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Swedish air pollutant emission scenarios to 2050

CLEO project report

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Summary

This study has been part of the CLEO (Climate Change and Environmental Objectives) research program funded by the Swedish Environmental Protection Agency. The main aim of the study was to assess influences on air pollutant emissions (mainly particulate matter, PM) by increased substitution of fossil fuels with biomass fuels for combustion in 2050, by analyzing various emission scenarios. Based on scenarios from the CLEO project Strategies for future forest management an analysis if future increase in biomass fuel demand could be met by domestically harvested forest biomass output is also made. The emission scenarios in this study are based on scenarios for fuel consumption developed during the Swedish Roadmap 2050 project and from the IEA NETP Carbon-Neutral high Bioenergy Scenario, in combination with Swedish national emission factors and emission factors corresponding to Best Available Technology. In addition, emission data from EU Commission baseline projection has been used.

Generally, the results in this study show that PM emissions 2007-2030 decrease significantly in all scenarios due to an expected reduction in the domestic transport sector. Moreover, this study indicates that PM emission trends 2030-2050 largely will depend on the end use sector, the combustion and emission abatement technology, and the type and quality of biomass used in Sweden. In particular, this applies to the small scale combustion sector. However, the level of PM2.5 emissions estimated for Sweden from this sector are uncertain - largely related to the emission measurement method used to derive the Swedish national EFs and the lack of sufficiently detailed knowledge of the type and extent of use of existing small scale combustion appliances in Sweden.

The analysis made in this study indicates that there is a theoretical potential to fulfill most of the needs at a high biomass use scenario by increased harvesting of biomass in Sweden by 2050.

Sammanfattning

Denna rapport beskriver resultaten av ett delprojekt inom forskningsprogrammet CLEO (Climate Change and Environmental Objectives), finansierat av Naturvårdsverket. Projektet syftade till att, genom analys av olika utsläppsscenarier, utvärdera hur utsläpp av luftföroreningar (främst i form av partiklar) påverkas av ökat utbyte av fossila bränslen till förmån för biomassa vid förbränning i Sverige fram till 2050. Dessutom har projektet, baserat på CLEO-projektet *Strategies for future forest management*, undersökt om ett eventuellt behov av ökad användning av biomassa som bränsle i framtiden kan mötas av nationellt uttag av skogsbiomassa.

Utsläppsscenarierna i detta projekt baserades på scenarier över bränsleförbrukning från Naturvårdsverkets Färdplan 2050 samt från IEA NETP Carbon-Neutral high Bioenergy Scenario, kombinerat med nationella emissionsfaktorer och emissionsfaktorer motsvarande Best Available Technology. Dessutom användes emissionsdata från EU-kommissionens baseline-scenario.

Resultaten visar på betydande utsläppsminskningar av partiklar 2007-2030 för alla scenarier till följd av förväntade reduktioner inom transportsektorn. Studien visar även att trenden för partikelutsläpp 2030-2050 till stor del kommer att bero på användarsektor, förbrännings- och reningsteknologi samt typ av och kvalitet på använd biomassa i Sverige. Detta gäller i synnerhet för småskalig förbränning. Beräknade utsläpp av partiklar från småskalig förbränning i Sverige är dock osäkra - främst kopplat till den mätmetod som används för att ta fram de underliggande nationella emissionsfaktorerna samt till bristen på tillräckligt detaljerad kunskap om befintligt bestånd och användning av småskaliga förbränningsanordningar i Sverige.

Analysen gjord i denna studie indikerar på att det finns en teoretisk potential att nationellt uttag av biomassa till stor del skulle kunna tillgodose behoven 2050 även vid antaganden om ökad användning av biomassa för förbränning i Sverige.

1 Introduction

The main objective in the CLEO (Climate Change and Environmental Objectives) research program is to provide scientific support for the assessment of climate change influences on the Swedish environmental objectives related to air pollution, i.e., “Clean Air”, “Natural Acidification Only”, “Zero Eutrophication” and “A Non-Toxic Environment” (mercury only). The Swedish environmental objective “Reduced Climate Impact” is also part of the overarching scope of the research program. The CLEO program includes specific research hypotheses as well as syntheses of available research, related to the selected environmental objectives. An important focus is to highlight the potential synergies and antagonistic effects related to, on the one hand, strategies to reduce climate change and on the other hand to reach environmental targets for air pollution.

Generally, carbon dioxide from biomass combustion is not considered to add net carbon to the atmosphere due to the uptake of carbon in land-use and forest during the biomass regrowth. In Sweden, substituting fossil fuels with biogenic fuels has thus been an approach to reduce the amount of fossil-fuel carbon dioxide emissions. However, biomass burning has a negative impact on air quality and thus human health, in particular due to its large contribution of particle matter emissions ($PM_{2.5}$, soot (black carbon, BC) and organic carbon (OC)). The use of biomass fuels may also have a significant effect on emission levels of other air pollutants of importance for the Swedish environmental objectives, e.g. NO_X, CH_4, NMVOC and Hg. Hence, increasing the use of biomass fuels in order to reduce the carbon added to the atmosphere may lead to a conflict of interests between the two Swedish environmental objectives, “Clean Air” and ”Reduced Climate Impact”.

In the Swedish Roadmap 2050 (in Swedish: Färdplan 2050), the Swedish Environmental Protection Agency (EPA), together with several other Governmental agencies laid down pathways to reach a society with no net emissions of greenhouse gases (GHG) 2050 (Swedish EPA, 2012). In its reference scenario, the Swedish EPA envisions that the target will be met partly through national reductions of emissions, but also via increased carbon storage in land and forest as well as underground sequestration techniques (carbon capture and storage, CCS). In addition, Sweden aims to continue using the various international emission trading mechanisms. Thus, despite efforts to reduce the greenhouse gas emissions in Sweden set out in the reference scenario there will likely still be significant amounts of carbon dioxide from fossil fuels emitted in 2050. The use of biomass fuels as a substitute for fossil fuels does not play a significant role in the reference scenario – the amount of biomass used for energy purposes is expected to rise slightly to 2020 and then level off (see Figure 1 below (left graph)). In order to reach a more carbon-neutral society one would need to look at alternative scenarios. In this study we have investigated the effects on emissions on several air pollutants from an increased use of biomass fuels as a substitute for fossil fuels for combustion in the Swedish energy system.

Globally, the production capacity of biomass feedstock (e.g. timber, crops, etc.) is limited. The competition for land areas hardens and the economic aspects of choosing between different commodities have, so far, on a large scale, tended to outweigh other aspects e.g. environmental and social concerns. It is thus important to take into consideration the origin of the biomass used for energy purposes. In Sweden, the majority of biomass consumption stems from domestically produced commodities, e.g. by-products from the paper and pulp industry is used for power and heat production. However, the increased use of liquid biofuels for transport in Sweden in the recent decade has led to higher demand for imported biomass.

Sweden is a vast country with a low population density. Large land areas are covered by forest and the potential to produce various biomass commodities is significant. In CLEO project *Strategies for future* *forest management*, three scenarios on harvested biomass output in Sweden 2050 have been developed that can be used to assess the potential of future domestic biomass availability.

1.1 Current national official estimated emissions and emission projections

Sweden annually reports emission inventories for CH_4 (and other GHG) to the UNFCCC and EU and projected GHG emissions to the EU (up to 2050). In addition, Sweden reports annual emission inventories and projections (up to 2030) for a wide range of air pollutants, $PM_{2.5}$, PM_{10}, NO_X, NMVOC, SO_2 and NH_3, to the Convention on Long-range Transboundary Air Pollution (CLRTAP). In the revised Gothenburg protocol (UNECE, 2013) and the revised guidelines for reporting emissions and projections under the CLRTAP (UNECE, 2014), reporting of black carbon (BC) emissions are included on a voluntary basis. Hence, there is a need for improved information on historic and projected BC emissions in terms of national emission inventories. At present, there are no official Swedish emission inventories available for BC. However, a preliminary annual Swedish BC emission inventory 2000-2012, based on default emission factors from EMEP/EEA Guidebook (2013), is in preparation (Skårman et al., 2014).

For projections of emissions from fuel combustion, the latest national official Swedish submission was done in the spring of 2013 and was based on underlying activity data from the Swedish Roadmap 2050 (Roadmap2050) and national emission factors (EFs), using 2007 as the base year. Below, projected fuel consumption and projected emissions of $PM_{2.5}$, NO_X, NMVOC, CH_4, and Hg are presented in Figure 1 to Figure 6 by main sectors: power and heat production, industry, domestic transport, small scale combustion, international transport and "other".

Regarding national total fuel consumption (fossil and biomass fuels aggregated) 2007-2050, domestic transport is the largest sector in terms of fuel consumption, followed by industry (Figure 1). It is obvious that overall only minor changes in fuel consumption over time are assumed in Roadmap2050, leading to a slight increase in total fuel used in 2050 compared to 2007. The increase in projected fuel use mainly stems from the transport sectors.

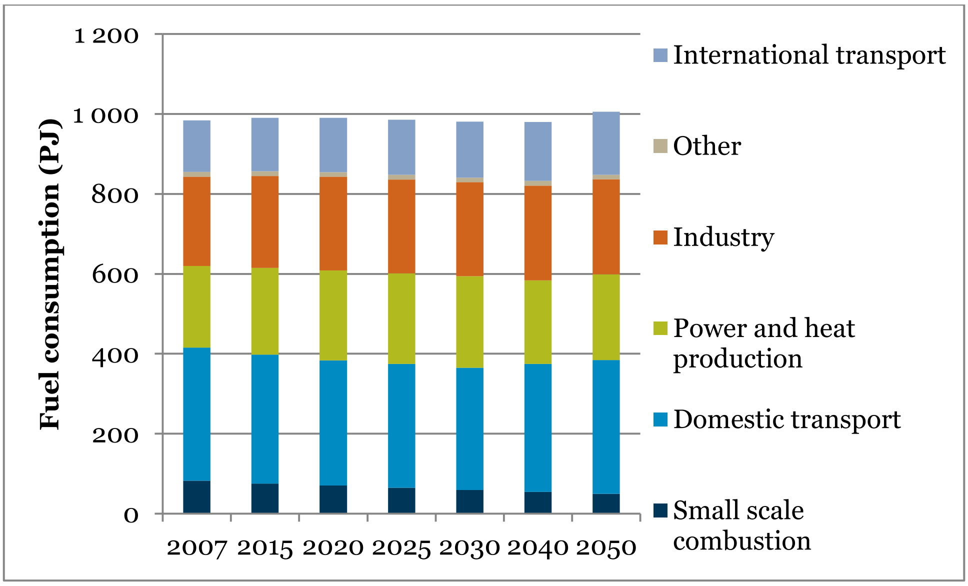


Figure 1. Swedish total fuel consumption (PJ) 2007-2050 based on Roadmap2050.

In Figure 2 below historic $PM_{2.5}$ emissions for 2007 and projected $PM_{2.5}$ emissions 2015, 2020, 2025 and 2030 for all Swedish sources, both from combustion related and other sources are presented. In 2007, international transport accounted for the largest $PM_{2.5}$ emission source (9 kton), followed by "other" (8 kton), small scale combustion (6 kton), tyre and brake wear and road abrasion (5 kton), and domestic transport (4 kton). $PM_{2.5}$ emissions in sector "other" mainly stem from processes in the pulp and paper industry and the iron and steel production industry and are thus not mainly related to fuel combustion activities. $PM_{2.5}$ emissions are expected to decrease up to 2030, mainly due to reductions in international transport, "other" and domestic transport. In contrast, $PM_{2.5}$ emissions are assumed to increase from tyre and brake wear and road abrasion due to increased traffic load.

Historic NO_X emissions for 2007 and projected NO_X emissions 2015, 2020, 2025 and 2030 are presented in Figure 3. It can be seen that domestic and international transports are the dominating sources of NO_X emissions and that significant reductions are expected up to 2030. For NMVOC emissions 2007-2030, the main source is solvents and other product use (included under "other") and domestic transport (see Figure 4). Emissions of CH_4 from combustion of fuels are relatively small 2007-2050 (see Figure 5). Instead the main sources of CH_4 emissions are agriculture and waste sectors (included under "other"). CH_4 from small scale combustion (mainly from biomass combustion) is the second largest sector in this aggregation. Historic Hg emissions 1990-2012 are presented in Figure 6. It can be seen that the largest contributor to Hg emissions stem from non-fuel related activities included in "other" (in this case iron and steel production processes, cremation and chemical industry processes). Power and heat production is the second largest contributor of Hg emissions.

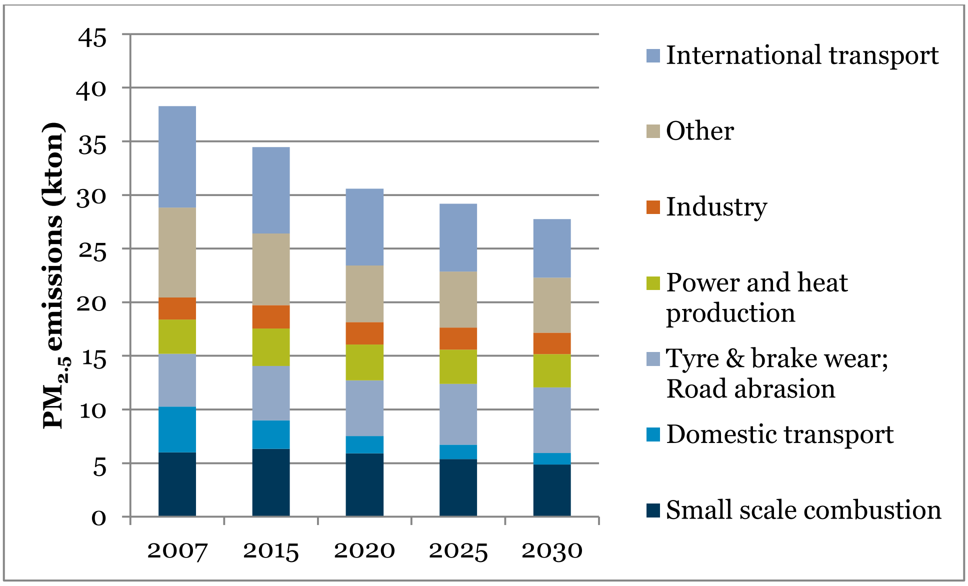


Figure 2. Estimated official Swedish $PM_{2.5}$ emissions by sector and year; historic (2007) and projected (2015, 2020, 2025 and 2030)

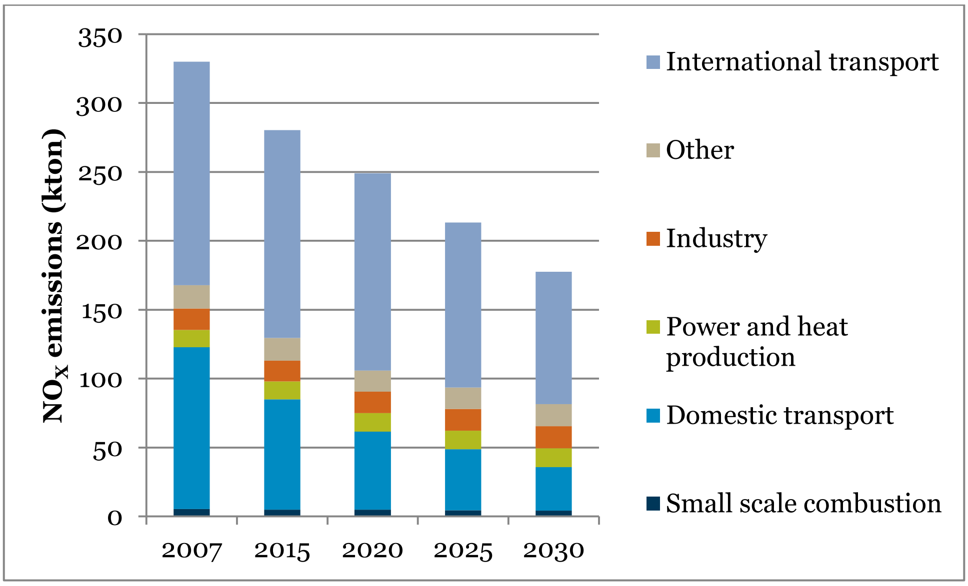


Figure 3. Estimated official Swedish NO_X emissions by sector and year; historic (2007) and projected (2015, 2020, 2025 and 2030)

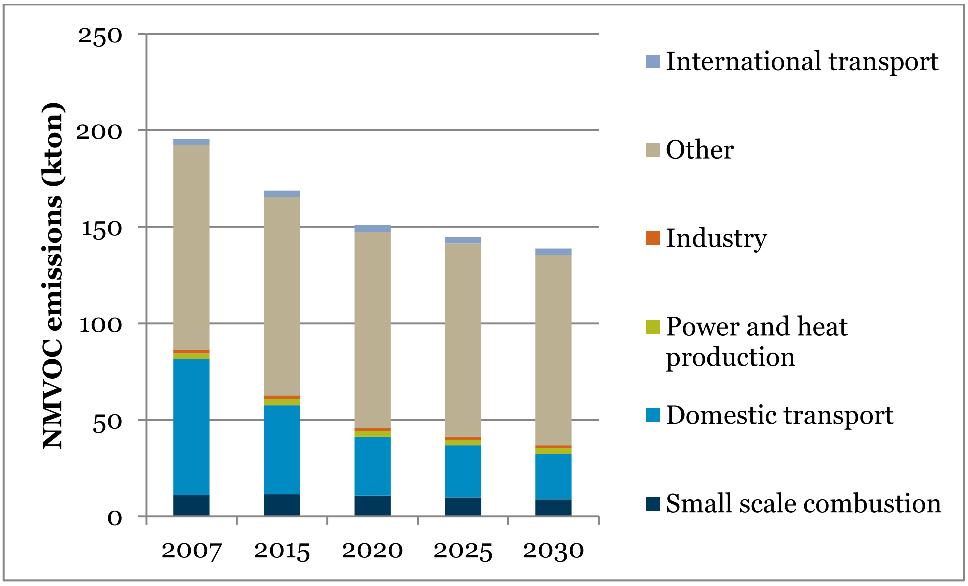


Figure 4. Estimated official Swedish NMVOC emissions by sector and year; historic (2007) and projected (2015, 2020, 2025 and 2030)

