson, 2007). Nussbaumer at al (2008) notes that particles from well designed and well operated automatic wood combustion consist mainly of inorganic matter such as salts, while particles from wood stoves operated under poor conditions consist mainly of soot and organic substances. Bäfver at al (2011) showed that measurements of $PM_{2.5}$ in hot flue gases in modern wood stoves and pellet stoves were rather similar. However, a considerably higher (typically more than 30 times) emission of organic gaseous carbon from combustion of wood logs (in comparison to pellets) indicated a potential additional contribution to the emissions from secondarily formed condensable organic particles.

Comparative studies by Ryde and Johansson (2007) and by Nussbaumer et al. (2008) of the sampling methods showed that the emissions of PM when using a dilution tunnel are between 2 and 10 times higher than when only taking into account the solid particles measured directly in the chimney.

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.

One of the most important sources of PM, and also of BC, in Sweden is combustion of biomass in small-scale installations (e.g. single house boilers, stoves, open fireplaces). In Sweden sampling in the flue gas channel is the most common approach, and the Swedish emission factors for small-scale combustion of biomass (Paulrud et al, 2006) are based on this sampling method, which thus is expected to give lower results for PM than if sampling in a dilution tunnel would have been used.

For combustion of diesel in mobile sources, the other large source of PM and BC in Sweden, the circumstances are somewhat different and the possible differences arising from sampling methodologies are less pronounced. Measurements of PM from e.g. road vehicle sources are standardized both in terms of PM and BC, while other sources, as e.g. non-road vehicles, are not entirely standardized and several standards can be in use.

Since the emissions of PM and BC are affected by both the applied sampling method and the combustion conditions in the specific source, it is not possible to derive straightforward conversion factors between different sampling methods.

Estimated emissions of $PM_{2.5}$ in Sweden

The Swedish national emissions of particulate matter, as TSP (Total Suspended Particulates), PM_{10} and $PM_{2.5}$, are annually estimated and reported to UNECE-CLRTAP. The reported data tables are accompanied by an Informative Inventory Report, IIR, which presents assumptions, underlying data and the inventory methodology for the various emission sources and pollutants (Swedish EPA, 2012). Data are reported according to the NFR-code system in line with the EMEP/EEA Air Emission Inventory Guidebook (EEA, 2009) and the UNECE reporting guidelines (UNECE, 2009).

A general way of estimating emissions is by multiplying the magnitude of an activity with a relevant emission factor:

E =AD x EF, where E=emissions, AD=activity data, EF= emission factor,

This means that the quality and representativeness of the activity data as well as of the emission factors used are important for the resulting estimated emissions.

The estimated annual national total anthropogenic emissions of $PM_{2.5}$ from 1990-2010, as reported in the Swedish official submission in 2012, is presented in Figure 2. The annual emissions have decreased from 37 Gg in 1990 to a level below 30 Gg from 1999-2009, and with an increase in 2010 to 31.5 Gg.

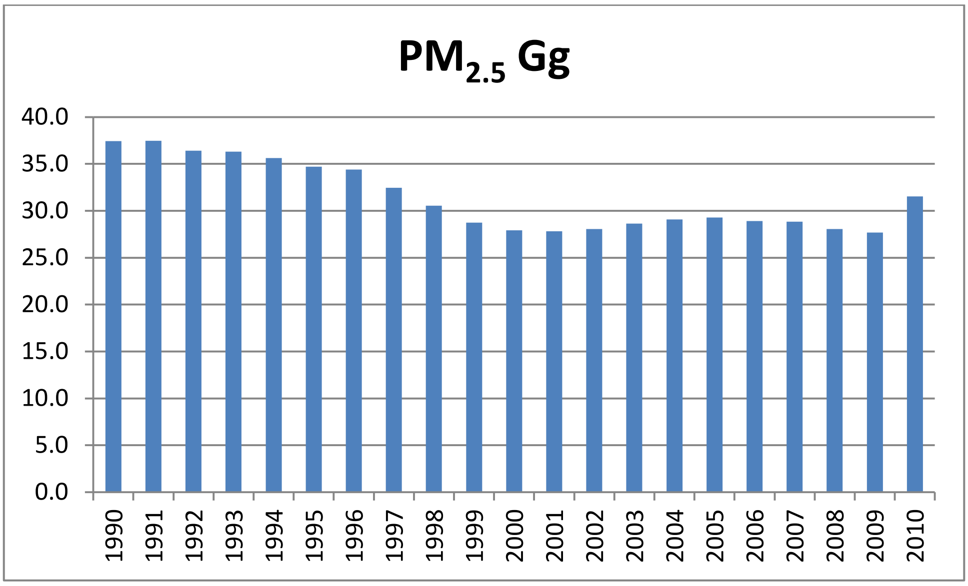

Figure 2 Annual total emissions of $PM_{2.5}$ (Gg) in Sweden as reported to CLRTAP in 2012.

The most important contribution to national emissions of $PM_{2.5}$ are presented in Figure 3, which shows the $PM_{2.5}$ keys sources for 2000, 2005 and 2010. Residential stationary combustion plants, which is an important source of BC-emissions, and large combustion plants for public electricity and heat production are the two largest $PM_{2.5}$ sources, and their $PM_{2.5}$ emissions have increased from 2000-2010.

The other important source for BC emissions, mobile sources (aggregated as off road machinery and as road transport), show a deceasing trend of $PM_{2.5}$ emissions (Figure 3) from 2000-2010 (green downward arrows). The road transport data include heavy duty and light duty vehicles as well as passenger cars and two-wheelers.

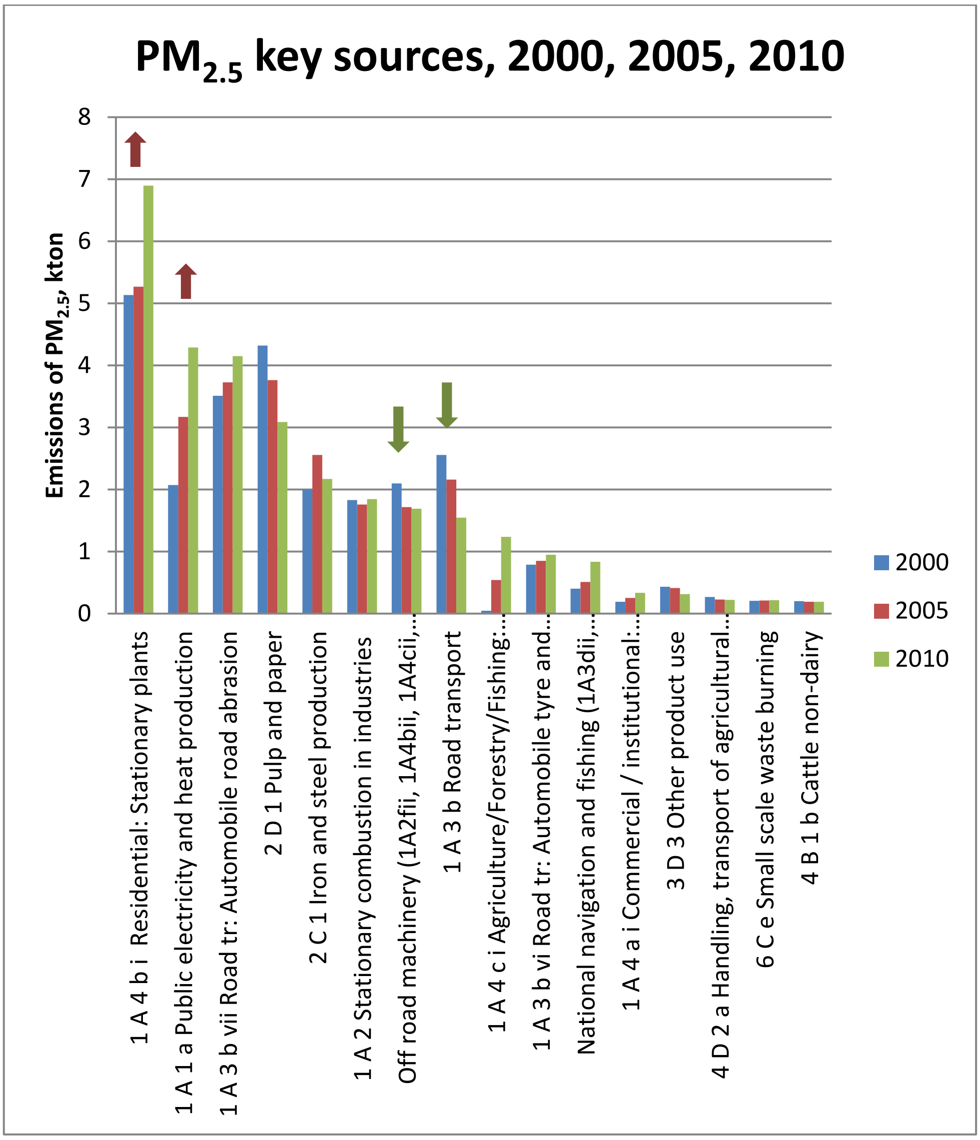

Figure 3 Key sources of $PM_{2.5}$ (95% of total national emissions) according to the Swedish official reporting for 2000, 2005 and 2010 as reported in 2012. Sources are sorted from largest to smallest contribution in 2010 (all fuels).