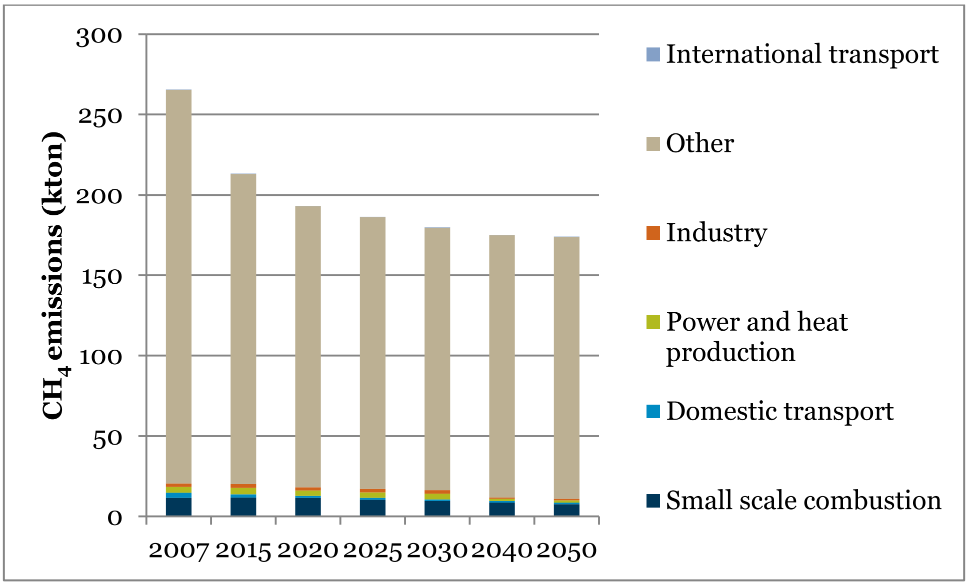


Figure 5. Estimated official Swedish CH_4 emissions by sector and year; historic (2007) and projected (2015, 2020, 2025, 2030, 2040 and 2050)

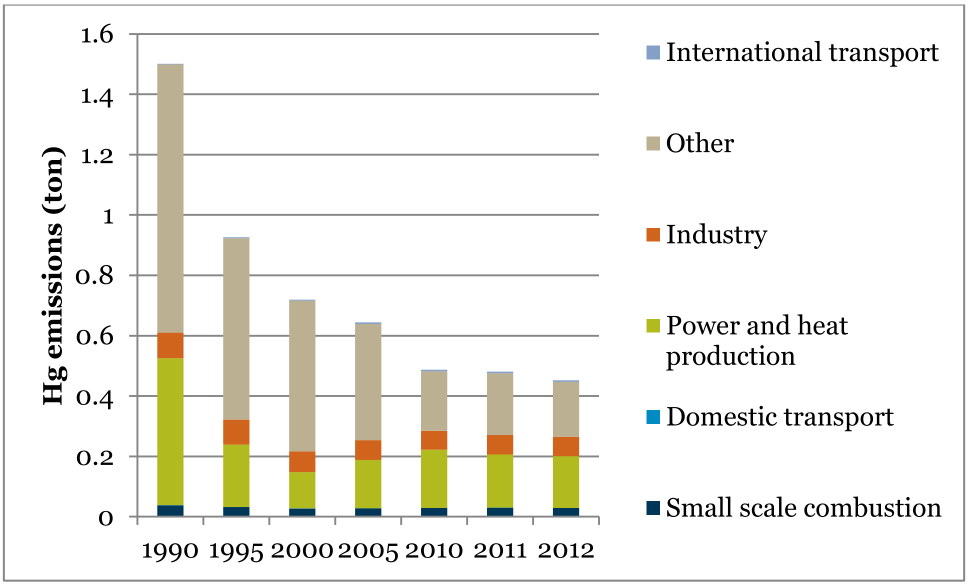


Figure 6. Estimated official Swedish Hg emissions by sector and historic year. No national Hg emission projections are available in Sweden.

The contribution to national total emissions (excluding international transport) from total biomass fuel combustion varies depending on air pollutant. From Figure 7 it can be seen that emissions from biomass combustion 2012 contributes significantly mainly to the national total emissions of $PM_{2.5}$ (and thus probably BC and OC), and to some extent Hg and NO_X. In 2012, combustion of biomass fuels accounted for about 42% of national total emissions of $PM_{2.5}$ in Sweden (Figure 7). (Estimations are based on data from the Swedish EPA, 2014).

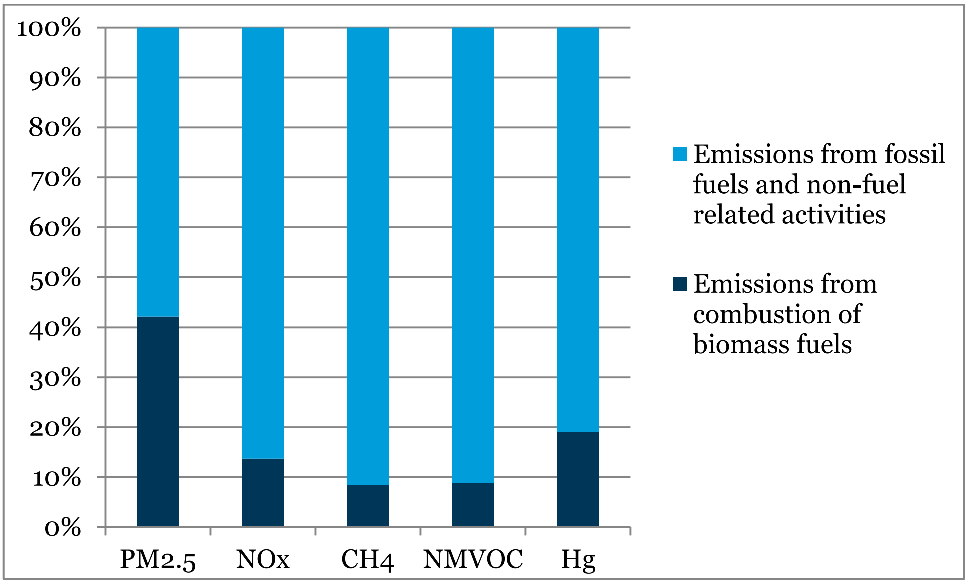


Figure 7. Share of national total emissions 2012 (excluding international transport) from combustion of fossil fuels and non-fuel related activities (light blue bars) and combustion of biomass fuels (dark blue bars).

1.2 Aim of study

The aim of this study is to assess influences on air pollutant emissions (in particular particulate matter ($PM_{2.5}$, BC and OC) emissions, but also NO_X, CH_4, NMVOC and Hg emissions by increased substitution of fossil fuels with biomass fuels for combustion in 2050. The study also illustrates how increased use of biomass for combustion may have different effects on the emissions depending on use sector and combustion technology. In addition, this study theoretically assesses the potential for covering the assumed increased demand for biomass for energy use in Sweden 2050 by domestically harvested biomass, based on the output scenarios of *CLEO* project *Strategies for future forest management*.

1.3 Research methods and limitations

In this study, three system models are used; the Swedish Roadmap 2050 reference scenario (Swedish EPA, 2012), the IEA Nordic Energy Technology Perspectives (NETP) (IEA, 2013) and the European Commission baseline scenario (European Commission, 2013). They are described in more detail in the next chapter (Scenario descriptions and assumptions). The models are more or less based on the same energy system input (i.e. energy statistics and projections from the Swedish Energy Agency) but reach various outputs due to different assumptions and definitions (for example Åström et al 2013 describes some of the difference between the Swedish Roadmap 2050 reference scenario and EU commission baseline).

In this study, emission scenarios for the air pollutants up to 2050 are estimated based on underlying activity data (AD) on fuel used for combustion from Swedish Roadmap 2050 reference scenario (Roadmap2050) and Swedish emission factors (EFs) used in the latest emission projections submitted to CLRTAP (Swedish EPA, 2013), where 2007 was used as base year. As the Swedish EF projections are only available up to 2030, EFs for 2040 and 2050 were extrapolated in this project. This assumption could in some cases lead to overestimation of emissions 2040 and 2050.

In order to assess how air pollutant emissions may be affected by an increased use of biomass for energy purposes, a number of emission scenarios are developed and analyzed, based on energy statistics from the IEA NETP Carbon-Neutral high Biomass Scenario (CNBS).

To be able to evaluate the impact of improved emission abatement technology for particles, information on best available technology (BAT) is applied to the energy scenarios.

In addition, EFs up to 2030 for Sweden from the European Commission (2013) is used to further broaden the scenario aspects. The EU Commission baseline EFs for 2040 and 2050 are estimated by extrapolation of the 2030 values. This assumption could lead to overestimation of emissions. The emissions for Sweden calculated in the EU Baseline are also included as a comparison to the estimated emission scenarios presented in this report.

BC and OC emission inventories have not yet been officially estimated and reported from Sweden, and thus information on EFs from EU commission baseline on their fraction of $PM_{2.5}$ was applied in this study. Emissions of BC from small scale combustion are however estimated applying detailed information on BC fractions of $PM_{2.5}$ by type of combustion appliance from the EMEP/EEA air pollutant emission inventory guidebook (EEA, 2013).

Estimated air pollutant emission scenarios in this study are presented with a similar sector aggregation as used in CLRTAP (UNECE, 2014); power and heat production, industry, domestic transport (including non-road mobile machinery (NRMM)), small scale combustion, and international transport. Note that emission inventories and projections reported to CLRTAP follow the Nomenclature For Reporting (NFR). That means that emissions from international and domestic LTO (Landing and Take-Off) stages are included in domestic transports whereas emissions from international and domestic cruise stages are included in international transport. For navigation, fuel consumption is based on statistics on fuel sold in Sweden. Fuel used for traffic between Swedish harbors is categorized as domestic navigation and fuel sold to ships, regardless of national flag, with destination abroad falls under international navigation. In addition, fuels are aggregated and presented by main fuel type: biomass, coal, gas, oil and waste. Note that coal also comprises derived energy gases (e.g. coke oven gas) and peat whereas gas only includes natural gas.

Off-road mobile machinery comprises all types of non-road vehicles and machinery regardless of where they are being used (e.g. industry, household, etc), and small scale combustion includes local heating of commercial and institutional premises, residential houses and agricultural premises.

In NFR- nomenclature, emissions from industries are split on energy- and process-related emissions. However, in this study we only take into account the fuel used for combustion in the Swedish energy system. Other use of fuels, for various industrial processes and non-energy use, is thus not within the scope of this study. For example, this means that the use of black liquor (biomass) is excluded from this study as black liquor is defined as non-energy use of fuels in the Swedish reporting to the CLRTAP. In IEA NETP-CNBS, the use of black liquor is included as biomass in the energy sector and its data is needed to be calibrated for before application in this study.

Furthermore, in this study, the harvested biomass output in CLEO project *Strategies for future forest management* is analyzed. The future potential domestic production of biomass for energy purposes from other sources e.g. agricultural crops and residues, and algae, are not included.

In order to make as comprehensive assessments as possible on the impact of high biomass use for energy purposes on emission levels one should apply a system model that covers all aspects from the origin of the biomass production to the level of emission abatement technology. Ideally, the model would be able to take into account all significant variables and parameters that could influence the emission output from the theoretic, economic, technical, political and sustainable material resource point of views (e.g. fuel type, import, export, production, policies and measures, prices, taxes, emission abatement technology, biodiversity, etc.). Due to limitations in the energy models used in this study, to a large extent, the social-political and sustainable implementation aspects are not taken into consideration. In terms of the assessment of future domestic biomass fuel production and availability, this study is mainly an analysis of the level of the theoretical potential.

2 Underlying scenarios and assumptions

2.1 Activity data scenarios

2.1.1 Roadmap 2050: Reference scenario

In the UNFCCC negotiations in Cancun 2010, industrialized countries agreed to develop national long-term strategies to reduce human-generated greenhouse gas emissions over time. EU has presented a roadmap for moving to a low-carbon economy 2050 (European Commission, 2011). It states that EU should reduce its GHG emissions by 80 per cent to 2050. In 2011, the Swedish Government gave the Swedish EPA the assignment to develop a Swedish Roadmap 2050, aiming at a society with no net GHG emissions (Swedish EPA, 2012). The project was carried out in close cooperation with several Swedish governmental agencies (e.g. Swedish Energy Agency, Swedish Transport Administration, Swedish Transport Agency, Swedish Board of Agriculture, and Swedish Forest Agency) and reported to the Swedish Government in December 2012. The agencies provided background information and underlying data for an emission projection (i.e. reference scenario) and various alternative scenarios. The scenarios included possible sector-specific policies and measures. The reference scenario shows that in order to reach the no-net-GHG-emission target, the development and use of large scale carbon capture and storage (CCS) is a necessity for Sweden, since eliminating GHG emissions will be a challenge in especially transport, industry and agricultural sectors.

More information on underlying data, assumptions and models used can be found in the various governmental agencies' background reports to the Swedish Roadmap 2050.

In this study, underlying energy statistics from the Swedish Roadmap 2050 reference scenario (Roadmap2050) is used.

In Roadmap2050, forthcoming international regulations applying to marine shipping were not taken into consideration, as assumptions are made of a more or less constant level of heavy fuel oil (HFO) use up to 2050. The EU Directive (2012/33/EU) and the revised Annex VI of the Protocol of 1997 of the International Convention for the Prevention of Pollution from Ships (MARPOL), sets limits on sulphur contents in marine fuel to (maximum) 0.1 % (by mass) in the Baltic Sea, the North Sea, the English Channel (Sulphur Emission Control Areas (SECAs)), to be implemented from January 1 2015. In addition, a global limit of 0.5 % sulphur in marine fuel will be introduced to 2020. Marine fuels containing higher sulphur contents may be supplied to ships using appropriate emission abatement methods in line with the directive. It is believed that the major part of the marine fuel sold in Sweden 2015 onwards will be low-sulphur marine gas oil (LSMGS) (Trafikanalys, 2013). Hence, the projection of the fuel use in marine navigation presented in Roadmap2050 cannot not be seen as the most likely scenario.

2.1.2 IEA Nordic Energy Technology Perspectives

In the Nordic Energy Technology Perspectives (NETP), the International Energy Agency (IEA) produced a number of pathways for the Nordic countries (Denmark, Finland, Iceland, Norway and Sweden) to reach a carbon neutral energy future (OECD/IEA, 2013). The study describes four energy scenarios to 2050: a) The 2° C Scenario (2DS), with the aim of achieving an 80% chance of limiting the global temperature rise to 2° C, b) The 4° C Scenario (4DS), similar but referring to a global temperature rise to 4° C, c) two Carbon-Neutral Scenarios. The Carbon-Neutral Scenarios are the most ambitious scenarios aiming at developing an energy system that, by 2050, produces no net greenhouse gas (GHG) emissions. This could be reached by either increased electrification and grid integration (throughout the Nordic region, and with Central European grids) (CNES), or higher use of bioenergy (CNBS – Carbon-Neutral high Bioenergy Scenario). The latter alternative has been used in this study as the scenario for high bioenergy use in Sweden 2050. The different scenarios are presented on the main sectors: power and heat production, industry, transport and small scale combustion. Non-road mobile machinery (NRMM) is not specified as a separate sector but included in the transport sector.

IEA has developed the energy scenarios using the ETP (Energy Technology Perspectives) model which combines analysis of energy supply and demand (OECD/IEA, 2013). The model supports the integration and manipulation of data from four soft-linked models (energy conversion: ETP-TIMES, industry: stock accounting modelling, transport: a Nordic variant of the mobility model (MoMo), buildings: stock accounting modelling). The ETP model works in five-year time steps and is the most comprehensive, up to date, scenario modelling of the Swedish energy system and it is based on official energy statistics projections from the Swedish Energy Agency (similar basis as in Roadmap2050). The NETP was a collaborative project between the IEA, Nordic Energy Research and leading Nordic institutes (for Sweden: Profu, IVL Swedish Environmental Research Institute, Luleå University of Technology, Chalmers University and KTH).

In order to satisfy a high demand on biomass, the NETP-CNBS makes optimistic assumptions on high availability and compatible prices and costs of biomass fuels.

In this study, NETP-CNBS data for Sweden has been derived from IEA (Koerner, 2013). IEA uses 2010 as base year for its scenarios. Note that 2010 in Sweden had extreme weather conditions – low precipitation and cold winters – resulting in significantly higher energy use compared to preceding and succeeding years. This makes 2010 unsuitable as base year for emission projections. In addition, there are differences in definition and categorization of plants and fuels between the Roadmap2050 and NETP-CNBS leading to significant problems to compare the two datasets. This means that for several sectors the NETP-CNBS data could not be used without adaptation. Thus for power and heat production fuel consumption trends are applied instead of the absolute values. For the industry sector information on specific energy efficiency and other measures presented in IEA (2013) are applied to Roadmap2050 data.

For small scale combustion the fuel use scenarios in Roadmap2050 and in NETP-CNBS the commercial, residential and agriculture/forestry/fishing sub-sectors are specified. In the NETP scenario, a “non-specified other” source is grouped with agriculture/fishing, which makes a straightforward comparison impossible since it is unclear what “non-specified other” covers. As far as the fuels are concerned, in Roadmap2050 biomass fuels are treated separately, while in the NETP scenarios, the fuel is defined as “biomass and waste”, which introduces another uncertainty. The scenarios are thus not directly comparable since in the NETP CNBS scenario covers also the “non-specified other” source, and the fuel does not only cover biomass but also waste. As a result of this and in order to achieve better comparability, only the residential and commercial combustion sectors are used in the scenarios for the of small scale combustion sector.

For transport the NETP-CNBS absolute values could be applied.

An overview of the NETP-CNBS activity data sources and assumptions applied in this study is presented in Table 1.

To take into account the EU directive on sulphur limits in marine fuels (Directive 2012/33/EU), in this study HFO use in NETP-CNBS is assumed to be reduced by 90% of the 2007 level from 2020 onwards (2015 value is interpolated 2007-2020).

Table 1. Overview of NETP-CNBS activity data sources and assumptions on energy use 2050 applied in this study

Sector	Subsector	Activity data source	NETP-CNBS assumptions 2050
Power and heat production		NETP-CNBS trends on Roadmap2050	100% biomass and waste fuels
Industry	Cement	Roadmap2050	50% biomass fuels
Industry	Chemicals and petrochemicals	Roadmap2050	10% energy use reduction compared to 2010. 6% bio-based feedstock in 2050.
Transport	NRMM	NETP-CNBS	100% biofuels (allocation of data based on Roadmap2050)
Transport	Aviation	NETP-CNBS	100% biofuels
Transport	Road transportation	NETP-CNBS	100% biofuels and gas
Transport	Navigation	NETP-CNBS	100% biofuels. 90% phase out of HFO by 2020.
Small scale combustion	Residential and commercial stationary combustion	NETP-CNBS	82% biomass

NETP-CNBS data is presented in Appendix A. In Table A 1 it can be seen that 130 PJ fossil fuels (excluding waste) remains in 2050 compared to 857 PJ in 2010. In order to reach a net-carbon neutral target, NETP-CNBS assumes that the remaining CO_2 emissions from fossil fuels are reduced via CCS. In addition, in NETP-CNBS it is assumed that the net import of biomass 2050 is 159 PJ. This constitutes about 19 % of the modelled total primary supply of biomass and waste. Furthermore, in 2050, in addition to a switch from the use of fossil to biomass fuels, there will be significant net export of electricity (133 PJ) and use of other renewables (such as wind and solar energy) (189 PJ).

2.1.2.1 Alternative NETP-CNBS scenario: Solid biomass replacing waste in power and heat production

Waste is used extensively as fuel in power and heat production in Sweden. As waste as fuel is presented together with biomass in NETP-CNBS, in this study, we have developed two scenarios; one where waste continuously is used as fuel in power and heat production and an alternative scenario where, starting at 2030, the waste is replaced by solid biomass by 2050.

2.2 Emission factor scenarios

All emission factors (EFs) used in this study are presented in Appendix B to this report.

2.2.1 Swedish national emission factors

During the development of emission projections reporting to CLRTAP in 2013, national emission factors (EFs) to 2030 for several air pollutants were developed (Gustafsson et al, 2013). In this study the same EFs are applied.

For stationary combustion, EFs for 2040 and 2050 are in this study estimated by extrapolation of the 2030 values. This assumption may lead to slight overestimations of emissions for sources where further decreases due to improved emission abetment technologies could be expected after 2030. However, it has not been possible to take such possible changes into account within the scope of this study. Additionally, during the course of this study, a quick review of information on $PM_{2.5}$ emission rates (i.e. implied emission factors) in plant-specific legal annual environmental reports from several large power and heat production plants in Sweden, indicate that the Swedish national EFs used in the most recent historic years (e.g. 2005 onwards) may be overestimated. However, more in-depth analyses are needed to determine the magnitude of such overestimation. Consequently, this implies caution when analyzing the $PM_{2.5}$ emission scenarios for these sources based on Swedish national EFs (SW) in this study.

For road transportation, fuel consumption and emission data from the Swedish Transport Administration for 2050 were available (produced during the Swedish Roadmap 2050 project). According to Swedish Transport Administration (Magnus Lindgren, personal communication, November 2013) the type of fuel used for combustion in road vehicles will not influence the emission levels as much as the vehicle European emission standards. This means that the current emission scenarios will not significantly be affected by a larger share of biofuels compared to the reference projections. For remaining mobile sources (air, marine, railways and NRMM), a review of previously projected EFs was made to estimate the 2050 factors (Fridell, 2014). Only minor changes in EFs over time were introduced after 2030, i.e. assumptions were made that for most pollutants and combustion technologies, any new abatement technology will already be implemented by 2030 (see Table B 6 to Table B 10). Also for NRMM, the assumption has been made that biofuels generate the same emissions per energy input as fossil fuels (i.e. the same EFs are applied).

For small scale combustion, the emission factors used are from the Swedish national projections, which are available up to 2030. For the time period 2035-2050 the emission factors were extrapolated (Table B 1211) in Appendix B for NMVOC, CH_4, NO_X and Hg) with the same factors as for 2030. This assumption may lead to an overestimation of emissions if further technological development for reduced emissions occurs.

All emission factors used in this study can be found in Appendix B to this report. (Revised EFs compared to Roadmap2050 are found in red.)

2.2.2 Emission factors from the EMEP/EEA Guidebook 2013

EMEP/EEA Air Pollutant Emission Inventory Guidebook 2013 (EEA, 2013) contains comprehensive information and technical guidance on methodologies and emission factors (EFs) to prepare air pollution inventories for reporting to the UNECE Convention on Long-range Transboundary Air Pollution (CLRTAP) and the EU National Emission Ceilings Directive. It contains different levels of detailed descriptions (Tiers) depending on sector and technology. In this study, information on Best Available Techniques (BAT) has been applied on large scale combustion and small scale combustion. For large combustion plants, BAT EFs for TSP (total suspended particles) are provided in the Guidebook 2013. As no specific information on BAT for $PM_{2.5}$ is available in Guidebook 2013 the BAT EFs for TSP has thus been applied for $PM_{2.5}$ in this study. This assumption may lead to overestimation of $PM_{2.5}$ emissions, but it is not likely to be of significant relevance to the outcome of this study. For large scale combustion BAT includes cyclone separators, fabric filters, wet scrubbers, electrostatic precipitators (ESP). In small scale combustion, BAT equals the assumption to use only pellets boilers and stoves. Furthermore, we have assumed that BAT is fully implemented in 2050 and that EFs for intermediate year from 2030 (2020 in the small scale combustion sector) are estimated through linear interpolation.

2.2.3 EU commission baseline scenario

The EU Commission emission baseline scenario is described below (see Emission). In this study, its activity data and emissions up to 2030 are used to derive implied emission factors (IEFs). For 2040 and 2050 the IEFs were extrapolated with the same factors as for 2030. This assumption may lead to slight overestimations of emissions for sources where further decrease in emission due to improved abetment technologies is expected after 2030. The IEFs are applied to activity data scenarios based on Roadmap2050 and NETP-CNBS.

2.3 Emission scenarios

2.3.1 EU Commission baseline scenario

The EU Clean Air Policy Package[1] was adopted 18/12 2013. Background information for the package was developed as a "baseline" scenario, or option 1, in the Impact Assessment (European Commission, 2013). Option 1 is defined as "No additional EU action", which means that no new EU policies are envisaged. For the Impact assessment, calculations of emissions were made with the GAINS model for all individual European countries for the years 2000-2030 in 5 year intervals. It includes effects of current legislation and assumes that for 2025 and 2030 the cost-effective measures have been implemented ("cost-optimal baseline", COB).

In this study, data on fuel consumption and emission of $PM_{2.5}$, BC, OC, NO_X and NMVOC has been extracted for Sweden based on the EU Impact Assessment, TSAP (Thematic Strategy on Air Pollution) September 2013 data set, which in this study is called the EU baseline. As data are only specified in five year intervals through the year 2030, in this study 2010 is assumed to be equal to the Roadmap2050 base year (i.e. 2007).

Based on information from the EU baseline, shares of BC and OC emissions in $PM_{2.5}$ emissions has been applied to the Swedish national EFs to develop BC and OC emission estimates for all sectors except for BC from small scale combustion (where more detailed information from EMEP/EEA Guidebook was used).

3 Emission scenarios developed in this study

In this study we have produced several different emission scenarios, presented in Table 2 below. However, not all scenario combinations are applicable for all air pollutants and all sectors. For all pollutants (except

[1] http://ec.europa.eu/environment/air/clean_air_policy.htm

CH_4[2]), energy scenarios from Roadmap2050 (RM) and NETP-CNBS (CNBS) together with Swedish national EF scenarios (SW) are combined. In addition, emission baseline scenarios from the EU Commission (EU BL) up to 2030 for Sweden were available for all pollutants except Hg. For large combustion plants, BAT EFs from Guidebook 2013 have been applied on $PM_{2.5}$ (and thus BC and OC), as PM emissions are the focus of this study. For small scale combustion, BAT equals the assumption to switch to 100% pellets combustion technologies for boilers and stoves.

Table 2. Emission scenarios included in this study

Emission scenario abbreviation (AD-EF)	Activity data (AD)	Emission factors (EFs), Implied emission factors (IEFs)	Comment
RM-SW	Roadmap2050	Swedish EF projections to 2030. Extrapolation 2040-2050 using EF 2030	
RM-EU BL	Roadmap2050	EU baseline IEF to 2030. Extrapolation 2040-2050 using EF 2030	IEFs derived using emission data and activity data
RM-BAT	Roadmap2050	Swedish EF projections to 2030. Best Available Techniques (BAT) by 2050. Interpolation 2030-2050	Small scale combustion: BAT equals 100% pellets technologies by 2050. Interpolation 2020-2050.
CNBS-SW	NETP-CNBS	Swedish EF projections to 2030. Extrapolation 2040-2050 using EF 2030	
CNBS- EU BL	NETP-CNBS	EU baseline IEF to 2030. Extrapolation 2040-2050 using EF 2030	IEFs derived using emission data and activity data
CNBS- BAT	NETP-CNBS	Swedish EF projections to 2030. Best Available Techniques (BAT) by 2050. Interpolation 2030-2050	Small scale combustion: BAT equals 100% pellets technologies by 2050. Interpolation 2020-2050.
CNBS no waste - SW	NETP-CNBS, no waste alternative scenario	Swedish EF projections to 2030. Extrapolation 2040-2050 using EF 2030	Only relevant for power and heat production sector
CNBS no waste - EU BL	NETP-CNBS, no waste alternative scenario	EU baseline IEF to 2030. Extrapolation 2040-2050 using EF 2030	Only relevant for power and heat production sector
CNBS no waste - BAT	NETP-CNBS, no waste alternative scenario	Swedish EF projections to 2030. Best Available Techniques (BAT) by 2050. Interpolation 2030-2050	Only relevant for power and heat production sector
EU BL – EU BL	EU Baseline	EU Baseline	Emission data 2010-2030

[2] For CH4 emissions, no results are presented here due to the overall minor contribution of CH4 from fuel combustion compared to agriculture and waste sources (however, CH4 emissions from small scale combustion are found in the sector-specific section below)

The emission scenario results are presented below, first as a sum of all domestic sectors (excluding international transport). Following the result on the total level, the main sectors adding up to the total are presented more in depth separately, namely: power and heat production, industry, small scale combustion, domestic transport (including non-road mobile machinery, NRMM) and international transport.

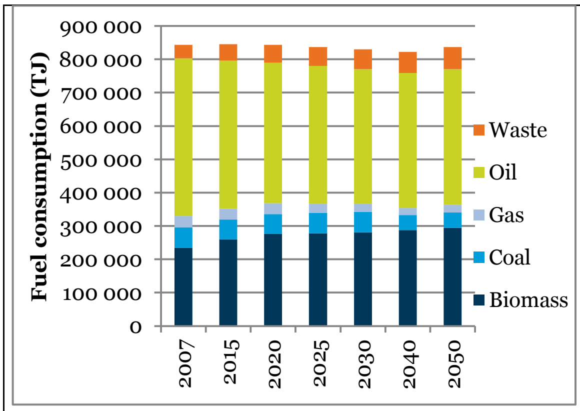
4 Results for Sweden

This section includes the scenario results for the sum of all domestic sources, i.e. international aviation and navigation are excluded.

4.1.1 Fuel consumption for all domestic sectors

Figure 8 below shows total domestic use of fuels for combustion activities in Sweden, presented as fuel consumption (TJ), based on Roadmap2050 (left) and NETP- CNBS (right) scenarios. A number of observations can be made from this figure. It can be seen that fuel consumption for 2007 through 2050 in the Roadmap2050 scenario show a slight decrease (from 843 PJ in 2007 to 837 PJ in 2050), whereas for the NETP-CNBS scenario, there is a significant decrease in fuel use (from 848 PJ in 2007 to 646 PJ in 2050). For 2050, total domestic fuel consumption is estimated to be about 23% lower in NETP-CNBS compared to Roadmap2050. The difference mainly stem from the assumption made in NETP- CNBS of significantly reduced average fuel consumption in the road transportation fleet as well as further development and use of alternative energy sources e.g. wind power and solar energy. It can also be seen that, in 2050, the amount of biomass and its share of total fuel used are assumed to be significantly higher in NETP- CNBS than Roadmap2050 (445 PJ vs 294 PJ and 69% vs 35%, respectively). This is largely due to an almost complete switch from fossil fuels to liquid biofuels in the transport sector (see Figure 9).

For NETP- CNBS, a high share of electrified vehicles are assumed in 2050, further leading to significantly reduced overall fuel consumption for transports, especially for road transportation. In 2050, the use of oil fuels in NETP-CNBS is estimated at 64 PJ and in Roadmap2050 at 407 PJ.



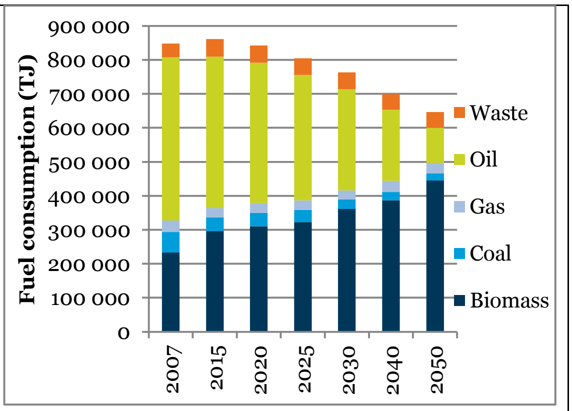


Figure 8. Sum of all domestic sectors' fuel consumption (TJ) by fuel type based on Roadmap2050 (left) and NETP-CNBS (right).

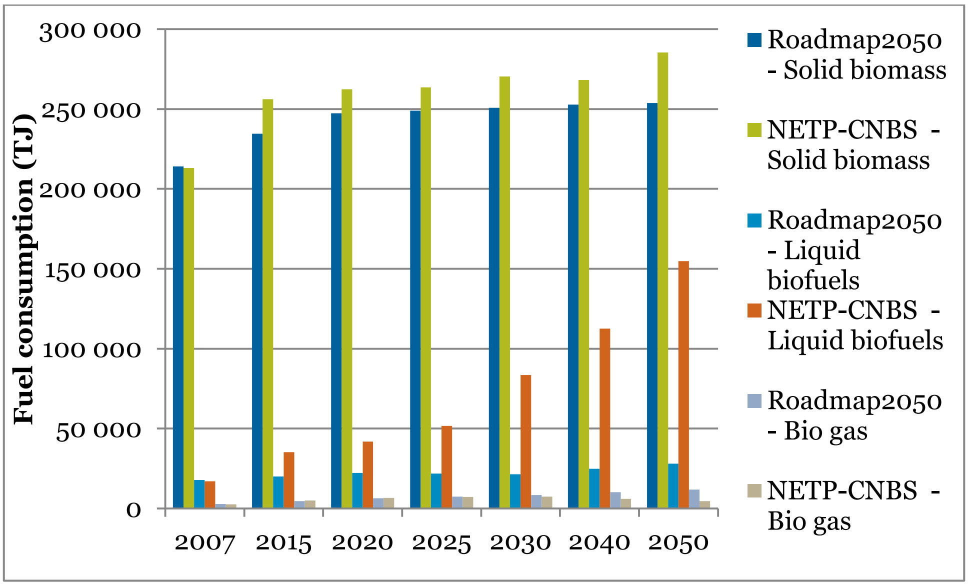


Figure 9. Sum of all domestic sectors' biomass fuel consumption (TJ) by fuel type in Roadmap2050 and NETP-CNBS 2007-2050.