The increase in $PM_{2.5}$ emissions from stationary combustion in 2010 can be attributed to a cold winter and an increased use of fuels, particularly in power plants for public electricity and heat production (Figure 4). A more detailed analysis shows that the increase in fuel consumption in 2010 was especially significant for biomass and natural gas for public electricity and heat production (NFR 1A1a) (Figure 5) and also for biomass in commercial, institutional and residential stationary combustion (NFR 1A4) (Figure 6).

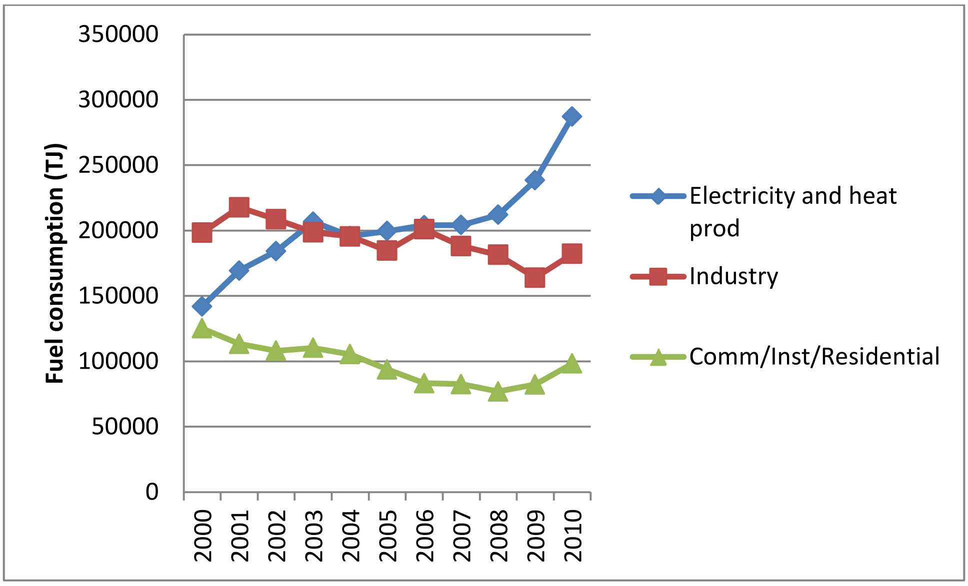

Figure 4 Total fuel use (TJ) in public electricity and heat production, in stationary combustion in industry and in the sectors of commercial/institutional and small-scale stationary combustion (residential, agriculture etc) 2000-2010.

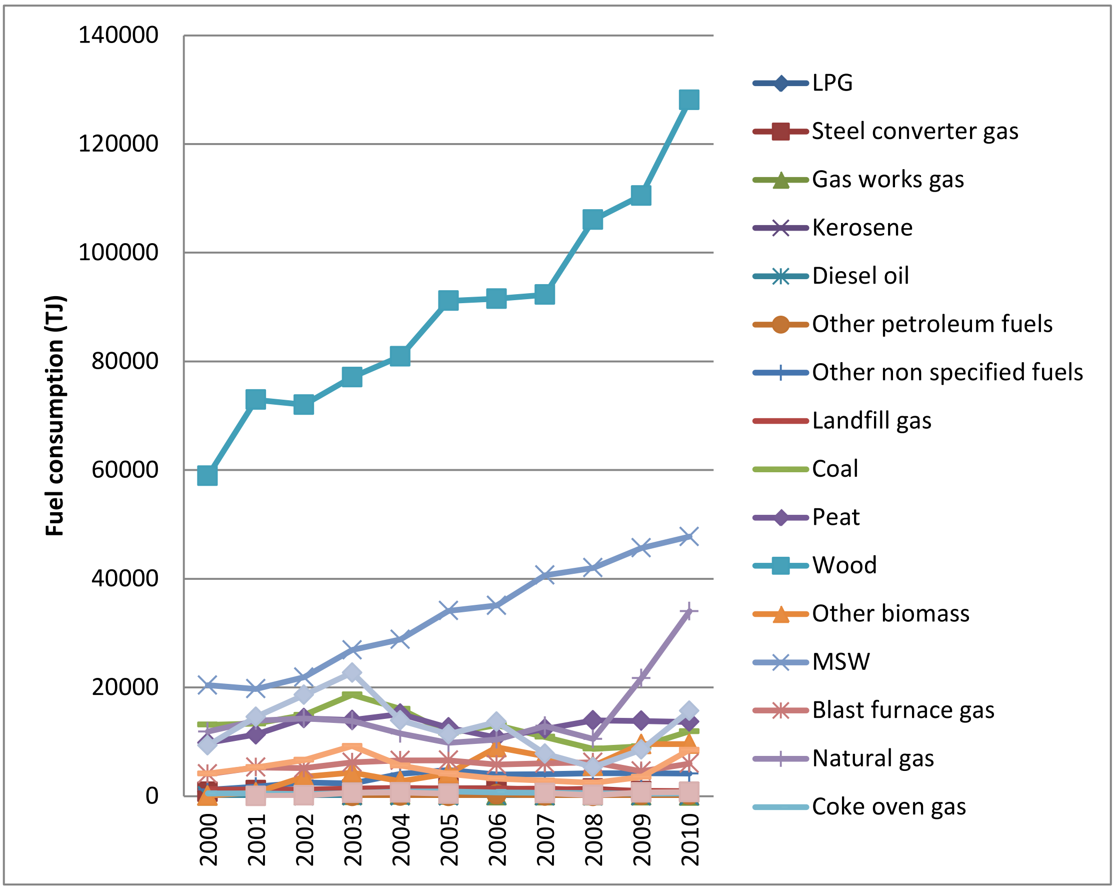

Figure 5 Fuel consumption in public electricity and heat production 2000-2010.

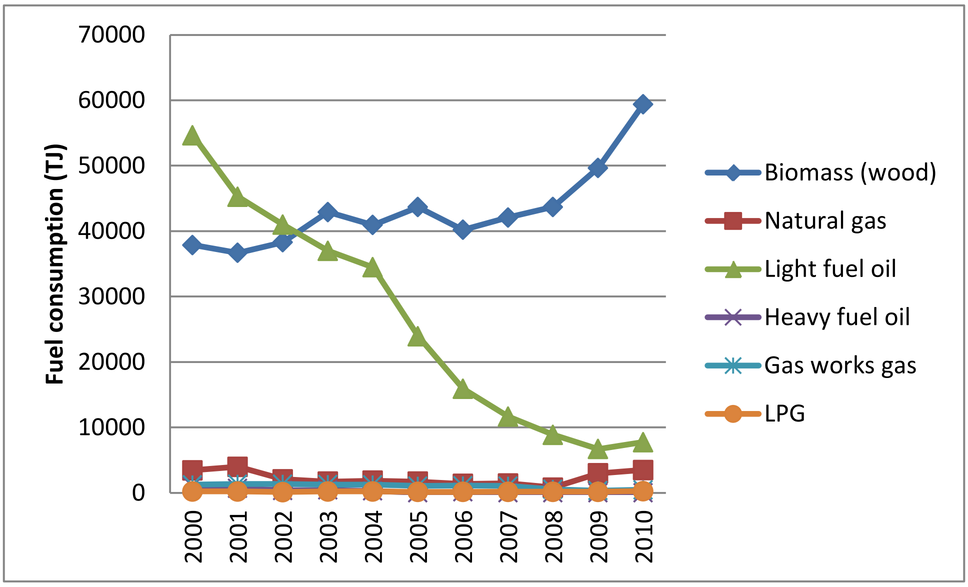

Figure 6 Fuel consumption in stationary residential sources (2000-2010).

The development of diesel fuel consumption and of emissions of $PM_{2.5}$ from the other large source of BC, diesel emissions from mobile sources in Sweden, is presented in Figure 7. Emissions have decreased both from road traffic and from off road vehicles and machinery. Due to the modernization of the vehicle fleet the emissions have decreased in spite of a substantially increased use of diesel fuel, especially in road traffic, over the same period of time.

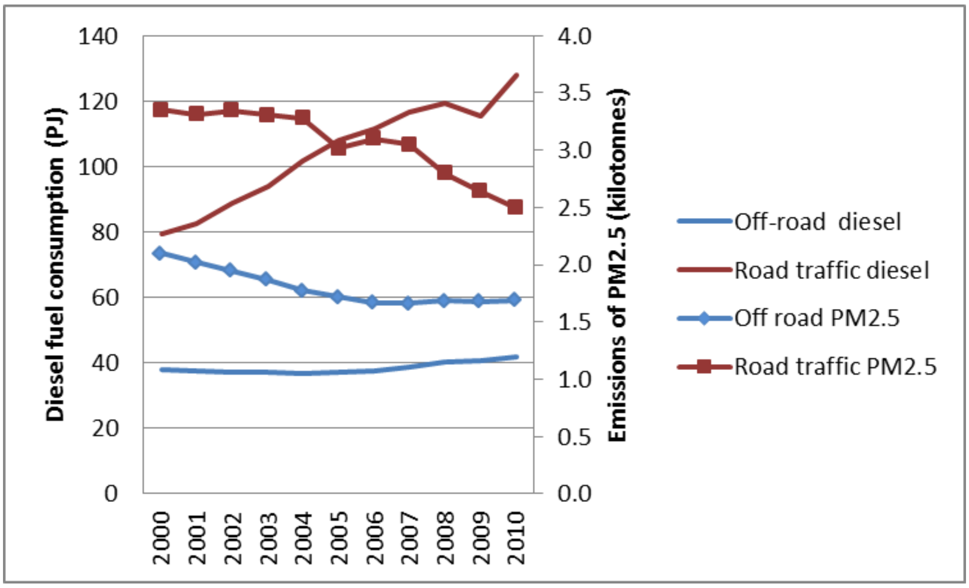

Figure 7 Diesel fuel consumption (PJ) and emissions of $PM_{2.5}$ (kton) from mobile diesel sources in Sweden 2000-2010.

Comparison with other PM estimates for Sweden

There are a few other estimates of emissions of PM from Sweden (Table 4 and Table 5). IIASA have calculated emissions for all European countries, using the GAINS model (data provided by Z. Klimont, 2012). TNO have in an EU project, MACC, estimated emissions of $PM_{2.5}$, among other pollutants (Kuenen, 2012 and Kuenen et al, 2011). The estimates of total national emissions are rather comparable (Table 4) while the sector breakdown for 2005 in Table 5 reveals some differences. For stationary combustion sources the Swedish data are the highest for non-industrial combustion (including small-scale combustion) while they are the lowest for combustion in manufacturing industries and from production processes. For mobile sources the Swedish data are the lowest for non-road transport. For the other sources, the Swedish data are either comparable to or in between the other estimates.

Table 4 Comparison of estimated national total emissions of $PM_{2.5}$

Emission year	Swedish official	IIASA	MACC/TNO
2000	28	36	32 (2003)
2005	29	32	33
2010	31.5	27	33 (2007)
2020	23.4	21	

Table 5 Comparison of estimated emissions of $PM_{2.5}$ by sector.

$PM_{2.5}$	Swedish official	IIASA	MACC
SNAP1 codes	2005	2005	2005
01: Combustion in energy and transformation industries	3.4	1.8	4.3
02: Non-industrial combustion	6.1	3.8	5.2
03: Combustion in manufacturing industry	1.8	2.4	4.7
04: Production processes	7.4	8.2	8.2
05: Extraction and distribution of fossil fuels	0.1	0.1	0.1
06: Solvent and other product use	0.4	0.0	0.6
07: Road transport	6.7	7.7	5.2
08: Non-road transport	2.3	4.4	3.6
09: Waste treatment and disposal	0.2	1.1	0.2
10: Agriculture	0.8	2.7	0.7
Sum	29.3	32.3	32.9

The similarity in total emissions may suggest some consensus in different approaches for emission inventories but the relatively large differences for some main sectors (e.g. 01, 02, 08, 10) indicate that the observed similarities are partly a result of differences in the three inventories cancelling out.

Comparison of emission factors for $PM_{2.5}$

The emission factors for $PM_{2.5}$ for stationary biomass combustion and for diesel combustion in mobile sources used in the Swedish national reporting (Swedish EPA, 2012) are presented in Table 6 - Table 8. Also included in these tables are the corresponding emission factors for Sweden used by IIASA (Klimont, 2012), and relevant emission factors from the draft EMEP/EEA Air Emission Inventory Guidebook (working material, October 2012). Stationary combustion of biomass and diesel in mobile sources are prioritised in these tables since these sources contribute most to the estimated emissions of BC. In Annex 1 comparison tables of emission factors for $PM_{2.5}$ for other sources and fuels are included.

The Swedish emission factors for stationary small-scale/residential biomass combustion are based on results from hot flue gas measurements. The IIASA emission factors are to a certain extent adapted to Swedish reporting via harmonisation to the national reporting. In the draft EMEP/EEA Guidebook the emission factors for small scale biomass combustion are based on measurements using dilution tunnel and are thus expected to be higher due to sampling of both primary particles and condensed organic substances. A comparison of emission factors for stationary biomass combustion in residential/small scale installations and in power-plants are presented in Table 6 and Table 7. In the Guidebook there are additional specific emission factors for defined technologies etc. available, which are not all reflected in the tables below.

As can be seen in Table 6, the Swedish emission factors for $PM_{2.5}$ from small scale combustion of biomass are considerably lower than those proposed in the draft Guidebook. It is also clear from the Guidebook indications of the uncertainties, that the 95% confidence interval usually is quite large. The large variation in reported emission factors in the literature, due to sampling methodology, operating conditions and other factors, is also highlighted in e.g. Nielsen et al (2010).

In 2007 a synthesis and analysis of emission factors for small scale combustion of biomass was performed in Sweden (Todorovic et al, 2007). Based on a literature review and additional calculations, a national emission factor for $PM_{2.5}$ for a hypothetic "average combustion appliance" for biomass combustion was derived to be 74 g/GJ, which is well in line with, or somewhat lower than the Swedish emission factors presented in Table 6 (30-150 g/GJ). The emission factor calculations were based on information for six different household appliance types. It is not explicitly mentioned which sampling method the emission factors are based on, but since it is Swedish measurements it is most likely in hot flue gases. The estimated emissions from household combustion of biomass was, 4 500 ton, with an interval from 1 800-14 000 tonnes (Todorovic et al (2007), somewhat lower than the Swedish national estimates of 5.2 kton in 2005. According to Todorovic et al (2007) emissions of $PM_{2.5}$ from small scale combustion of biomass are strongly dependent on combustion practices and the estimated emissions can roughly be assumed to have an uncertainty of a factor of 2.

For mobile sources, the Swedish emission factors (actually implied emission factors) are presented for 2005 and also for 2010 (Table 8), since changes have occurred over time due to modernisation of the vehicle fleet. The introduction of larger shares of newer EURO standards changes the composition of the vehicle fleet, which influences the emissions. The corresponding emission factors for 2005 from IIASA (Klimont, 2012) and from the draft Guidebook are also presented. When sampling PM emissions from road traffic mobile sources, dilution before sampling is the commonly employed method and no differences in emission factors due to measurement method are expected for these sources.

As can be expected, the differences in emission factors for mobile sources are not as pronounced as for stationary biomass combustion, but generally the IIASA emission factors for off-road vehicles as well as for road traffic are somewhat higher than the Swedish factors for 2005. In the draft Guidebook, the detailed inventory methodology provides specific emission factors for different age classes or EURO classes of vehicles. In Table 8 the intervals in emission factors due to different EURO classes are represented as the min and max value. For the inventory in Sweden, specific age/class dependent emission factors are used in the calculations. In Table 8, the emission factors given for Sweden are back-calculated from detailed estimated emissions and fuel use for a given vehicle type (e.g. passenger cars) and are thus implied emission factors, which depend on the composition of the vehicle fleet.

Table 6 Emission factors for $PM_{2.5}$ (g/GJ) from small scale biomass combustion. SWE EF=Swedish national emission factors.

		SWE EF	IIASA	EMEP/EEA Guidebook draft October 2012				
		g/GJ	g/GJ	g/GJ	95% confidence interval			References in Guidebook
Boilers	Wood logs	150	135	740	370	1480	Tier 1*	Alves et al. (2011) and Glasius et al. 2005
Conventional boilers <50kW	Wood and wood waste			470	235	940	Tier 2	Winther (2008) and Johansson et al. (2003). Assumed 2/3 of the wood is combusted in old boilers and 1/3 in new boilers
Boilers	Wood chips	100						
Automatic boilers	Wood		37	33	17	67	Tier 2	Johansson et al. (2004)
Boilers/stoves	Pellets	30		29	9	47	Tier 2	Boman et al. (2011)
Stoves (GB conventional)	Wood logs/chips	100	112	740	370	1480	Tier 2	Alves et al. (2011) and Glasius et al. 2005
Energy efficient stoves	Wood			370	285	740	Tier 2	Glasius et al. (2005)
Advanced / ecolabelled stoves and boilers	Wood			93	19	233	Tier 2	Johansson et al.(2003); Goncalves et al. (2010); Schmidl et al. (2011)
Open fireplace	Wood logs	150	198	820	410	1640	Tier 2	Alves et al. (2011)
All technologies, incl medium size boilers (IIASA)	Biomass	150	69	140	70	279	Tier 1/Tier 2	Naturvårdsverket, Sweden
All technologies, incl medium size boilers (IIASA)	Biomass		77	133	66	266	Tier 1	USEPA 2003

* Tier 1 is a default factor to be used when detailed information is not available. Tier 2 refers to a more detailed methodology requiring more specific information e.g. regarding combustion technologies

Table 7 Emission factors for $PM_{2.5}$ (g/GJ) from stationary biomass combustion in power plants and industry

		SW EF	IIASA	EMEP/EEA Guidebook draft October 2012				
		g/GJ	g/GJ	g/GJ	95% confidence interval			Ref/comment
Wood/biomass	Power plants, district heating	24.5	8.4	133	66	266	Tier 1	GB:USEPA 2003, IIASA: existing power plants
Wood/biomass	Power plants, district heating	24.5	4.62					IIASA: New power plants
Wood/biomass	Industry	28	10.16	na*				IIASA: industrial boilers
Wood/biomass	Industry	19.1	0.3	149	50	240	GB2006	IIASA: industry other combustion
Other biomass	Other consumption	31.5						

Table 8 Emission factors for $PM_{2.5}$ (g/GJ) for combustion of diesel in mobile sources

						EMEP/EEA Guidebook draft October 2012			
			SWE EF	**SWE EF**	**IIASA**	**Mean/Tier 1***	**Min***	**Max***	
Fuel type	**Sector**	**Subsector**	**g/GJ**	**g/GJ**	**g/GJ**	**g/GJ**			
			2005	**2010**	**2005**				
Diesel	Fisheries	Fisheries	22.85	22.85	25.74				
	Off Road Vehicles and Working Machinery	Farming	42.80	35.70	83.67	41.38	*13.83*	*89.40*	Tier 1, min-max Tier 2**
		Forestry	23.61	23.55		23.24	*13.64*	*88.83*	Tier 1, min-max Tier 2**
		Households	13.16	9.30					
		Industry	41.97	39.01	74.92	49.67	*22.79*	*102.57*	Tier 1, min-max Tier 2**
		Other	33.49	29.66					
	Railways	Railways	95.67	95.66	96.43	32.62			Tier 1
	Road Traffic	Heavy duty buses	13.16	9.30	21.03	22.38	*14.52*	*37.38*	Tier 1
		Heavy duty trucks			19.32				
		Light duty vehicles	35.42	24.12	41.74	36.19	*26.19*	*71.19*	Tier 1
		Passenger cars	22.01	7.03	27.60	26.19	*19.05*	*62.86*	Tier 1
Diesel	Navigation/Shipping		16.01	16.01	25.74				

* Calculated from emission factors given as g/kg (or tonnes) of fuel.