4.1.2 Emissions from all domestic sectors

In Figure 10 to Figure 12 below emissions of different types of particle matter (PM), $PM_{2.5}$, soot (black carbon, BC) and organic carbon (OC), from total domestic fuel combustion based on the various energy and EFs scenarios are presented. Until 2030 the scenarios result in similar emission estimations. All scenarios indicate a downward emission trend from the base year 2007 (2010 for EU baseline) to 2030, mainly due to significant reduction of PM emissions from the domestic transport sector. It is obvious that, despite lower total fuel consumption, the NETP-CNBS energy scenario render higher PM emissions 2050 due to assumptions of higher use of biomass for combustion, unless improved abatement technologies are implemented. Most of the emission increase would occur after 2030 due to the higher replacement rate of fossil fuels to biomass. Moreover, it can be seen that implementation of emission abatement technologies 2050, comparable with BAT, would result in significantly reduced PM emissions.

The wide range of PM emissions 2050 is mainly due to differences associated with the type of small scale combustion technology (for further information on emissions from small scale combustion, see chapter5.3).

In 2050, the largest difference between $PM_{2.5}$ emission scenarios can be found for the CNBS–SW scenario and the RM-BAT scenario; the differences in $PM_{2.5}$ emissions 2020, 2030 and 2050 amount to 0.4, 1.0 and 7.1 kton, respectively.

Furthermore, it is obvious that applying EU baseline (EU BL) IEFs for $PM_{2.5}$, BC and OC on Roadmap2050 or NETP-CNBS activity data generally render lower emissions, mainly affected by significantly lower EU baseline EFs for hard coal and brown coal (peat) in the power and heat production sector.

The differences between EU baseline emission data (EU BL-EU BL) and emissions reported to the CLRTAP (RM-SW) for $PM_{2.5}$, BC and OC are relatively small (<±7%) in 2015, 2020 and 2025, whereas for 2030, the differences increased to 11% (1.2 kton), 17% (0.2 kton) and -10% (-0.2 kton), respectively. It is not within the scope of this study to analyze the underlying reasons for the increased gap between EU baseline and emissions reported to CLRTAP over time, but data suggests that estimated emissions from industry may be the main cause. As the energy-related emissions from industry in relation to the process-related emissions are defined differently in the EU baseline compared to Roadmap2050, we can but to speculate that the differences in underlying allocation methodologies of emissions from industry on energy and industrial processes are the main driver behind the increased gap.

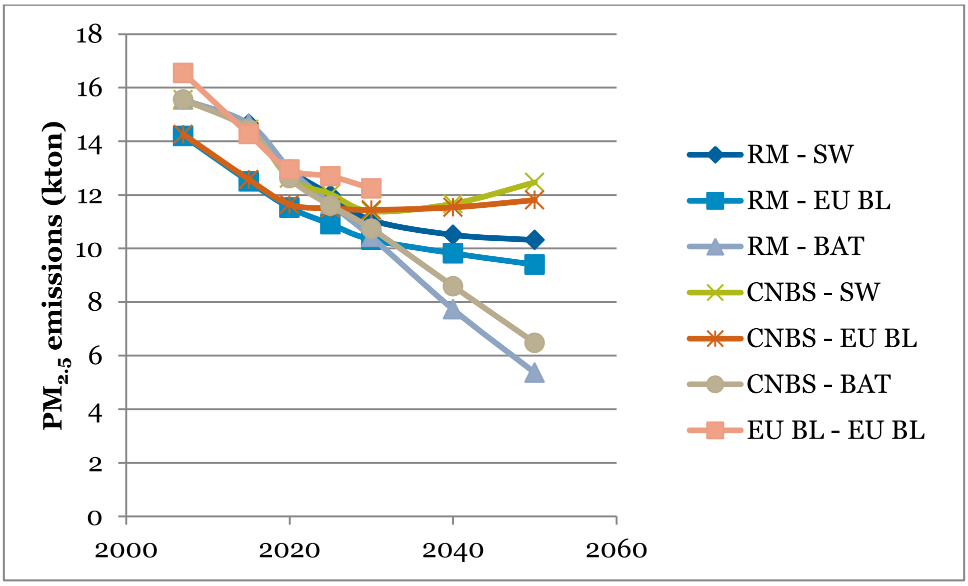


Figure 10. Estimated emissions of $PM_{2.5}$ from all domestic sectors' fuel combustion in the different scenarios.

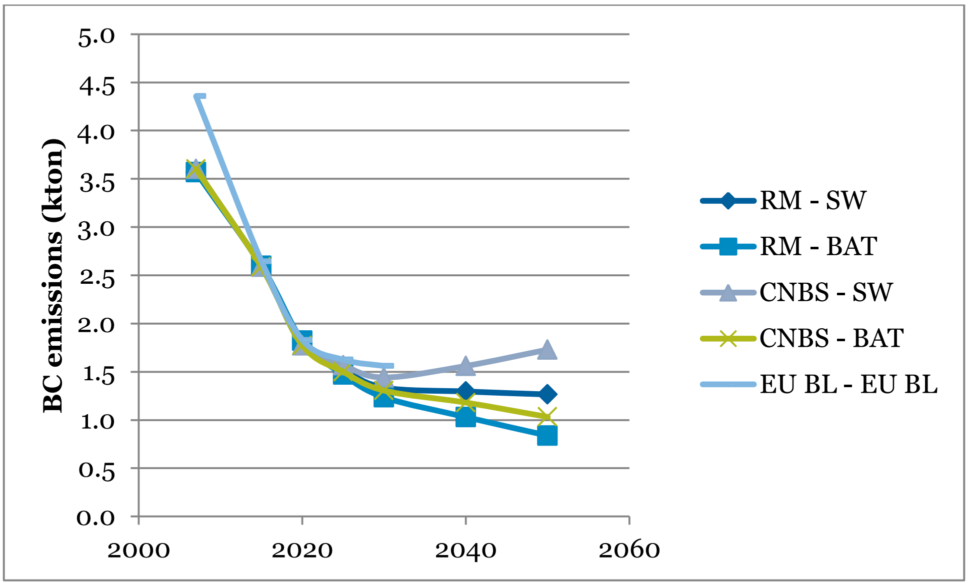


Figure 11. Estimated emissions of BC from all domestic sectors' fuel combustion in the different scenarios.

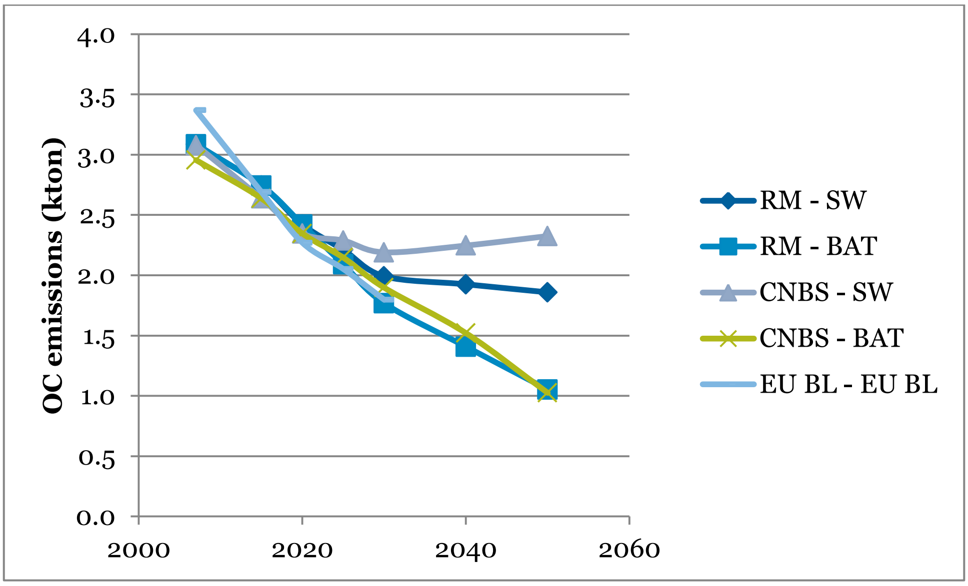


Figure 12. Estimated emissions of OC from all domestic sectors' fuel combustion in the different scenarios.

Below the various scenario results for emissions of NO_X, NMVOC and Hg from the sum of all domestic fuel combustion in Sweden 2007-2050 are presented (Figure 13 to Figure 15).

For NO_X emissions (Figure 13), the NETP-CNBS results in lower emission levels from 2020 onwards compared to Roadmap2050 given the same EFs. The main reason is that NETP-CNBS assume significantly lower fuel use in the transport sector, especially for 2040 and 2050. In addition, EU baseline IEFs render lower NO_X emissions, mainly in industry and transport sectors. EU baseline NO_X emission data are 2% and 6% lower than Roadmap2050 in 2020 and 2030, respectively. Again, mainly due to lower emissions from industry and transport sectors.

The Roadmap2050 and NETP-CNBS scenarios result in similar NMVOC emissions until 2030 (Figure 14). From 2040, the NETP-CNBS scenario render lower NMVOC emissions compared to the Roadmap2050 scenario due to assumptions of lower fuel consumption in transports in NETP-CNBS. NMOVC emissions from EU baseline are significantly higher 2015 onwards compared to the Roadmap2050 and NETP-CNBS scenarios.

For Hg, NETP-CNBS results in significantly lower emissions than Roadmap2050, mainly due to assumption on lower biomass and waste fuel use in power and heat production (see Figure 15).

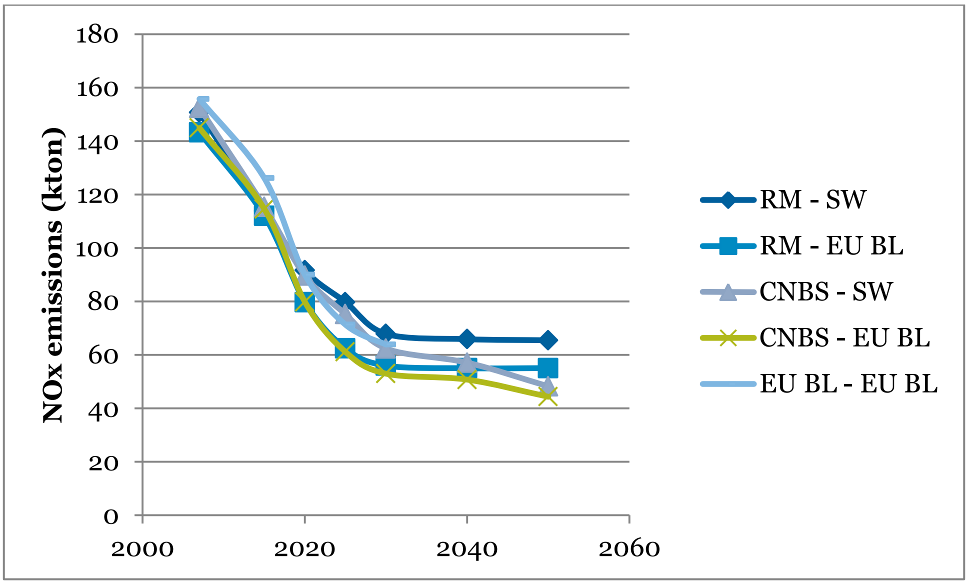


Figure 13. Estimated emissions of NO_X from all domestic sectors' fuel combustion in the different scenarios.

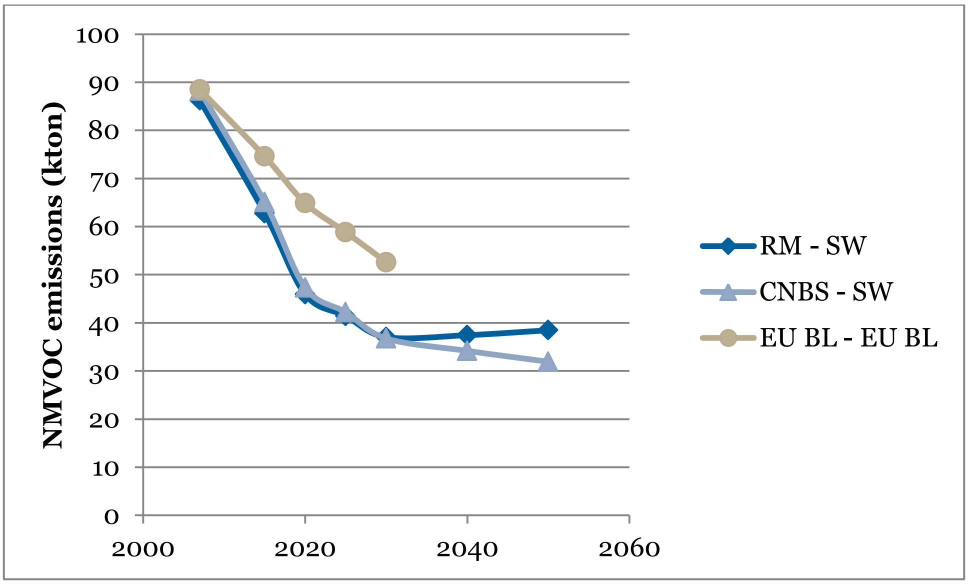


Figure 14. Estimated emissions of NMVOC from all domestic sectors' fuel combustion in the different scenarios.

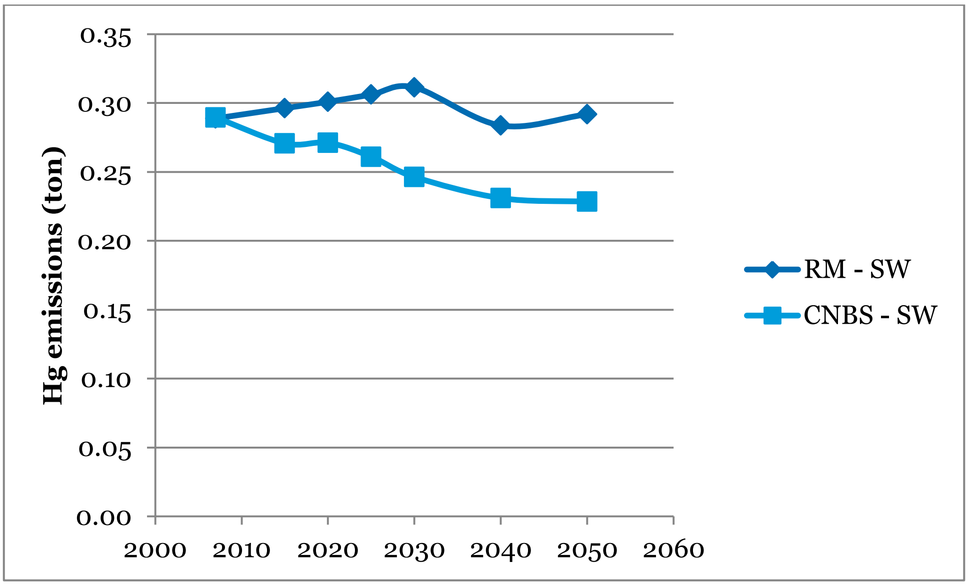


Figure 15. Estimated emissions of Hg from all domestic sectors' fuel combustion in the different scenarios.

5 Emission scenario results by domestic sector

5.1 Scenarios for the power and heat production sector

This section contains information on fuel consumption and emission scenarios for all plants producing heat (i.e. for district heating systems), electricity (power generation) or cogeneration of heat and power (CHP). Activities for industries generating heat and/or power wholly or partly for their own use, as an activity which supports their primary activity, are included under the industry sector in line with the methodologies for estimating emission inventories provided in UNECE (2014).

5.1.1 Fuel consumption in power and heat production

In Figure 16 below the reference scenario on fuel consumption (TJ) by fuel group (natural gas (gas), waste, oil, solid fuels (coal) and biomass) in power and heat production 2007-2050 based on Roadmap2050 (left) and NETP-CNBS (right) are presented. It can be seen that biomass accounts for the majority of the fuel consumption in all years in both scenarios. Waste accounts for the second largest fuel for energy production.

In Roadmap2050, the biomass and waste consumption is assumed to increase over time. In 2040 and 2050 almost all natural gas and oil fuels are assumed to be phased out and replaced by biomass and waste (see Figure 16). However, some solid fuel consumption (aggregated as coal in Figure 16) remains 2050, mainly in terms of non-specified solid fossil fuels (e.g. used tyres) and coal and coke derived energy gases sold as by-products from the iron and steel production industry in northern Sweden to nearby power and heat production facilities.

In the NETP-CNBS scenario, the biomass and waste consumption peaks in 2015 and is then slightly reduced up to 2050. The reduction is mainly due to assumptions made on increased electricity generation via wind and solar power, and significantly increased nuclear power production. In the NETP-CNBS scenario, no coal or derived energy gas from iron and steel production is expected to be used in this sector by 2050.