** Min and max represents the interval of emission factors for different age or stage classes of vehicles.

Estimating emissions of Black Carbon

Definition of BC

Black Carbon, BC, is defined by the measurement technology, as light absorbing carbon measured by optical methods. BC includes elemental carbon, EC, but can also include some light absorbing organic carbon. EC, elemental carbon, is all carbon in elemental form, as measured by thermal methods. In the literature, either BC or EC are referred, but for emission inventory purposes usually BC is assumed to equal EC, even though it strictly speaking is not correct.

Emission factors for BC

In the international literature there is no complete information available on specific emission factors for BC from all relevant emission sources. Another approach than using specific emission factors for BC is to start from estimated emissions of particulate matter and then apply different fractions of BC depending on fuel/sector etc. This is motivated since the total BC emission is constrained by the amount of PM emitted. This means that the PM and BC emission data is consistent but it does not mean that the resulting BC emission data is more exact or correct. IIASA have compiled BC fractions for most emission sources and in the draft EMEP/EEA Inventory Guidebook, which was on review in October 2012, BC as fraction of $PM_{2.5}$ has also been compiled based on available literature.

BC emission factors given as a fraction of $PM_{2.5}$ from IIASAs material (Klimont, 2012) for Sweden and from the draft EMEP/EEA Air Emission Inventory Guidebook (working material, October 2012) are presented in Table 9 - Table 13 for stationary biomass combustion and for diesel combustion in mobile sources. Previous work refers to the report by Hansson et al (2011), where BC fractions available from IIASA at that time (Kupiainen and Klimont 2004 and 2007) were used to estimate BC emissions. The fractions presented from IIASA in the tables below have been updated in recent years.

In Annex 2 comparison tables of BC as a fraction of $PM_{2.5}$ for other sources and fuels are presented.

When comparing the BC fractions, it is important to note that these can be related to estimated PM in hot flue gases, or to estimated PM after dilution (important particularly for small scale biomass combustion). Apart from influencing the PM emission factor itself, this also influences the expected fraction of BC. Most, if not all, of the particulate BC exists already in the hot flue gases. After dilution, the particle mass may increase due to condensation of gaseous organic compounds and other condensable material, but the absolute amount of BC does not increase. In cases of incomplete or inefficient combustion conditions, with high levels of gaseous organic compounds in the hot flue gas, the fraction of BC will thus be higher if measured in hot flue gases than if measured after dilution. In the material from IIASA it is not defined what measurement method the data are based on. In the draft Guidebook, it is explicitly mentioned that PM emission factors from diluted sampling are prioritised for inclusion as guidance in the Guidebook. Presumably this implies that this is also true for the presented BC fractions.

From Table 9 this seems to be the case, where the BC fractions from the Guidebook for domestic combustion, conventional boilers <50 kW, conventional stoves and for open fireplaces are lower than those from IIASA. More difficult to explain is the large difference between the BC fractions for power plants (Table 10), where the fraction given in the draft Guidebook is considerably lower than that from IIASA. The opposite is the case for industrial combustion of biomass. There may be differences in e.g. definitions or coverage of sources between the IIASA data and the Guidebook data which can explain the discrepancy, but this has not been further investigated in this work.

The BC fractions from diesel non-road vehicles and machinery are generally somewhat higher from the Guidebook than from IIASA (Table 11).

BC as a fraction of $PM_{2.5}$ from combustion of diesel in road traffic is presented in Table 12. For road traffic, the diesel exhaust BC emissions depend on vehicle type, the Euro standard and after treatment. In Table 13 (from the EMEP/EEA Guidebook) specific BC fractions for each vehicle category and Euro standard are presented, accompanied with an estimated uncertainty.

Table 9 BC as fraction of $PM_{2.5}$ for domestic (NFR* 1A4b) and other (NFR 1A4a/1A4c/1A5) small-scale combustion (institutional/commercial) of biomass fuels

		Previous work	IIASA	EMEP/EEA Guidebook draft October 2012				
Source	**Fuel**	**BC/PM$_{2.5}$**	**BC/PM$_{2.5}$**	**BC/PM$_{2.5}$**	**95% confidence interval**			**References*** **
Automatic boilers, institutional/commercial	wood	0.376	0.117	0.150	0.06	0.39	Tier 2**	Schmidl et al. (2011)
Institutional/commercial	biomass	0.323	0.260	0.280	0.11	0.39	Tier 1/Tier 2	Goncalves et al. (2010), Fernandes et al. (2011), Schmidl et al. (2011)
Domestic combustion	biomass	0.376		0.100	0.02	0.2	Tier 1	Alves et al. (2011), Goncalves et al. (2011), Fernandes et al. (2011), Bølling et al. (2009), US EPA SPECIATE (2002), Rau (1989)
Conventional boilers < 50 kW	wood and wood waste	0.323	0.315	0.160	0.05	0.3	Tier 2	Kupiainen & Klimont (2007)
Pellet stoves and boilers	pellets	0.376	0.081	0.150	0.06	0.39	Tier 2	Schmidl et al. (2011)
Conventional stoves	wood and wood waste	0.215	0.478	0.100	0.02	0.2	Tier 2	Alves et al. (2011), Goncalves et al. (2011), Fernandes et al. (2011), Bølling et al. (2009), US EPA SPECIATE (2002), Rau (1989)
Energy efficient stoves	wood			0.160	0.05	0.3	Tier 2	Kupiainen & Klimont (2007)
Advanced / ecolabelled stoves and boilers	wood			0.280	0.11	0.39	Tier 2	Goncalves et al. (2010), Fernandes et al. (2011), Schmidl et al. (2011)
Open fireplaces	wood	0.124	0.246	0.070	0.02	0.18	Tier 2	Alves et al. (2011), Goncalves et al. (2011), Fernandes et al. (2011), Bølling et al. (2009), Fine et al. (2002), Kupiainen & Klimont, IIASA (2004)

* NFR refers to the source code system used in reporting national emission inventories to CLRTAP.

** Tier 1 is the default factor to be used if specific information is not available. Tier 2 is a more detailed factor to be used if more information is available, e.g. regarding combustion technologies or other source specific information.

*** References are those presented in the EMEP/EEA draft Guidebook, October 2012.

Table 10 BC as fraction of $PM_{2.5}$ from combustion of biomass in power plants (NFR 1A1a) and in industry (NFR 1A2)

		Previous work	IIASA	EMEP/EEA Guidebook draft October 2012 *				
Source	**Fuel**	**BC/PM2.5**	**BC/PM2.5**	**BC/PM2.5**	**95% confidence interval**			**References/comment**
Power plants	Biomass	0.200	0.254	0.033	0.016	0.066	Tier 1	BC emission factor average of data in Dayton & Bursey (2001) and the Speciate database. (IIASA Renewable waste fuel)
Industrial comb.	biomass	0.052	0.070	0.280	0.11	0.39	Tier 1/Tier 2	
Industrial comb.	biomass	0.200	0.240	0.280	0.11	0.39	Tier 1/Tier 2	(IIASA, Black Liquor)

*GB fractions for industrial combustion are based on Tier 1 for 1A4a

Table 11 BC as fraction of $PM_{2.5}$ from combustion of diesel in non-road vehicles and machinery

		Previous work	IIASA	EMEP/EEA Guidebook draft October 2012		
Source	**Fuel**	**BC/PM2.5**	**BC/PM2.5**	**BC/PM2.5**	**Uncertainty**	**References/comment**
Agriculture	Diesel	0.489	0.411	0.57	ca 75%	For agriculture, forestry, industry and gasoline machinery, the following BC fractions of PM (f-BC) are proposed: 0.57, 0.65, 0.62 and 0.05,
Off-road machinery	Diesel	0.489		0.65		
Construction machinery	Diesel	0.489	0.489	0.62		
Railways	Diesel	0.456	0.456	0.65	20%	
Railways	Diesel	0.456		0.15	30%	Equipped with exhaust filter

Table 12 BC as fractions of $PM_{2.5}$ from combustion of diesel in road traffic.

		Previous work	IIASA	EMEP/EEA Guidebook draft October 2012	
Source	**Fuel**	**BC/PM2.5**	**BC/PM2.5**	**See detailed Table 13 below**	**Uncertainty (%)**
Heavy duty buses	Diesel	0.495	0.625	0.15-0.75	5-20
Heavy duty trucks	Diesel	0.495	0.653	0.15-0.75	5-20
Passenger cars	Diesel	0.631	0.721	0.10-0.87	5-50
Light duty vehicles,	Diesel	0.631	0.698	0.10-0.87	5-50

Table 13 EC/$PM_{2.5}$ and uncertainty for diesel vehicles, road traffic (EEA, 2009. Chapter 1A3b, Road transport, GB 2009 update May 2012, p 100).

Category / Euro standard	EC*/$PM_{2.5}$ (%)	Uncertainty (%)
Diesel Passenger cars and Light Duty Vehicles		
Conventional	55	10
Euro 1	70	10
Euro 2	80	10
Euro 3	85	5
Euro 4	87	5
Euro 3, Euro 4, Euro 5 equipped with DPF** and fuel additive	10	50
Euro 3, Euro 4, Euro 5 equipped with a catalyzed DPF	20	50
Diesel Heavy Duty Vehicles		
Conventional	50	20
Euro I	65	20
Euro II	65	20
Euro III	70	20
Euro IV	75	20
Euro V	75	20
Euro VI	15	30

* EC= Elemental Carbon. Assumed to be an approximation of BC.

** DPF= Diesel Particle Filter

With increasing regulation on emissions of air pollutants from national sources, more attention has been given to the international shipping sector in recent years. Several activities related to PM and BC emissions in the shipping sector are currently underway. Research activities such as the FP7 project Transphorm (www.transphorm.eu) have contributed with measurement results and proposed emission factors from ships using different fuel qualities. Emissions to air from international shipping, which is not included in the national emissions reporting to international conventions, contribute with substantial emissions. According to a presentation on “A high resolution emission inventory of particulate EC and OC for Europe” (Denier van der Gon et al, 2011) land based European emissions in 2005 were estimated to 621 kton EC (particle sizes up to 2.5 μm) and international shipping within the European area to 124 kton. The international shipping emissions have not been further investigated in this current project, but given the on-going research activities, knowledge is growing and it should be possible to make reasonably reliable estimates in the near future.

Recalculated emissions of $PM_{2.5}$ and of BC

Calculated data for $PM_{2.5}$

Based on the emission factors for $PM_{2.5}$ from IIASA and from the draft EMEP/EEA Guidebook, as presented in Table 6 - Table 8 above, alternative emissions of $PM_{2.5}$ have been calculated and compared with the national Swedish estimates (Table 14). Activity data are in all cases the fuel consumption data for Sweden for 2005 from the official national reporting. Since stationary biomass combustion and diesel vehicle exhaust are the most important sources of BC in Sweden, the alternative calculations of $PM_{2.5}$ emissions have been focused on these sources.

Generally, the emissions of $PM_{2.5}$ are higher when using the emission factors from the draft Guidebook. For residential small scale combustion they are 3-6 times higher, and for biomass combustion in power plants the emission factor from the draft Guidebook gives about 5 time higher emissions. Emissions calculated by using the IIASA emission factors for stationary combustion of biomass are more comparable to or lower than the Swedish data. Especially the power plant emissions are about one third of the Swedish emissions.

For mobile sources both the IIASA factors and the draft Guidebook factors give $PM_{2.5}$ emissions that are higher than the Swedish national estimates, but differences are not as pronounced as for stationary biomass combustion.

Table 14 Estimated emissions (EM) of $PM_{2.5}$ (kton) for 2005 using emission factors from the Swedish national reporting (SWE), from IIASA (2012) and from the draft EMEP/EEA Guidebook (GB). Indicated are also min and max values as calculated based on 95% confidence intervals given in the GB. Fuel consumption data (PJ) for 2005 are from the Swedish national reporting.

	2005	**EM $PM_{2.5}$ (kton)**			***EM $PM_{2.5}$ (kton)***		
Source of emission factor		**SWE**	**IIASA**	**GB**	***GB min***	***GB max***	**note**
Stationary biomass combustion	**PJ**						
Power plants	95.3	2.34	0.80	12.68	*6.29*	*25.36*	
Industrial combustion	18.5	0.49	0.19	2.75	*0.92*	*4.43*	
Industrial combustion, pulp and paper	40.5	0.77	0.01	6.03	*2.02*	*9.72*	
Commercial/institutional/farming	5.02	0.75	0.35	0.67	*0.33*	*1.33*	1
			0.39	0.70	*0.35*	*1.40*	1
Residential small scale	43.7	5.19	5.90	32.32	*16.16*	*64.65*	2
			4.89	20.53	*10.27*	*41.06*	2
			1.62	16.16	*12.45*	*32.32*	2
Mobile diesel combustion	**PJ**						
RT* Heavy duty vehicles	73.8	0.97	1.55	1.65	*1.07*	*2.76*	
RT Light duty vehicles	16.5	0.58	0.69	0.60	*0.43*	*1.17*	
RT Passenger Car	17.4	0.38	0.48	0.46	*0.33*	*1.09*	
Railways	0.89	0.09	0.09	0.03			
Forestry	4.71	0.11		0.11	*0.06*	*0.42*	
Navigation/shipping	6.01	0.11	0.15	0.20			3
Off-road vehicles and machinery	22.2	0.83	1.67	1.10	*0.51*	*2.28*	
Farming\Households	10.2	0.43	0.85	0.42	*0.14*	*0.91*	4

* RT= Road Traffic
1, NFR 1A4a + 1A4c, alternative EFs and BC shares from IIASA and GB in the two rows
2, Implied EF for total NFR 1A4b (residential, all technologies) for Sweden. Different EFs from IIASA and GB used for calculations in the three different rows
3, Sum of fisheries, domestic and military navigation
4, Sum of non-road for Households and Farming

It should be noted that for some of the sources calculations have been done on a more aggregated scale than in the Swedish inventory when applying the emission factors from IIASA and from the draft Guidebook. More detailed calculations, e.g. by technology or vehicle fleet composition are needed for a more robust analysis of the differences. It is also not possible to clearly suggest, based on this study, if (and which) Swedish emission factors for $PM_{2.5}$ will need revisions. There are however strong indications that at least the emission factors for residential small scale combustion need more detailed attention, due to the large absolute contribution to the national emissions and due to the highly different results. There are also surprisingly large differences for biomass combustion in power plants which need to be investigated further.

Calculated data for BC

Emissions of BC were calculated from Swedish fuel consumption, and emission factors for $PM_{2.5}$ and BC shares from the same source (SWE, IIASA or GB, respectively), to avoid any possible mismatch due to different measurement methodologies underlying the emission factors and fractions (Table 15). For cross-calculations using different combinations of sources for emission factors for $PM_{2.5}$ and for BC shares, as well as a presentation of the factors underlying the calculations, see Tables in Annex 3. One cross-calculation is presented in the last column in Table 15. The BC emissions presented in this column are calculated using the Swedish emission factors for $PM_{2.5}$ and BC shares from the Guidebook. This is to illustrate the result of using emission factors for $PM_{2.5}$ derived from hot flue gas sampling in combination with BC fractions from diluted sampling, as assumed they are in the Guidebook.

For stationary biomass combustion the calculated BC emission vary considerably for some sources. For industrial combustion, differences are large between the three sets of data (SWE, IIASA and GB). For small scale combustion, and the set of alternative factors given by IIASA and the Guidebook, BC emissions could be between 0.5 and 5 ktonnes, while those calculated using Swedish data are between 1.7 and 2 ktonnes. Some sets of alternative factors from IIASA and the Guidebook, respectively, give results which agree well with the estimates based on Swedish factors.

The estimated BC emissions from mobile diesel combustion are lower when using the set of Swedish factors than if using either the IIASA or Guidebook factors, especially for heavy duty vehicles and off-road vehicles and machinery. The Swedish estimates are for these sources about half of those estimated by using IIASA or Guidebook factors.

As pointed out for the $PM_{2.5}$ emission calculations, also regarding BC more detailed calculations, e.g. by technology or vehicle fleet composition are needed for a more robust analysis of the differences and way forward.

Table 15 Calculated emissions of BC (kton) for 2005 by using Swedish activity data. Data in SWE are based on national emission factors for $PM_{2.5}$ and shares of BC from the previous Swedish work, IIASA on factors for $PM_{2.5}$ and shares of BC from IIASA (2012) and GB is based on emission factors for $PM_{2.5}$ and shares of BC from the draft EMEP/EEA Guidebook, October 2012. The last column shows calculations based on Swedish emission factors for $PM_{2.5}$ and BC-shares from the Guidebook.