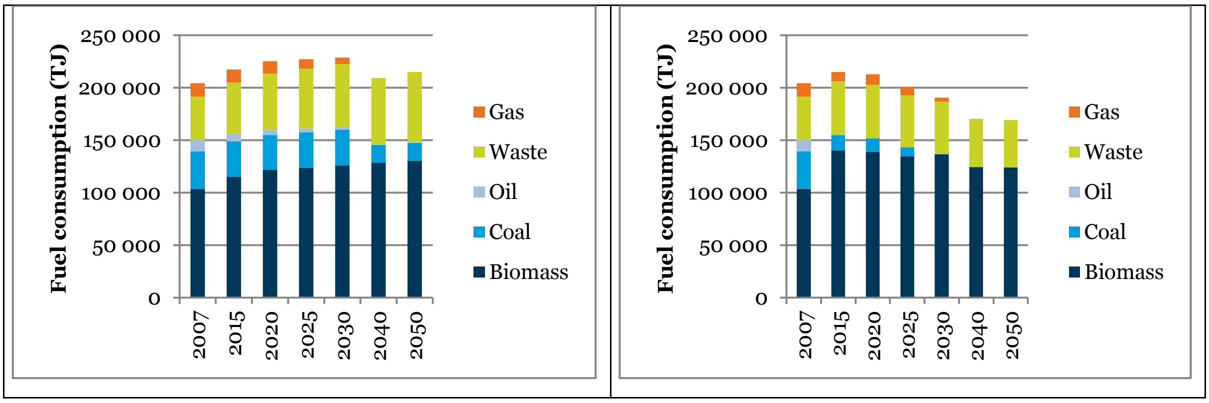


Figure 16. Fuel consumption (TJ) by fuel type for power and heat production based on Roadmap2050 (left) and NETP-CNBS (right).

In the alternative NETP-CNBS scenario developed in the study, where waste is replaced by solid biomass by 2050, all fuel consumption is represented by biomass 2050 (Figure 17).

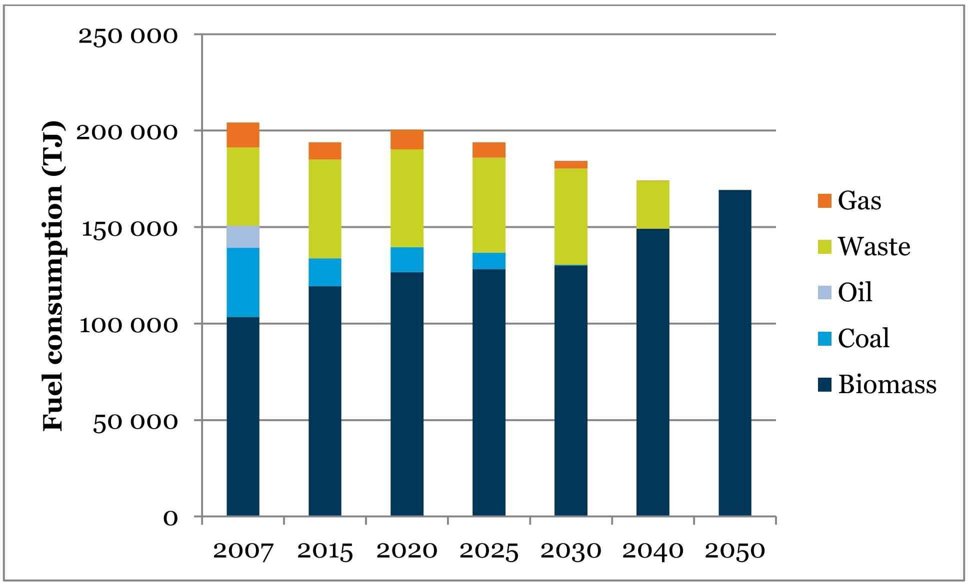


Figure 17. Fuel consumption (TJ) by fuel type for power and heat production based the alternative NETP-CNBS scenario where waste is replaced by solid biomass 2050 (2040 interpolated).

5.1.2 Emissions from power and heat production

$PM_{2.5}$ emissions from power and heat production in Sweden based on Roadmap2050 (RM) and Swedish national EFs (SW) almost entirely stem from biomass combustion (Figure 18). The slight decrease in $PM_{2.5}$ emissions up to 2050 is mainly caused by the phase out of hard coal. It is notable that gas, waste and oil combustion have little impact on $PM_{2.5}$ emissions due to low emission factors.

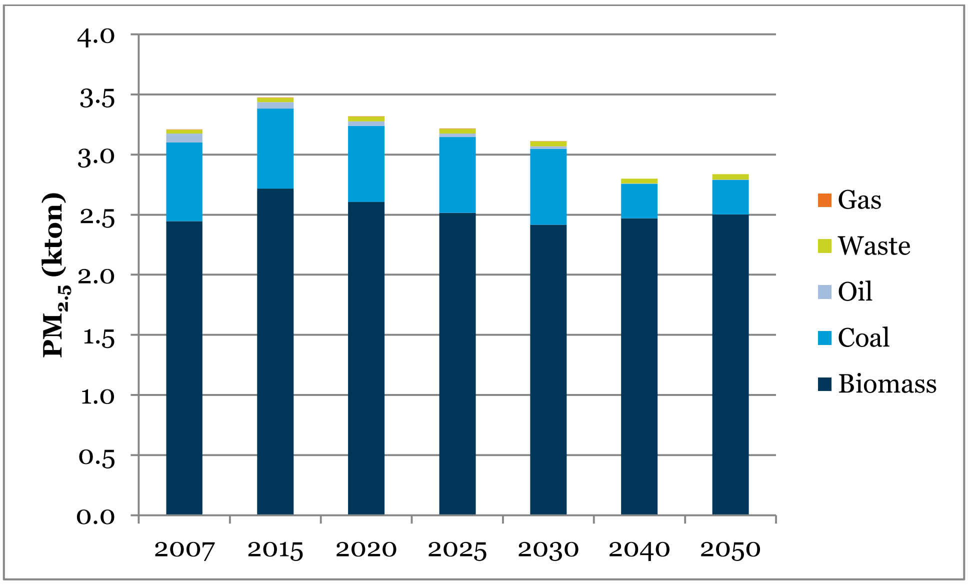


Figure 18. Estimated emissions of $PM_{2.5}$ from power and heat production by fuel type based on Roadmap2050 and Swedish national EFs (SW).

The various scenario results for emissions of $PM_{2.5}$, BC and OC are presented in Figure 19 to Figure 21, respectively.

For $PM_{2.5}$ emissions, the use of Swedish national EFs (SW) result in the highest estimates regardless of energy scenario. The use of EU baseline (EU BL) IEFs give significantly lower $PM_{2.5}$emissions compared to SW, mainly stemming from lower biomass, hard coal and brown coal (peat) EFs. As mentioned in section *Underlying scenarios and assumptions* above, there are indications that the historic Swedish national EFs (SW) for $PM_{2.5}$for power and heat production plants may be overestimated.

In Figure 19 it can be seen that large reductions of $PM_{2.5}$ emissions could be achieved by installing BAT emission abetment. Compared to Roadmap2050 and Swedish national EFs (RM - SW), the BAT scenario (RM - BAT) shows a 74% reduction (or 2.1 kton) for $PM_{2.5}$ emissions 2050.

The alternative NETP-CNBS scenario with the assumption that waste used for power and heat production will be replaced by solid biomass would result in increased particulate matter ($PM_{2.5}$, BC and OC) emissions 2050 compared to NETP-CNBS (e.g. by about 0.9 kton $PM_{2.5}$), given the same EFs (SW) (see Figure 19 to Figure 21). The increase mainly would stem from the assumption that biomass fuels have higher EF than waste (19.6 kg $PM_{2.5}$/TJ and 0.6 kg $PM_{2.5}$/TJ, respectively). For OC, derived energy gases available in the Roadmap2050 scenario contribute significantly to emission levels.

For particulate matter emissions from power and heat production, EU baseline emission data (EU BL-EU BL) 2015-2030 are significantly higher than the other emission scenarios. The higher emission level for EU baseline is mainly due to differences in sector definitions, which means that the data are not really comparable between the scenarios since they cover partly different emission sources.

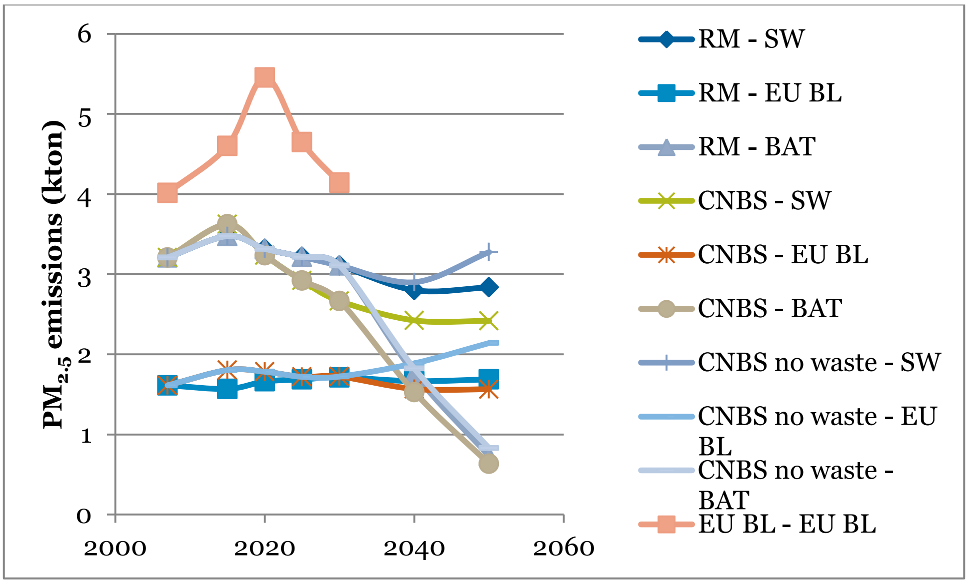


Figure 19. Estimated emissions of $PM_{2.5}$ from power and heat production in the different scenarios.

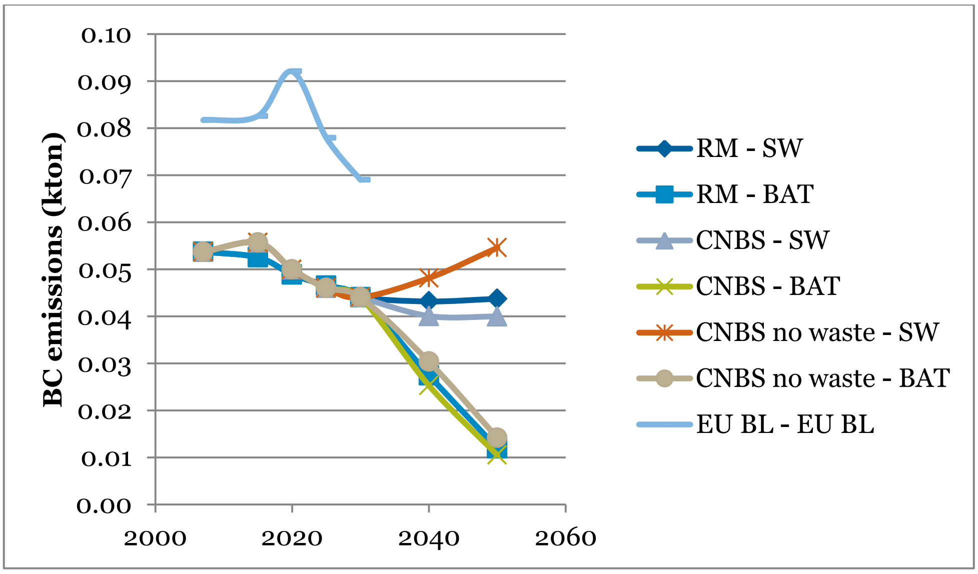


Figure 20. Estimated emissions of BC from power and heat production in the different scenarios.

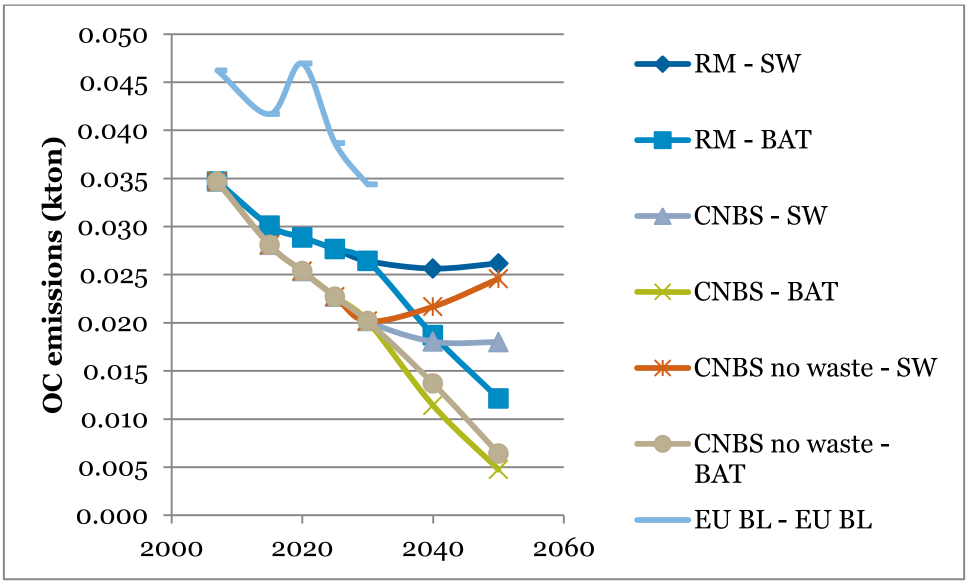


Figure 21. Estimated emissions of OC from power and heat production in the different scenarios.

For NO_X and NMVOC emissions, except for EU baseline emission data, there are generally little differences between the scenario results (Figure 22 and Figure 23). EU baseline emission data show significantly higher NO_X and NMVOC emissions, mainly due to differences in allocation of activity data between combined heat and power plants, industry and processes compared to Roadmap2050. Emissions of Hg from power and heat production largely depend on the amount of waste used as fuel (Figure 24). In NETP-CNBS, less waste is assumed than in Roadmap2050. The alternative NETP-CNBS scenario with no waste results in significantly lower Hg emissions.

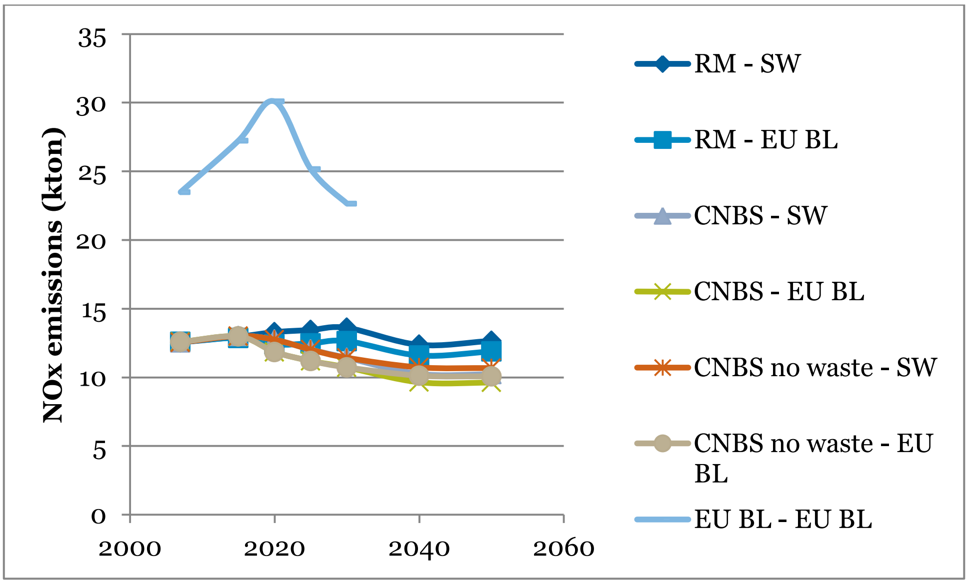


Figure 22. Estimated emissions of NO_X from power and heat production in the different scenarios.

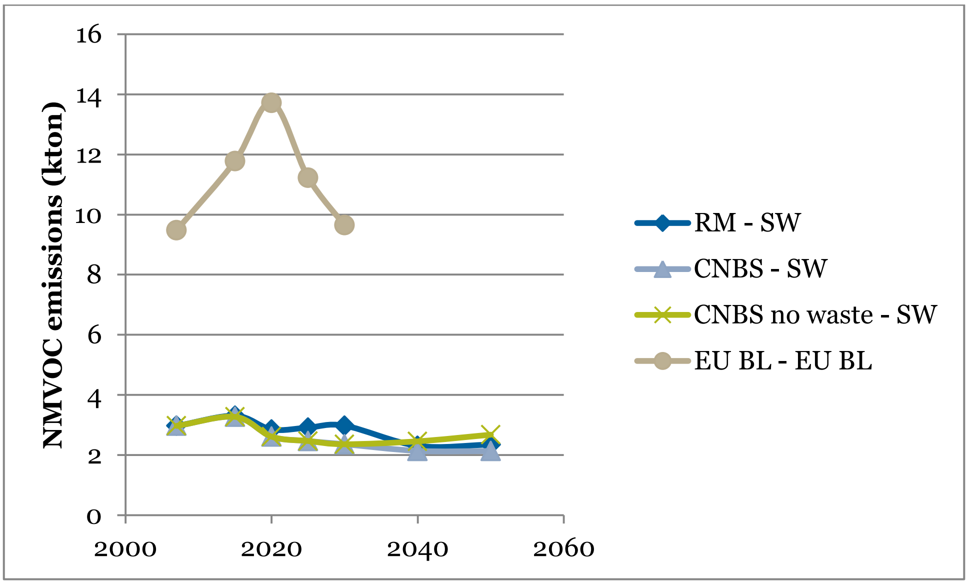


Figure 23. Estimated emissions of NMVOC from power and heat production in the different scenarios.

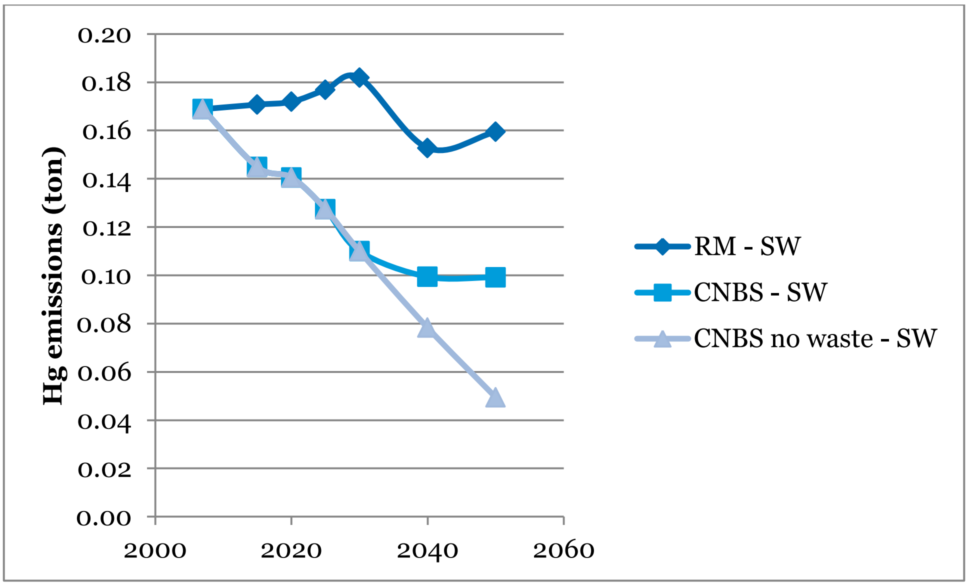


Figure 24. Estimated emissions of Hg from power and heat production in the different scenarios.

5.2 Scenarios for the Industry sector

This section describes the scenarios for fuel consumption and emission estimations for industries. The sector includes combustion of fuels in all manufacturing industries, refineries and coke plants. Industrial emissions defined as process emissions are excluded in line with the methodologies provided in UNECE (2014).

5.2.1 Fuel consumption in industry

Fuel consumption by fuel type in the industry sector for the Roadmap2050 (left) and the NETP-CNBS (right) scenarios are presented in Figure 25.

For Roadmap2050, oil fuels contribute with the majority of the total fuel consumed in industry 2007, but there is a slight decreasing trend up to 2050. Biomass is the second largest fuel in industry and is expected to increase about 27% 2007-2050. The consumption of coal and gas are relatively small in industry and expected to stay more or less constant over time.

In the NETP-CNBS scenario fuel consumption 2007-2050 it is obvious that in 2040 and 2050, a larger share of the fuel consumption stem from biomass compared to Roadmap2050. The increase in biomass use is assumed to primarily happen in the cement, chemicals and petrochemicals industries.

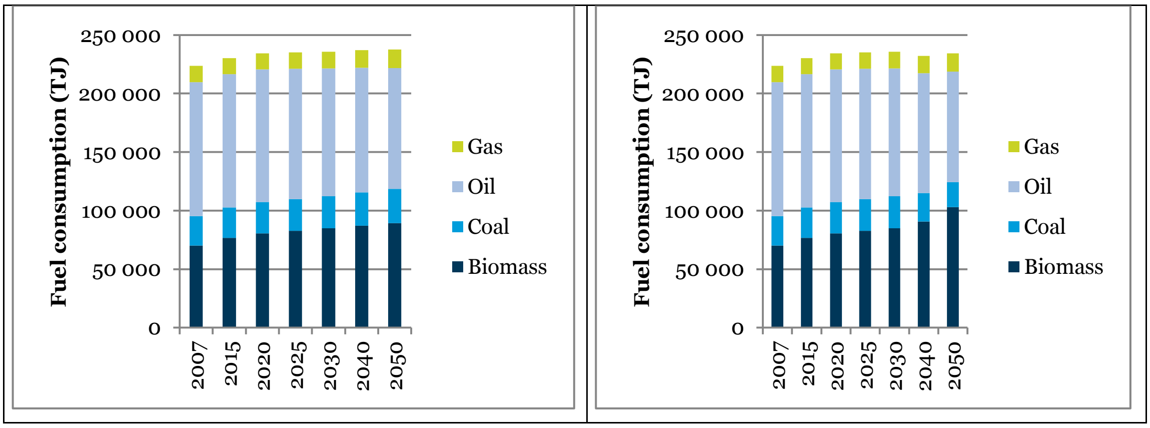


Figure 25. Fuel consumption (TJ) by fuel type for industry based on Roadmap2050 (left) and NETP-CNBS (right).

5.2.2 Emissions from industrial combustion

$PM_{2.5}$ emission from industry by fuel type 2007-2050 based on Roadmap2050 and Swedish national EFs (SW) are presented in Figure 26. It can be seen that biomass fuel use account for the major part of the emissions. Based on this scenario there is little change in total $PM_{2.5}$ emission expected up to 2050 from this sector.

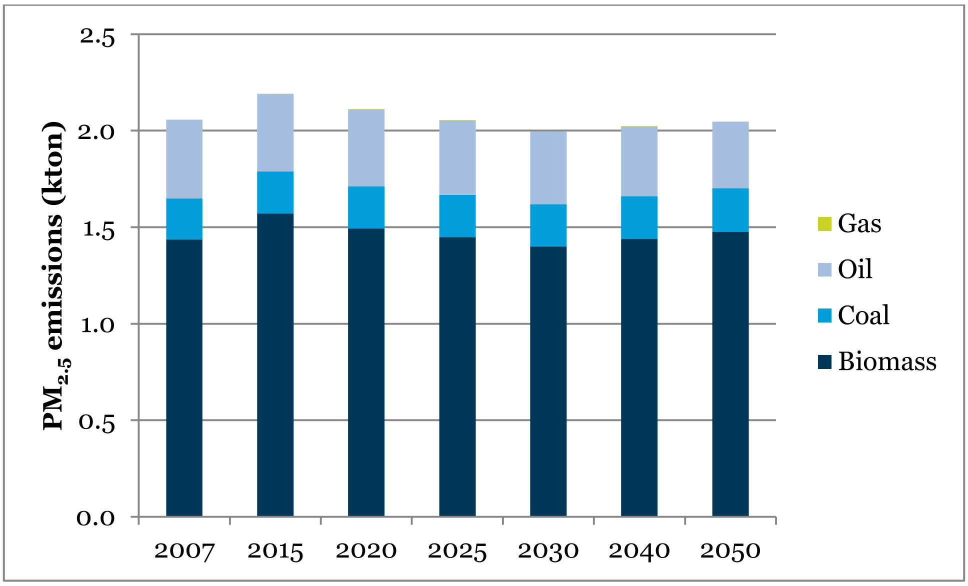


Figure 26. Estimated emissions of $PM_{2.5}$ from industry by fuel type based on Roadmap2050 and Swedish national EFs (SW).

The various scenario results for $PM_{2.5}$, BC and OC are presented in Figure 27 to Figure 29, respectively. It is obvious that there is still some room for particulate matter emission reduction due to improved emission abatement in terms of BAT. It can be seen that installing BAT emission abetment by 2050 would reduce $PM_{2.5}$ emissions by 0.6 kton (or 31%) compared to Roadmap2050 (RM) and Swedish national EFs (SW) (see Figure 27).

In addition, it can be seen that EU baseline (EU BL) IEFs give significantly lower emissions, mainly due to lower IEFs for biomass compared the Swedish national EFs (see Figure 27 to Figure 29). Moreover, the EU baseline emission data (EU BL-EU BL) for industry show an increasing but unstable trend. In 2030, $PM_{2.5}$ emissions in the EU baseline is estimated at 3.0 kton, about 49 % higher than the Roadmap2050 scenario using Swedish national EFs (Figure 27).

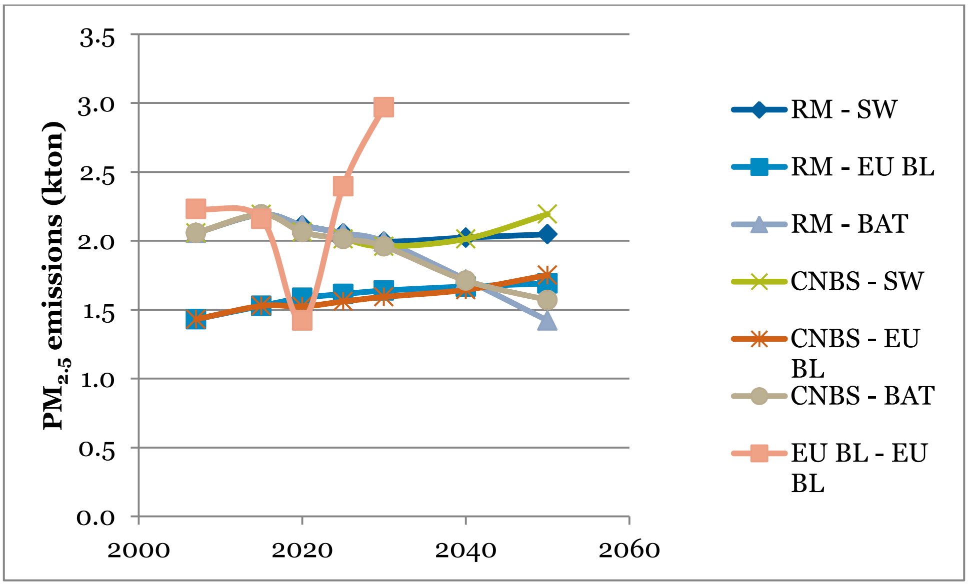


Figure 27. Estimated emissions of $PM_{2.5}$ from industry in the different scenarios.

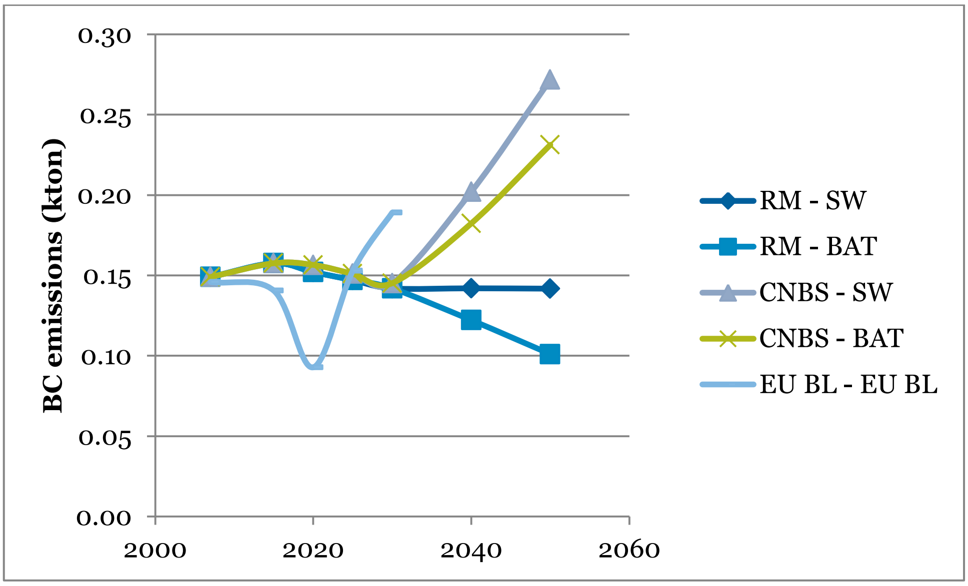


Figure 28. Estimated emissions of BC from industry in the different scenarios.

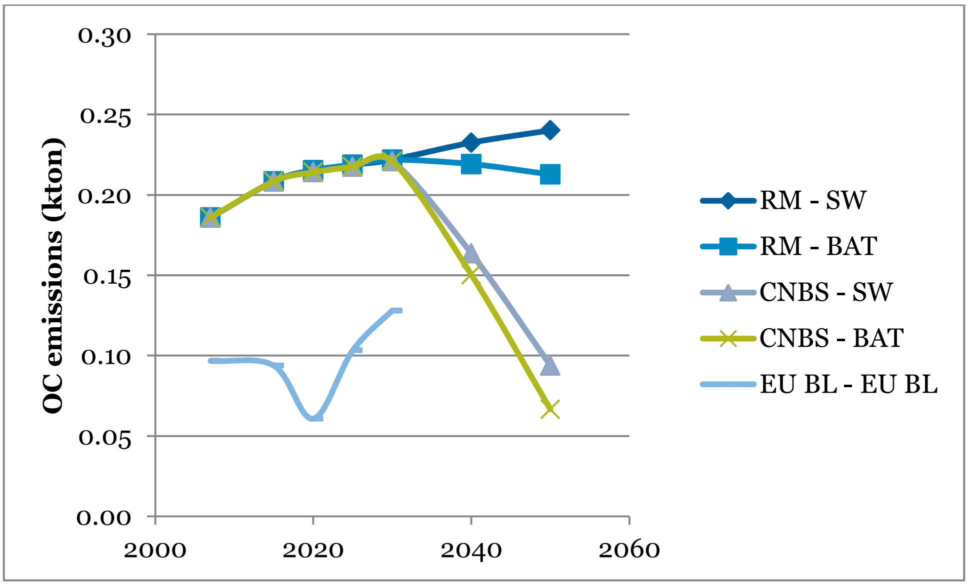


Figure 29. Estimated emissions of OC from industry in the different scenarios.

For NO_X and Hg, the NETP-CNBS scenario shows lower emission levels 2050 compared to Roadmap2050 given the same EFs, mainly due to the switch of fuels in cement industries, from coal to biomass fuels (see Figure 30 and Figure 32, respectively). For NMVOC (Figure 31), there are no significant differences between the Roadmap2050 and NETP-CNBS scenarios. The EU baseline emission data for NMVOC shows higher NMVOC emissions for industry mainly due to higher estimated emissions from biomass fuels.

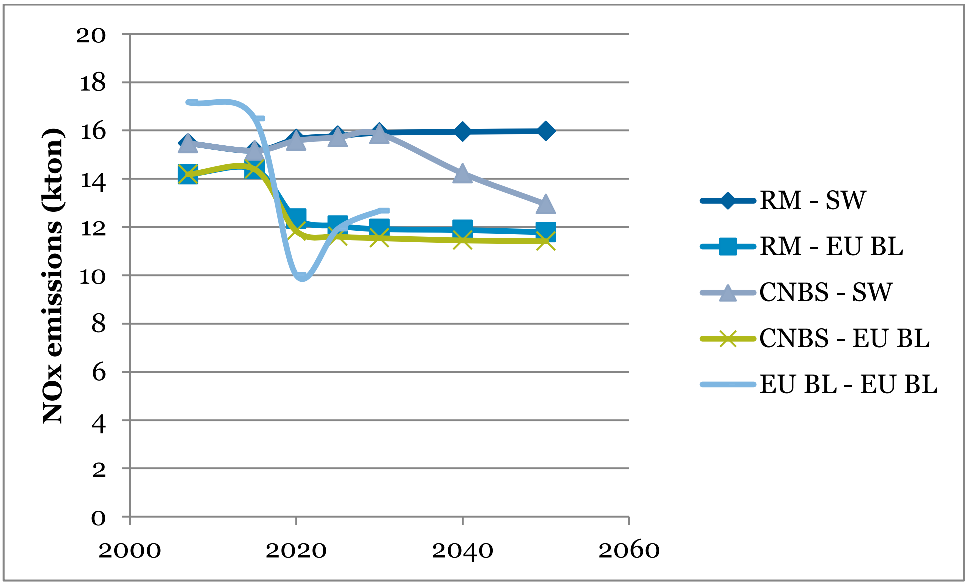


Figure 30. Estimated emissions of NO_X from industry in the different scenarios.

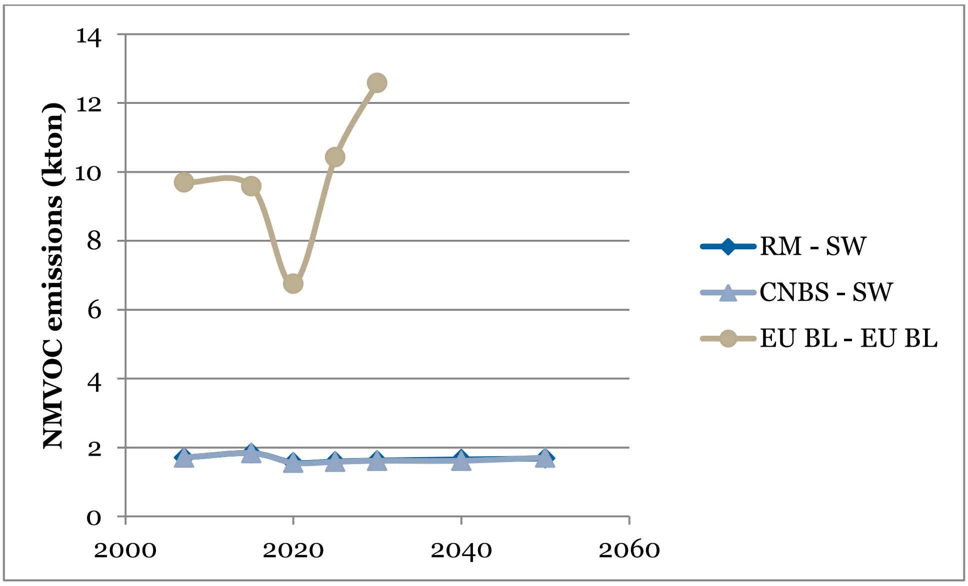


Figure 31. Estimated emissions of NMVOC from industry in the different scenarios.