		Emissions of BC (kton)					
Stationary biomass combustion	**PJ**	**SWE**	**IIASA**	**GB**	**note**		**SWE EFs for $PM_{2.5}$ and GB BC-shares**
Power plants	95.3	0.47	0.20	0.42			0.08
Industrial combustion	18.5	0.03	0.01	0.77			0.14
Industrial combustion, pulp and paper	40.5	0.15	0.003	1.69			0.22
Commercial/institutional/farming	5.02	0.24	0.09	0.19	1		0.21
			0.10	0.39	1		
Residential small scale	43.7	1.95	1.86	5.17	2		0.83
		1.68	0.57	2.05	2		0.52
		-	0.51	2.59	2		-
Mobile diesel combustion	**PJ**						
RT* Heavy duty vehicles	73.8	0.48	1.01	1.16	3		0.68
RT Light duty vehicles	16.5	0.37	0.48	0.48	4		0.47
RT Passenger Car	17.4	0.24	0.35	0.39	5		0.33
Railways	0.89	0.04	0.04	0.02			0.06
Forestry	4.71						
Navigation/shipping	6.01	0.05	0.06	0.06	6		0.04
Off-road vehicles and machinery	22.2	0.40	0.81	0.70	7		0.52
Farming\Households	10.2	0.21	0.35	0.24	8		0.25

* RT=Road Traffic
1, NFR 1A4a + 1A4c, alternative EFs and BC shares from IIASA and GB in the two rows
2, Different EFs from IIASA and GB used for calculations in the three different rows
3, Assumed EURO III as representative average for GB calculations
4, Assumed EURO 2 as representative average for GB calculations
5, Assumed EURO 3 as representative average for GB calculations
6, Sum of fisheries, domestic and military navigation
7, BC-share GB 0.63 average of 0.62 and 0.65
8, Sum of non-road for Households and Farming

Discussion and conclusions

Potential use of emission data of PM and BC

The results presented above clearly demonstrate the large uncertainties involved in preparing emission inventories for $PM_{2.5}$ and BC. Before discussing the necessary future steps to improve the national inventories, it is of importance to discuss what these inventories are used for.

Emission inventories of $PM_{2.5}$ (and of BC) are or can potentially be used:

1. To follow up of the development of emissions over time nationally
2. To compare emission levels between countries
3. In atmospheric modelling work, e.g. on the LRTAP-scale
4. As background/input information in negotiations and setting of national targets
5. As background information for assessment of health effects
6. Evaluation of BC as a component in climate change
7. As input information for integrated assessment of abatement measures for several pollutants

At present, the Swedish $PM_{2.5}$ emission estimates are or can be used to a varying degree for all the above mentioned objectives. Given the uncertainty introduced by the measurement standards underlying the emission factors used for estimating $PM_{2.5}$ from small-scale biomass combustion, the following comments can be made:

1. National follow up of trend development is OK, since a consistent methodology has been employed over the years, even if the absolute numbers may contain errors.
2. Comparison of emission levels between countries is not straightforward at present since emission factors derived from different measurement standards are used
3. It is currently unclear what the requirements of the modelling community on emissions data are, and how currently available data are used as a basis for atmospheric dispersion modelling on the LRTAP-scale.
4. An improved knowledge and understanding of uncertainties and lack of consistent standards is needed on the policy level e.g in international negotiations and agreements.
5. Choice of sampling standard and the derived emission factors will impact assessment of health effects.
6. Choice of derived emission factors and BC fractions will impact the assessment of the importance of BC in climate change.
7. Choice of sampling standard and the derived emission factors will impact the importance of $PM_{2.5}$ (and BC) in integrated assessment studies.

Uncertainties in nationally reported emissions of $PM_{2.5}$

In the Swedish emission inventory of $PM_{2.5}$ the total national uncertainty is estimated to 15% for 2010 data using standardized methods for uncertainty assessment (Swedish EPA, 2012, IIR Annexes). The most important source of $PM_{2.5}$, residential combustion, is estimated to have an uncertainty of 64% and to contribute to 89% of the variance in the national $PM_{2.5}$ emission in 2010 (Table 16). Other large sources of $PM_{2.5}$ emissions are road transport (6.6 kton, including emissions from combustion of fuels, from tyre and brakewear, and road abrasion), public electricity and heat production (4.3 kton), pulp and paper production (3.1 kton) and iron and steel production (2.2 kton). Their estimated uncertainties are 10, 15, 21 and 29 % respectively, and their individual contributions to variance are less than 2% (Table 16). All remaining sources are together estimated to emit 8.1 kton of $PM_{2.5}$.

Table 16 Uncertainty analysis of $PM_{2.5}$ emissions in 2010 (Swedish EPA, 2012, IIR Annexes, table 24). Uncertainties are including all fuels in a source category.

Source category	**Emissions in 2010 (Gg)**	**Combined uncertainty (%)**	**Contribution to variance in 2010 (%)**
1A4b Residential combustion	7.2	64	89.0
1A3b Road transport (incl road, tyre and brake wear)	6.6	10	1.8
1A1a Public electricity and heat production (combustion of fuels)	4.3	15	1.8
2D1 Pulp and paper production	3.1	21	1.7
2C1 Iron and steel production	2.2	29	1.7
All remaining sources categories (31)	8.1		4.0
National total	**31.5**	**15**	**100**

The uncertainty for $PM_{2.5}$ from small scale combustion (where emissions from biomass combustion dominates) is assumed given the defined measurement methodology (sampling in hot flue gases, without dilution) on which the Swedish emission factors for $PM_{2.5}$ are based. As discussed above the emission factors for $PM_{2.5}$ would be higher if they were based on a measurement method with sampling after dilution. The uncertainty introduced by different possible measurement methods is not included in the uncertainty estimates discussed above.

Uncertainties for Black Carbon

Since BC has not been a part of the official national reporting, no formal uncertainties for the Swedish inventory have been calculated. Uncertainties for BC will be a function of the basic uncertainties in PM emissions and the additional uncertainties introduced in assuming

BC fractions. In general it can thus be assumed that the uncertainties in BC emissions will be greater than those of $PM_{2.5}$.

For small scale biomass combustion, the fraction of BC in undiluted samples at high temperature and in diluted samples of lower temperature cannot automatically be assumed to be comparable. Especially if there is incomplete combustion, the flue gases can include substantial amounts of gaseous organic matter. In this case, the relative content of BC will be comparatively higher in the hot flue gases than after dilution and condensation of (some of) this gaseous organic matter in the dilution step. The BC exists as particles/aerosols already in the chimney and the absolute amount does not increase in the condensation step, the relative content just becomes lower due to condensation of other substances.

The fractions used to estimate the Swedish BC emissions from emitted $PM_{2.5}$ for small scale combustion of biomass thus need to be assessed taking into account two important factors:

1) The sampling method for measuring PM from small scale biomass combustion. If only primary particles in hot flue gases are included, or also condensed aerosols from a dilution step. The Swedish emission factors for $PM_{2.5}$ are derived from a measurement method in hot flue gases which thus give lower emission factors than if a method with dilution of the flue gases prior to sampling had been applied.

2) The relative content of BC in measured PM is (usually) higher if measured in the undiluted hot flue gases than in the PM measured in a diluted sample. In the literature (e.g Klimont, 2012, draft EMEP/EEA Guidebook) it is not defined from which type of measurement method the fractions of BC in $PM_{2.5}$ are derived. This introduces another uncertainty in the estimates of BC.

The result of this is that the Swedish $PM_{2.5}$ emissions from small scale biomass combustion are underestimated in comparison to the guidance in the EMEP/EEA Guidebook. Furthermore, if the BC fractions given in the draft Guidebook refer to diluted sampling, these could be non-representative for the Swedish data (derived from PM measurements in hot flue gases). The estimated BC emissions from small scale biomass combustion in Sweden may thus be underestimated twice, first by using a low (sampling method dependent) emission factor for $PM_{2.5}$, and second, if BC shares in $PM_{2.5}$ derived from diluted measurements are used, where the relative BC content may be lower than in the hot flue gases. This case of combination of factors is shown in Table 15, where Swedish emission factors for $PM_{2.5}$ in combination with BC fractions from the draft Guidebook results in low calculated BC emissions for residential small scale combustion. It is thus very important to use a set of factors which are consistent and represent the conditions either in hot flue gases or after dilution and cooling of the flue gases.

In the draft EMEP/EEA Guidebook, the BC fractions are accompanied with max and min values in a 95% confidence interval, which give an indication of the assumed uncertainty in the BC estimates, presumably not taking measurement methodology into account.

Further work for improved emission inventories for PM and BC

Based on this study it is not possible to clearly suggest if (and which) Swedish emission factors for $PM_{2.5}$ will need revisions. There are however strong indications that at least the emission factors for residential small scale combustion need more detailed attention, due to the large absolute contribution to the national emissions and due to the highly different results obtained by using different suggested emission factors in the literature. The way forward to develop and improve the national emission inventories of both $PM_{2.5}$ and BC will require more detailed calculations, e.g. by technology or vehicle fleet composition, which are needed for a robust analysis of the differences presented in this study.

- There is a need to carefully adapt the present national emission inventory and to disaggregate the reporting by fuel and technologies in order to be able to estimate and report BC for all relevant national emission sources. This is to a large extent already the case in the underlying work in inventory compilation, but adaptations may be needed for specific source categories with significant BC emissions.

- It has to be clarified which standard to use when determining the emission factors for PM from residential and other small scale combustion of biomass. In order to assess the differences for Swedish conditions between the two principally different measurement methods, well designed and consistent measurements of PM and BC on typical and common Swedish combustion appliances are needed to build up a national knowledge and assess the representativeness for Swedish conditions of PM emission factors and BC fractions given in the draft EMEP/EEA Air Pollutant Emission Inventory Guidebook. In the meantime, it has to be stated clearly in the current official Swedish national reporting that the emission factors for $PM_{2.5}$ for small scale residential combustion of biomass are based on results from hot flue gas measurements.

- A more detailed and in depth study on the impact on estimated total national Swedish BC emissions following the choice of sets of BC factors for all relevant emission sources is needed when the draft EMEP/EEA Air Pollutant Emission Inventory Guidebook has been updated and endorsed by the TFEIP in spring 2013.