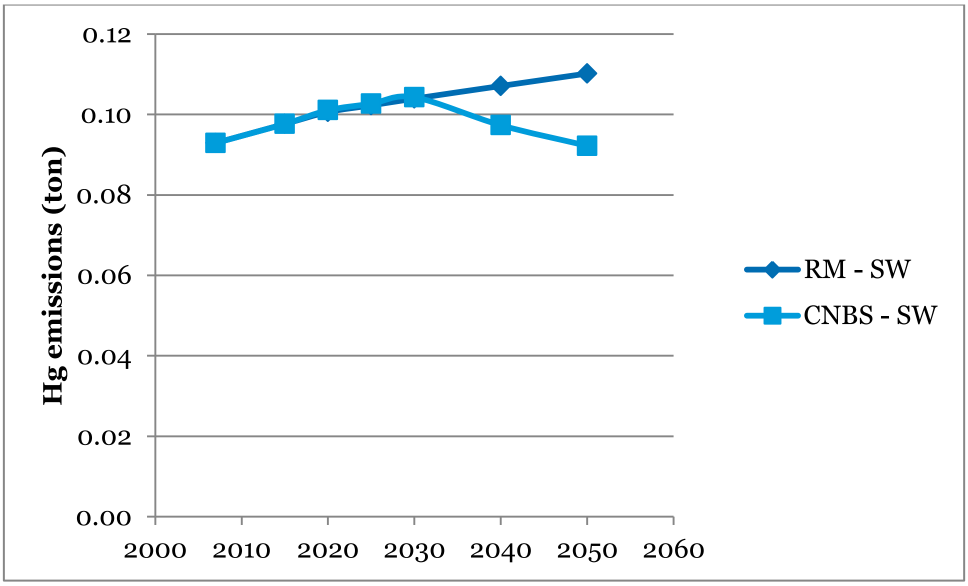


Figure 32. Estimated emissions of Hg from industry in the different scenarios.

5.3 Scenarios for the Small scale combustion sector

This section includes scenarios on fuel consumption and emissions from small scale combustion of different types of heating of premises and residential buildings. In addition, uncertainties in particulate matter emissions due to different measurement standards are presented.

5.3.1 Fuel consumption in small scale combustion

In the fuel use scenarios in Roadmap2050 and in NETP-CNBS the commercial, residential and agriculture/forestry/fishing sub-sectors are specified. In the NETP scenarios, a “non-specified other” source is grouped with agriculture/fishing, which makes a straightforward comparison impossible since it is unclear what “non-specified other” covers. As far as the fuels are concerned, in Roadmap2050 biomass fuels are treated separately, while in the NETP scenarios, the fuel is defined as “biomass and waste”, which introduces another uncertainty.

Below the combustible fuel use (not energy use from e.g. other renewables or electricity) projected in the Roadmap2050 and NETP for Sweden for all small scale combustion (residential, commercial and agriculture/forestry/fishing + other non-specified (NETP)) and the share of biomass is presented (Figure 33).

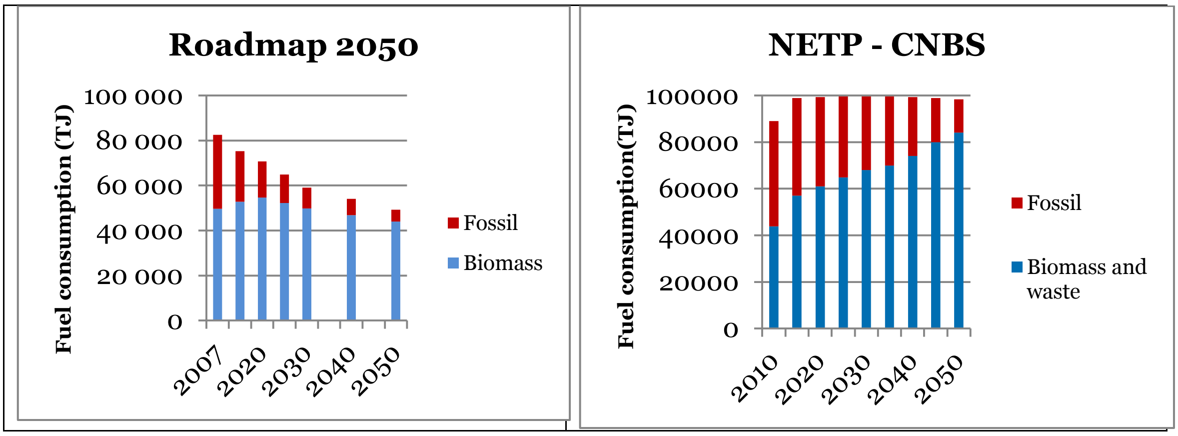


Figure 33. Total combustible fuels (commercial, residential and agriculture/forestry/fishing) and share of biomass in Roadmap 2050, reference scenario, and total combustible fuels (residential+ commercial+ agriculture, fishing and non-specified other) and share of biomass+waste in NETP – CNBS scenario

In Roadmap2050 there is an expect decreased in total combustible fuel use in the future, while a high constant total combustible fuel use is expected in NETP-CNBS. According to Roadmap 2050 the total combustible fuel use in 2030 is about 60 PJ to decrease to approximately about 50 PJ in 2050. The NETP-CNBS on the other hand expects a total combustible fuel use both in 2030 and 2050 of almost 100 PJ. Different assumptions regarding the influences of increased energy efficiency as well as the extent of alternative energy sources in the small scale sector, such as district heating, heat-pumps, electricity etc, may contribute to the differing future fuel use scenarios.

As highlighted earlier, the scenarios are not directly comparable since in the NETP CNBS scenario covers also the “non-specified other” source, and the fuel does not only cover biomass but also waste. As a result of this and in order to achieve better comparability, only the residential and commercial combustion sectors are used in the analyses below.

5.3.2 Activity data used as the basis for the scenario calculations of emissions in the small scale combustion sector

The fuel use scenarios used in the further analysis from Roadmap2050 and NETP CNBS are presented in Figure 34, including only the residential and commercial sectors. (Agriculture/forestry/fishing/other is excluded as a source since the data in Roadmap 2050 and in CNBS, where "other not specified" is included, was not comparable).

In the NETP CNBS the biomass fuel use in the future is considerably higher than in Roadmap 2050. The future use of fossil fuels is expected to decrease substantially over time, and the decrease is more pronounced in the Swedish Roadmap 2050 than in the NETP CNBS scenario.

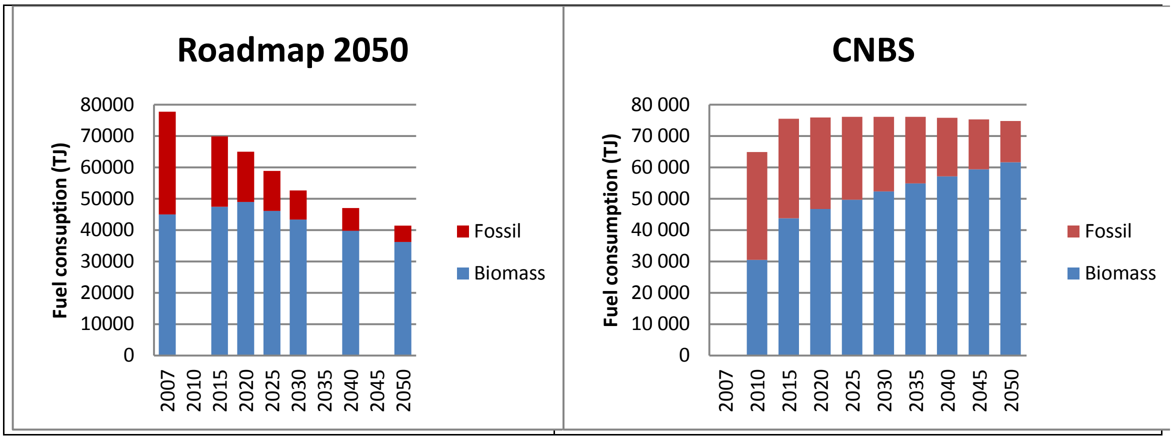


Figure 34. Biomass and fossil fuel consumption in residential and commercial combustion sources in the scenarios.

5.3.3 Emissions from small scale combustion

For residential biomass combustion the two basic activity data scenarios regarding biomass fuel use are the Swedish Roadmap 2050 scenario (RM), and the NETP CNBS scenario (CNBS), where more biomass is assumed to be used. Additionally, as alternatives in both of these activity data scenarios it was assumed that in 2050 all the biomass fuel used will be combusted as pellets, which for the small scale combustion sector is designed as the Best Available Technology scenario (BAT). The pellets use is interpolated from the actual projected use in 2020 to be the only type of biomass used in small scale combustion in residential boilers and stoves in 2050.

In the CNBS activity data scenarios, only the total amount of biomass is available, while in the Roadmap 2050, a disaggregation on wood logs and on pellets is available. In order to be able to use the Swedish emission factors to estimate emissions based on the CNBS biomass amount, the relative shares of wood logs and pellets fuels from Roadmap 2050 were applied to the CNBS activity data.

5.3.4 Particulate matter emission factors for small scale combustion

The emission factors used are from the Swedish national projections, which are available up to 2030. For the time period 2035-2050 the projected emission factors for 2030 were extrapolated. This may lead to an overestimation of emissions.

The Swedish emission factors for $PM_{2.5}$, and those applied for BC (taken from the EMAP/EEA Air Emission Inventory Guidebook) and for OC (derived from the EU Baseline) are presented in Table 3. The emission factors applied in the BAT-scenarios are those for pellets combustion presented in Table 3.

Table 3. Swedish emission factors (SW) for $PM_{2.5}$, BC and OC. Until 2030 as in the national Swedish projections, extrapolated for 2040-2050 in this work. BC as % of $PM_{2.5}$ (from EMAP/EEA Air Emission Inventory Guidebook), and OC as % of $PM_{2.5}$, derived from the EU Impact Assessment.

			PM2.5 g/GJ)						% BC (GB)	%OC (IIASA)
Sector	**Appliance type**	**Fuel type**	**2007/2010**	**2015**	**2020**	**2030**	**2040**	**2050**	**all years**	**all years**
Residents	Boilers	Wood logs	150	150	135	120	*120*	*120*	16	30
		Wood chips	100	100	90	80	*80*	*80*	28	30
		Pellets	30	30	30	30	*30*	*30*	15	15
	Stoves	Wood logs	100	100	90	80	*80*	*80*	10	30
		Pellets	30	30	30	30	*30*	*30*	15	15
	Open fire places	Wood logs	150	150	150	150	*150*	*150*	7	32
Other consumption	All technologies	All biomass	150	150	135	120	*120*	*120*	15	15

5.3.5 Emissions from small scale combustion

For all pollutants the CNBS-SW scenario results in future higher emissions than in RM-SW. This is a result of the higher absolute biomass fuel consumption in the CNBS scenario. For all pollutants the contribution to emissions from fossil fuel combustion in the small scale sector is minor compared to the estimated emissions from biomass combustion. In the two scenarios where BAT technologies are assumed, the emissions decrease substantially in the future due to significantly lower emissions associated with the use of pellets. Estimated emissions from the EU Baseline are included in the figures for comparison.

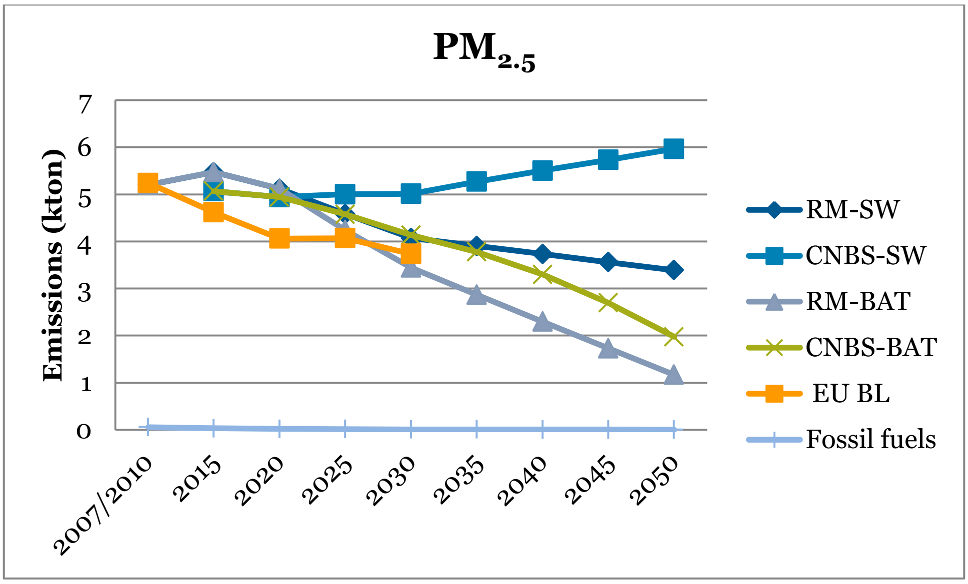


Figure 35. Estimated emissions of $PM_{2.5}$ from small scale biomass combustion in the different scenarios.

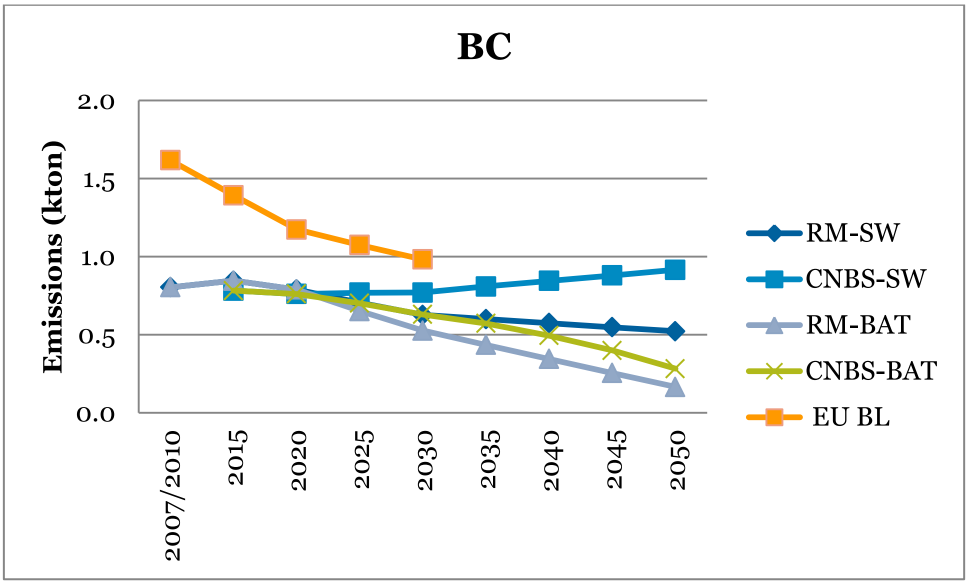


Figure 36. Estimated emissions of Black Carbon (BC) from small scale biomass combustion in the different scenarios.

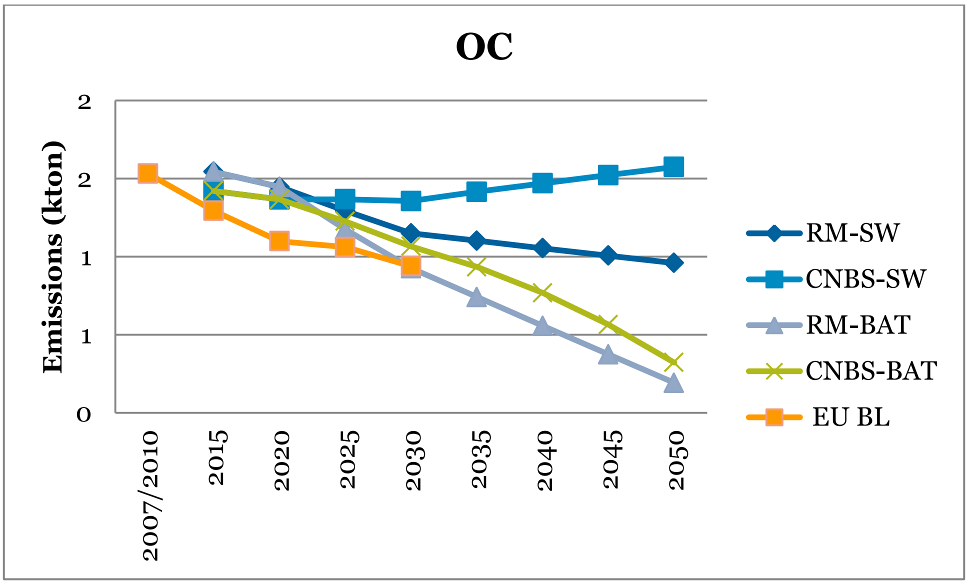


Figure 37. Estimated emissions of Organic carbon (OC) from small scale biomass combustion in the different scenarios.