The aim with the further work outlined above would be to produce improved estimates of national and source specific emissions of $PM_{2.5}$ and BC, taking into account the potential policy relevant uses of Swedish emission data on PM and BC.

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Annex 1 Emission factors for $PM_{2.5}$

Table 1-1 Emission factors for $PM_{2.5}$ (g/GJ) from stationary combustion of fuels.

				EMEP/EEA Guidebook draft October 2012				
		SWE EF	IIASA		95% confidence interval			References in Guidebook/comments
Fuel type	Area of consumption	g/GJ	g/GJ	g/GJ				
Refinery oil	All consumption	5	8.19	31	5.4	12.6	Tier 2	USEPA 1998
Gas/diesel oil	Power plants, district heating, industry	2	0.50	0.8	0.3	2.5	Tier 1	USEPA 1998
Gas/diesel oil	Industrial boilers		0.19					
Gas/diesel oil	Other consumption	3	0.52	20	12	28	Tier 1	
Gas/diesel oil	Domestic			1.5	1	2	Tier 2	Italian Ministry for the Environment (2005)
Residual fuel oil	Power plants, district heating, industry	8.3	6.51	19.3	0.9	90	Tier 1	USEPA 1998
Residual fuel oil	Other consumption	12.45	7.27					
Residual fuel oil	Domestic		6.65					
Kerosene	All consumption	2		1.9	1.1	2.6	Tier 1	
Methane	All consumption	0.1						
Petroleum coke	Power plants, district heating	16.6						
Petroleum coke	Industry	21						
Petroleum coke	Other consumption	25						
LPG	Power plants, district heating, industry	0.1	0.2					IIASA sources: IN_BO-LPG, IN_OC-LPG
LPG	Other consumption	0.2	0.2					IIASA source: CON_COMB-LPG
LPG	Domestic		0.3					IIASA source: DOM-LPG
Refinery gases	All consumption	5		0.89	0.297	2.67	Tier 1	
Other petroleum fuels	All consumption	35						
Carbide furnace gas	All consumption	35						
Coke	Power plants, district heating	16.6						

				EMEP/EEA Guidebook draft October 2012				
		SWE EF	**IIASA**		**95% confidence interval**			**References in Guidebook/comments**
Coke	Industry	21	1.92					IIASA source: IN_BO_OTH-DC
Coke	Other consumption	25	0.38	70	35	140	Tier 2 average)	IIASA source: IN_OC-DC
Coke oven gas	All consumption	1						
Coking coal, other bituminous coal	Power plants, district heating (IIASA L)	16.6	0.77	3.4	0.9	90	Tier 1	USEPA 1998
Coking coal, other bituminous coal	Power plants, district heating (IIASA S)		0.87	3.1	3	12	Tier 2	USEPA 1998
Fluid bed, hard coal	Power plants, district heating			5.2	3	12	Tier 2	USEPA 1998
Fluid bed, brown coal	Power plants, district heating			2.8	0.9	8.4	Tier 2	USEPA 1998
Hard coal	Industry	9	3.71	3.2	7	28	Tier 1	USEPA 1998
Hard coal	Industry (IN_BO_OTH_L-HC1-[PJ])		3.88					IIASA source: IN_BO_OTH_L-HC1
Hard coal	Industry(IN_BO_OTH_S-HC1-[PJ])		2.17					IIASA source: IN_BO_OTH_S-HC1
Coking coal, other bituminous coal	Other consumption	25						
Hard and brown coal	commercial/institutional medium size boilers			108	60	220	Tier 1	Guidebook (2006)
Coal	commercial/institutional medium size boilers			170	72	220	Tier 2	Guidebook (2006)
Coal	Domestic			398	72	480	Tier 1	Guidebook (2006)
Steel converter gas	All consumption	1						
Blast furnace gas	All consumption	1						
Peat	Power plants, district heating, industry	24.5	4.21					IIASA source: PP_EX_L-BC1
Peat	Power plants, district heating, industry		2.73					IIASA source: PP_EX_S-BC1

				EMEP/EEA Guidebook draft October 2012				
		SWE EF	**IIASA**		**95% confidence interval**			**References in Guidebook/comments**
Peat	Industry		20.7					IIASA source: IN_BO/IN_OC-BC1
Other solid fuels	All consumption	35						
Gaseous fuels	Power plants, district heating, industry	0.1	0.1	0.89	0.445	1.34	Tier 1	USEPA 1998
Gaseous fuels	Other consumption	0.5		1.2	0.7	1.7	Tier 1	
Gaseous fuels	Other consumption			0.78	0.47	1.09	Tier 1	
Landfill gas	Power plants, district heating, industry	0.1						
Landfill gas	Other consumption	0.5						
Tall oil	All consumption	2						
Municipal Solid Waste	Power plants, district heating, industry	0.81	0.19					
Other not specified fuels	All consumption	35						

Table 1-2 Emission factors for $PM_{2.5}$ (g/GJ) for mobile sources

						EMEP/EEA Guidebook draft October 2012				
			SWE EF	**SWE EF**	**IIASA**	**Mean/Tier 1***	**Min***	**Max***		**comment**
Fuel type	**Sector**	**Subsector**	**g/GJ**	**g/GJ**	**g/GJ**	**g/GJ**				
			2005	**2010**	**2005**					
Aviation Gasoline	Aviation		10	10	0.356					
Gasoline	Navigation/Shipping	Small boats	90	90	105.0	86.07	*84.27*	*138.51*	Tier 1, min-max Tier 2**	2-stroke
	Off Road Vehicles and Working Machinery	Farming	106.3	80.46	27.99					
		Forestry	67.00	67.99						
		Households	66.16	55.07	331.66	86.07	*84.27*	*138.51*	Tier 1, min-max Tier 2**	2-stroke
		Industry	19.97	20.04	27.99					
		Other	7.25	7.26		3.59	*3.04*	*3.64*	Tier 1, min-max Tier 2**	4-stroke
	Road Traffic	Light duty vehicles	2.98	2.36	0.45	0.46	*0.46*	*0.69*	Tier 1	
		Mopeds & Motorcycles	35.16	24.06	23.61	50.34	*12.58*	*137.74*	Tier 1	
		2-stroke			84.61					
		Passenger cars	1.00	0.81	0.67	0.69	*0.46*	*0.92*	Tier 1	
Jet Kerosene	Aviation	Domestic	1.16	1.16	0.36					
Residual Oil	Navigation/Shipping	Bunkers	104.3	104.3	112.5					

* Calculated from emission factors given as g/kg (or tonnes) of fuel.

** Min and max are emission factors for different age or stage classes of machinery

Annex 2 BC as shares of $PM_{2.5}$

Table 2-1 BC as fraction of $PM_{2.5}$ for processes in refineries (NFR 1A1b)

		IIASA	Previous work	EMEP/EEA Guidebook draft October 2012				
Source	**Fuel**				**95% confidence interval**			**References**
Refineries	Gaseous fuels	0.070	0.067	0.086	0.043	0.172	Tier 2**	Wien et al 2004
Refineries	Residual fuel oil	0.097		0.056	0.0022	0.0869	Tier 2	BC emission factor derived as the average of the data found in Olmez et al. (1988), England et al. (2007) and the Speciate database.
Refineries	Gas oil	0.065	0.417	0.335	0.289	0.38	Tier 2	Hildeman et al, 1981 &Bond et al 2006

Table 2-2 BC as fraction of $PM_{2.5}$ for domestic (NFR 1A4b) and other (NFR 1A4a/1A4c/1A5) small-scale combustion (institutional/commercial)

		IIASA	Previous work	EMEP/EEA Guidebook draft October 2012				
Source	**Fuel**				**95% confidence interval**			**References/ comment**
Institutional/commercial	gaseous fuels			0.040	0.021	0.07	Tier 1	
Institutional/commercial	liquid fuels	0.977	0.720	0.560	0.33	0.78	Tier 1	(IIASA refers to Heavy fuel oil)
Domestic combustion	Gaseous fuels	0.070	0.067	0.054	0.027	0.11	Tier 1	
Domestic combustion	other liquid fuels	0.068		0.085	0.048	0.17	Tier 1	
Domestic boilers	Gas oil	0.977	0.720	0.039	0.02	0.08	Tier 2	US EPA (2011)

Table 2-3 BC as fraction of $PM_{2.5}$ from combustion in Industry (NFR 1A2)

		IIASA	Previous work	EMEP/EEA Guidebook draft October 2012*				
Source	**Fuel**				**95% confidence interval**			**References/comments**
Industrial comb.	gaseous fuels	0.070	0.067	0.040	0.021	0.07	Tier 1	
Industrial comb.	liquid fuels	0.065	0.067	0.560	0.33	0.78	Tier 1	(IIASA, LPG)
Industrial comb.	liquid fuels	0.097	0.072	0.560	0.33	0.78	Tier 1	(IIASA, Heavy Fuel Oil)
Industrial comb.	biomass	0.070	0.052	0.280	0.11	0.39	Tier 1/Tier 2	
Industrial comb.	biomass	0.240	0.200	0.280	0.11	0.39	Tier 1/Tier 2	(IIASA, Black Liquor)
Industrial comb.	gas oil/liquid fuels	0.568	0.417	0.560	0.33	0.78	Tier 1	
Industrial comb.	Hard/brown coal	0.008-0.051	0.007-0.043	0.064	0.02	0.26	Tier 1	

*GB fractions based on Tier 1 for 1A4a

Table 2-4 BC as fraction of $PM_{2.5}$ from combustion in power plants (NFR 1A1a)

		IIASA	Previous work	EMEP/EEA Guidebook draft October 2012				
Source	**Fuel**				**95% confidence interval**			**References/comments**
Power plants	Gaseous fuels	0.070	0.067	0.025	0.01	0.063	Tier 1	BC emission factor average of data available in England et al. (2004), Wien et al. (2004) and the Speciate database.
Power plants	Heavy fuel oil	0.097	0.072	0.056	0.0022	0.0869	Tier 1	BC emission factor derived as average of data found in Olmez et al. (1988), England et al. (2007) and the Speciate database.
Power plants	Gas oil	0.339	0.250	0.335	0.289	0.38	Tier 1	Hildemann et al., 1981 & Bond et al., 2006
Power plants	Biomass	0.254	0.200	0.033	0.016	0.066	Tier 1	BC emission factor average of data in Dayton & Bursey (2001) and the Speciate database.
Power plants	MSW		0.035					
Power plants	Peat		0.007					
Power plants	Hard coal	0.001	0.021	0.022	0.0027	0.0808	Tier 1	BC share derived as average of data from Henry & Knapp (1980), Olmez et al. (1988), Watson et al. (2001), Fisher et al. (1979), Griest & Tomkins (1984), Engelbrecht et al. (2002), Chow et al. (2004) and Speciate.

Table 2-5 BC as fraction of $PM_{2.5}$ from combustion of fuels in non-road vehicles and machinery

		IIASA	Previous work	EMEP/EEA Guidebook draft October 2012		
Source	**Fuel**				**Uncertainty**	**References/comment**
Navigation/shipping	Heavy fuel oil	0.431	0.433	0.12		
Navigation/shipping	Gas oil/diesel	0.411	0.411	0.31		
Agriculture	Diesel	0.411	0.489	0.57	ca 75%	For agriculture, forestry, industry and gasoline machinery, the following BC fractions of PM (f-BC) are proposed: 0.57, 0.65, 0.62 and 0.05,
Off-road machinery	Diesel			0.65		
Construction machinery	Diesel	0.489	0.489	0.62		
Off-road machinery	Gasoline	0.181	0.181	0.05	50%	
2-stroke Off-road machinery	Gasoline	0.062		0.05	50%	
Railways	Diesel	0.456	0.456	0.65	20%	
Railways	Diesel		0.456	0.15	30%	Equipped with exhaust filter

Table 2-6 BC as fractions of $PM_{2.5}$ from combustion of fuels in road traffic.

			IIASA	Previous work	EMEP/EEA Guidebook draft October 2012
Source	**Source**	**Fuel**			
Road traffic	Heavy duty buses	Gas	0.196	0.163	not yet available
Road traffic	Heavy duty trucks	Gas	0.158	0.163	-”-
Road traffic	Passenger Car	Gas	0.228	0.163	-”-
Road traffic	Light duty vehicles	Gas	0.222	0.163	-”-
Road traffic	Heavy duty vehicles	Gasoline	0.166	0.166	-”-
Road traffic	Mopeds & Motorcycles	Gasoline	0.155	0.166	-”-
Road traffic	Passenger Car	Gasoline	0.228	0.166	-”-
Road traffic	Light duty vehicles	Gasoline	0.222	0.166	-”-
Road traffic	Mopeds & Motorcycles	Gasoline	0.166	0.166	-”-

Table 2-7 BC as fraction of $PM_{2.5}$ from road traffic, non-combustion

			IIASA	Previous work	EMEP/EEA Guidebook draft October 2012		
Source	**Source**	**Fuel**					**References/comment**
Road traffic	Road abrasion		0.036	0.036			
Road traffic	Automobile tyre and brake wear		0.017	0.017	0.1	Tier 1	1.A.3.b.vi, road vehicle tyre and brake wear combined
Road traffic	Automobile tyre and brake wear		0.017	0.017	0.12	Tier 1	2-wheelers

Annex 3 BC calculations

Table 3-1 Emissions (EM) of $PM_{2.5}$ based on Swedish emission factors, IIASA 2012 emission factors and emission factors from the draft EMEP/EEA Guidebook (GB). Calculated emissions of BC (kton) based the three sets of $PM_{2.5}$ emissions, and information on BC-shares in the previous Swedish work (SWE), from IIASA 2012 and from the draft EMEP/EEA Guidebook, respectively.

		EM $PM_{2.5}$(kton)			EM BC (kton)			EM BC (kton)			EM BC (kton)			
	SWE				SWE EM $PM_{2.5}$			IIASA EM $PM_{2.5}$			GB EM $PM_{2.5}$			
Stationary biomass combustion	PJ	SWE	IIASA	GB	SWE	IIASA	GB	SWE	IIASA	GB	SWE	IIASA	GB	Source BC shares
Power plants	95.3	2.34	0.80	12.68	**0.47**	0.59	0.08	0.16	**0.20**	0.03	2.54	3.22	**0.42**	
Industrial combustion	18.5	0.49	0.19	2.75	**0.03**	0.03	0.14	0.01	**0.01**	0.05	0.14	0.19	**0.77**	
Industrial combustion, pulp and paper	40.5	0.77	0.01	6.03	**0.15**	0.18	0.22	0.002	**0.003**	0.003	1.21	1.45	**1.69**	
Commercial/institutional/farming	5.02	0.75	0.35	0.67	**0.24**	0.20	0.21	0.11	**0.09**	0.10	0.22	0.17	**0.19**	alternative EFs and BC shares from IIASA and GB
			0.39	0.70	**0.24**	0.20	0.21	0.12	**0.10**	0.11	0.45	0.36	**0.39**	
Residential small scale	43.7	5.19	5.90	32.32	**1.95**	1.64	0.83	2.22	**1.86**	0.94	12.15	10.18	**5.17**	Implied EF for total 1A4b for Sweden. Different EFs from IIASA and GB
			4.89	20.53	**1.68**	0.61	0.52	1.58	**0.57**	0.49	6.63	2.40	**2.05**	
			1.62	16.16		1.64	0.83	0.61	**0.51**	0.26	6.08	5.09	**2.59**	
Mobile diesel combustion														
RT* Heavy duty vehicles	73.8	0.97	1.55	1.65	**0.48**	0.63	0.68	0.77	**1.01**	1.09	0.82	1.08	**1.16**	EURO III as average
RT Light duty vehicles	16.5	0.58	0.69	0.60	**0.37**	0.41	0.47	0.43	**0.48**	0.55	0.38	0.42	**0.48**	EURO 2 as average
RT Passenger Car	17.4	0.38	0.48	0.46	**0.24**	0.28	0.33	0.30	**0.35**	0.41	0.29	0.33	**0.39**	EURO 3 as average
Railways	0.89	0.09	0.09	0.03	**0.04**	0.04	0.06	0.04	**0.04**	0.06	0.01	0.01	**0.02**	
Forestry	4.71	0.11	0.00	0.11										
Navigation/shipping	6.01	0.11	0.15	0.20	**0.05**	0.05	0.04	0.06	**0.06**	0.05	0.08	0.08	**0.06**	Fisheries, domestic military navigation
Off-road vehicles and machinery	22.2	0.83	1.67	1.10	**0.40**	0.40	0.52	0.81	**0.81**	1.05	0.54	0.54	**0.70**	BC-share GB 0.63 average of 0.62 and 0.65
Farming\Households	10.2	0.43	0.85	0.42	**0.21**	0.18	0.25	0.42	**0.35**	0.48	0.21	0.17	**0.24**	Sum of non-road

Table 3-2 Emission factors for $PM_{2.5}$ and BC-shares used to calculate results in Table 3-1.

	EF for $PM_{2.5}$						BC shares				
Stationary biomass combustion	**SWE**	**IIASA**	**GB**	**GB interval**			**SWE**	**IIASA**	**GB**	**GB interval**	
Power plants	24.5	8.4	133	66	266		0.2	0.254	0.033	0.016	0.066
Industrial combustion	28.0	10.2	149	50	240		0.052	0.07	0.28	0.11	0.39
Industrial comb., pulp and paper	19.2	0.3	149	50	240		0.2	0.24	0.28	0.11	0.39
Commercial/institutional/farming	150	69	133	66	266		0.323	0.26	0.28	0.11	0.39
		77	140	70	279						
Residential small scale	118.9	135	740	370	1480		0.376	0.315	0.16	0.05	0.3
		112	470	235	940		0.323	0.117	0.1	0.02	0.2
		37	370	285	740			0.315	0.16	0.05	0.3
Mobile diesel combustion											
RT* Heavy duty vehicles	13.2	21.0	22.4	14.5	37.4		0.495	0.653	0.7	5-20%	
RT Light duty vehicles	35.4	41.7	36.2	26.2	71.2		0.631	0.698	0.8	5-20%	
RT Passenger Car	22.0	27.6	26.2	19.1	62.9		0.631	0.721	0.85	5-20%	
Railways	95.7	96.4	32.6				0.456	0.456	0.65	0.2	
Forestry	23.6		23.2	13.6	88.8						
Navigation/shipping	18.8	25.7	33.3				0.411	0.411	0.31		
Off-road vehicles and machinery	37.1	74.9	49.7	22.8	102.6		0.489	0.489	0.63	0.75	
Farming\Households	42.7	83.7	41.4	13.8	89.4		0.489	0.411	0.57	0.75	