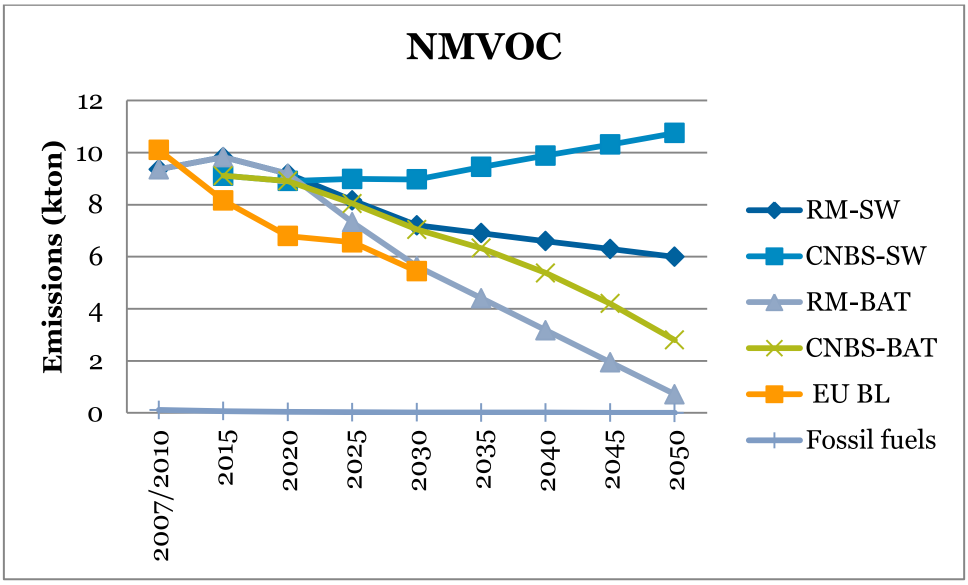


Figure 38. Estimated emissions of non-methane volatile organic compounds (NMVOC) from small scale biomass combustion in the different scenarios.

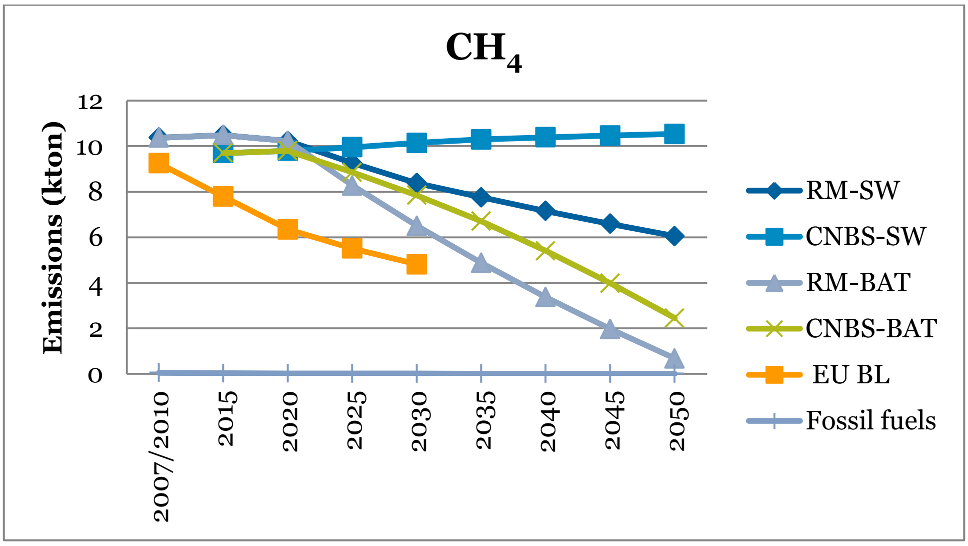


Figure 39. Estimated emissions of methane (CH_4) from small scale biomass combustion in the different scenarios.

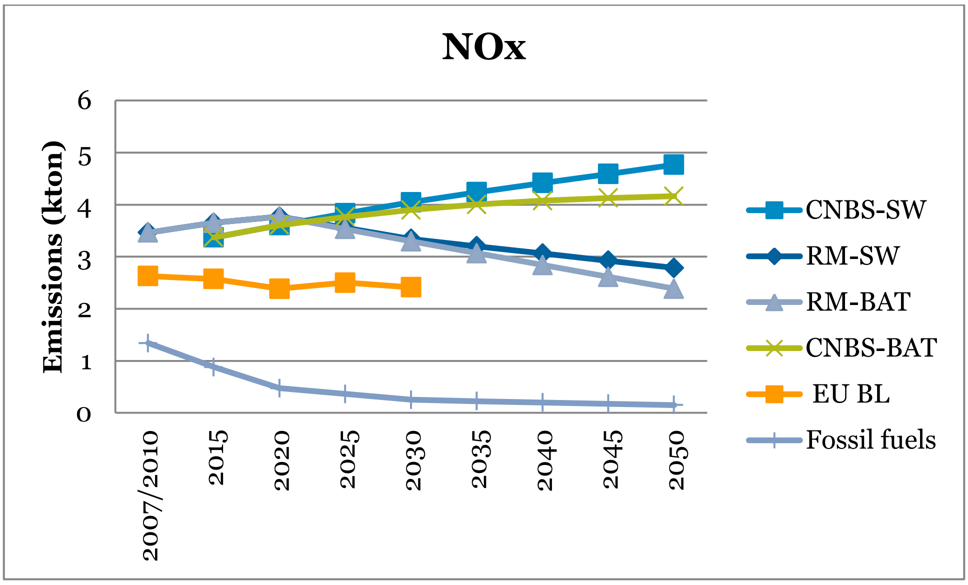


Figure 40. Estimated emissions of nitrogen oxides (NOx) from small scale biomass combustion in the different scenarios.

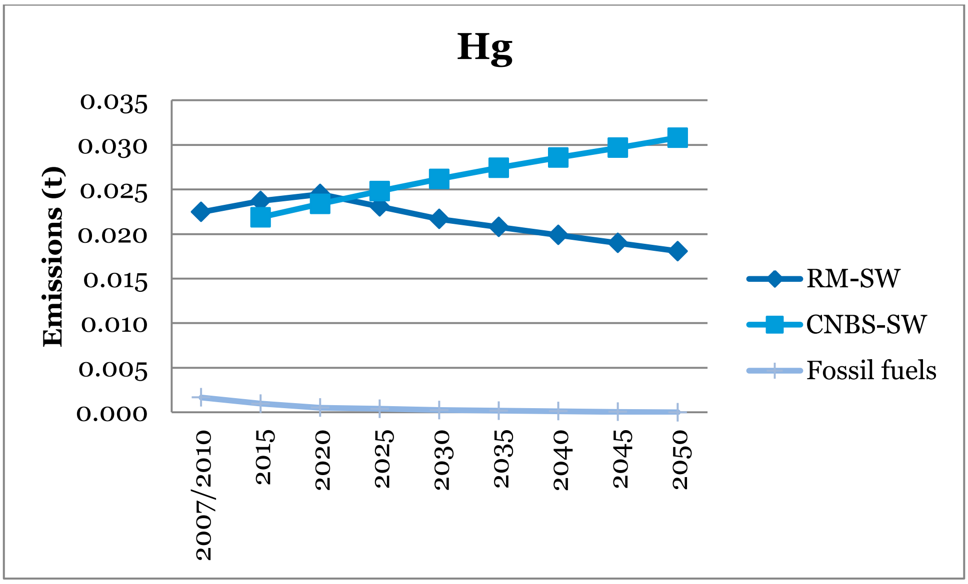


Figure 41. Estimated emissions of mercury (Hg) from small scale biomass combustion in the different scenarios.

5.3.6 Uncertainty in estimated levels of particle emissions from small scale biomass combustion

Emissions of especially $PM_{2.5}$ and BC from residential biomass combustion are highly dependent on the combustion technology (EEA, 2013). The emission factors for $PM_{2.5}$ however also depend on the emission measurement method used to derive the emission factors. There are two principally different measurement standards, one where particulate matter (PM) is measured in the hot flue gases (hot filter) and one where a dilution tunnel is used to dilute and cool the flue gases after leaving the stack. Sampling in a dilution tunnel gives higher results on particle mass, as semivolatile organic compounds in the flue gas condense in the dilution tunnel and add to the particle mass. The differences can be large, in the order of 2-10 times higher from dilution tunnel measurements than in hot flue gas measurements, especially at bad and inefficient firing conditions (e.g. Nussbaumer et al, 2008).

The level of PM emissions from small scale combustion is presently very much discussed in international fora, since there are examples of emission factors derived from both types of measurements used in reporting, different in different countries due to tradition and national standards. The dilution tunnel method is generally regarded as better representing the PM emissions in the atmosphere, as the dilution tunnel measurement technique resembles what happens to the PM in the flue gas after having been emitted to the atmosphere. Modern and efficient combustion technologies, such as pellets technologies, reduce the risk of inefficient combustion and also the extent of emissions of semivolatile compounds, why the type of measurement method is of far less importance in deriving emission factors for e.g. pellets combustion technologies..

The emission factors for $PM_{2.5}$ used in the national Swedish emission inventory (SW) are based on hot flue gas measurements (Table 4), while those given in the Guidebook are based on sampling in a dilution tunnel, including condensable organic matter (Table 5).

Table 4. Swedish emission factors for $PM_{2.5}$ (g/GJ) from biomass combustion. Data up to 2030 as in the Swedish national projections. Data for 2025 is interpolated while data for 2040 and 2050 have been extrapolated in this work.

Technology	Fuel	2007	2015	2020	*2025*	2030	*2040*	*2050*
Commercial/ institutional	wooden fuels	150	150	135	*128*	120	*120*	*120*
Boiler	wood logs	150	150	135	*128*	120	*120*	*120*
Boiler	wood chips	100	100	90	*85*	80	*80*	*80*
Boiler	pellets	30	30	30	*30*	30	*30*	*30*
Stove	wood logs	100	100	90	*85*	80	*80*	*80*
Stove	pellets	30	30	30	*30*	30	*30*	*30*
Open fire place	wood logs	150	150	150	*150*	150	*150*	*150*

Table 5. Technology specific emission factors for $PM_{2.5}$ and BC from EMEP/EEA Air Pollutant Emission Inventory Guidebook

	Emission factors	
Technology/fuel	**$PM_{2.5}$ (g/GJ)**	**BC (% of $PM_{2.5}$)**
Conventional boilers < 50 kW burning wood and similar wood waste	470	16
Conventional stoves burning wood and similar wood waste	740	10
Energy efficient stoves burning wood	370	16
Advanced / ecolabelled stoves and boilers burning wood	93	28
Pellet stoves and boilers burning wood pellets	29	15

Open fireplaces burning wood	820	7
Non-residential sources, manual boilers burning wood	140	28
Non-residential sources, automatic boilers burning wood	33	15

The differences in $PM_{2.5}$ emission factors between the Swedish factors and those from the Guidebook are both in general level and especially in technology specifications. Generally the emission factors in the Guidebook are higher, e.g. for stoves, where the Swedish factors are from 100 to 80 g/GJ for wood logs (with unspecified technology), while the Guidebook factors for conventional stoves is 740, for energy efficient stoves 370 and for advanced/eco-labelled stoves 93 g/GJ. For pellets technologies the emission factors agree with 30 and 29 g $PM_{2.5}$/GJ respectively. In order to be able to make more accurate emission estimations from small scale combustion, and to follow the changes over time, there is a need for better knowledge and statistics on the existing combustion technology stock in Sweden. At present it is not possible to use the detailed technology specific information provided in the EMEP/EEA Guidebook in the national emission inventories in Sweden.

Due to these alternative emission factors for $PM_{2.5}$ in the Guidebook, additional scenario calculations for $PM_{2.5}$, BC and OC were done using the emission factors provided in the Guidebook (GB). In the table below the different combinations of biomass activity data, emission factors and the additional assumption on increased share of pellets is presented.

Table 6. Scenario descriptions for small scale biomass combustion alternatives. Those with the Swedish emission factors (SW) are the same as presented above, while those using Guidebook (GB) emission factors are the additional scenarios.

Scenario abbreviation	Activity data, biomass	Emission factors	Additional change
RM-SW	Roadmap 2050	SW	-
CNBS-SW	NETP CNBS	SW	-
RM-BAT	Roadmap 2050	SW	All biomass as pellets 2050*
CNBS-BAT	NETP CNBS	SW	All biomass as pellets 2050*
RM-GB	Roadmap 2050	**GB**	-
CNBS-GB	NETP CNBS	**GB**	-
RM-GB-BAT	Roadmap 2050	**GB**	All biomass as pellets 2050*
CNBS-GB-BAT	NETP CNBS	**GB**	All biomass as pellets 2050*
EU BL	EU Baseline	EU Baseline	Emission data 2010-2030

*interpolated 2020-2050

In order to be able to use the more technology specific emission factors from the Guidebook, information on the future trends in technologies is necessary. In the scenario for Sweden, calculated in the EU Baseline (EU BL), the assumed changes in the use of biomass combustion technologies over time are presented in Figure 42 and Figure 43. Since no national information on technology shares or the future development of the combustion appliances stock is available, these assumptions were applied to the RM and CNBS biomass fuel use projection, using the shares of technologies as in Figure 42 and Figure 43.

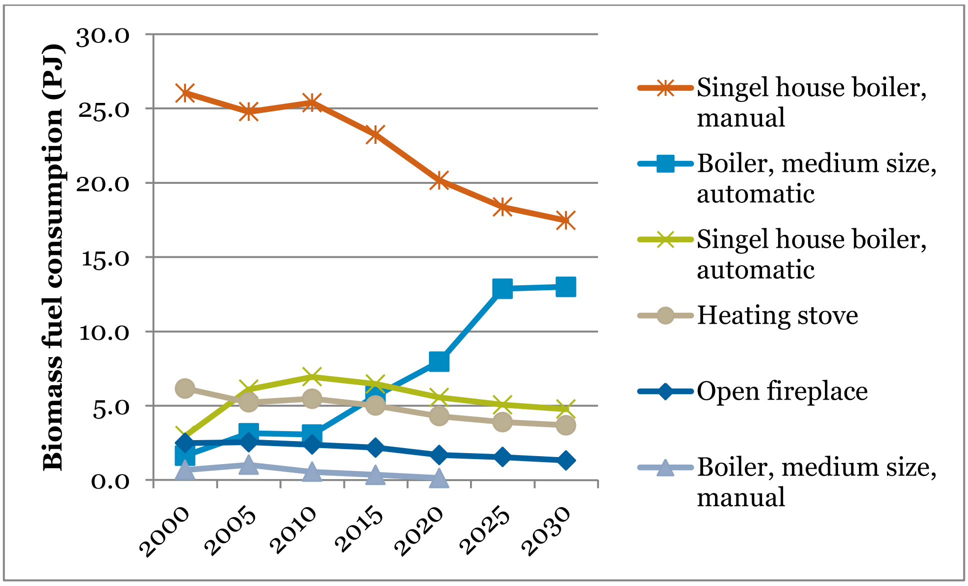
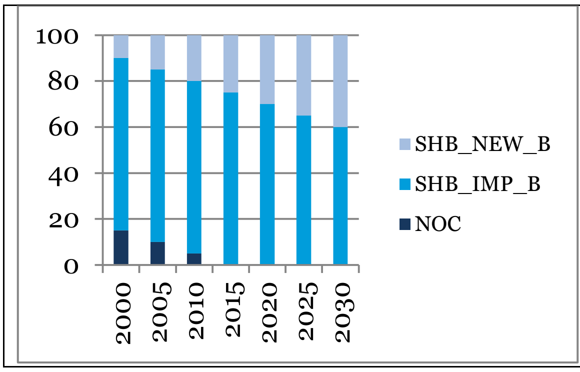


Figure 42. Projected biomass fuel use in different combustion technologies in Sweden 2000-2030 according to the EU Baseline.

According to the assumptions made in the EU Baseline, the manually operated combustion technologies are expected to be used less in the future while automatic devices increase in importance. The automatic combustion technologies require more homogenous fuels, such as pellets, and can also be assumed to result in more efficient combustion and less emissions of many air pollutants. There are further differentiations in the combustion technologies abatement levels underlying the calculations in the EU Baseline, such as shown in Figure 43. New technologies (with the lowest emission factors assumed, see table Table B 12 in Appendix B) as well as improved technologies (intermediate emission factors) are becoming relatively more important with larger shares of the fuel combusted in those, while those defined as “with no control” (highest emission factors) disappear until 2030.



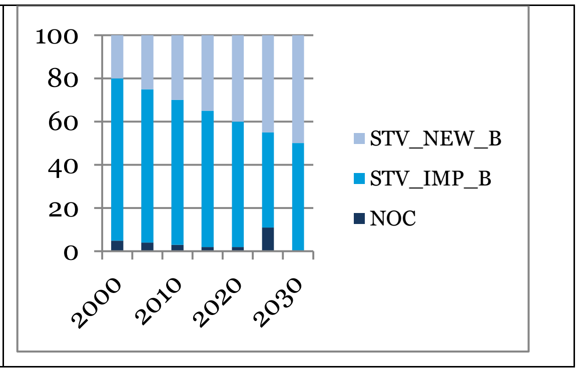


Figure 43. Differentiation of the biomass use (%) on manual combustion technologies with different abatement levels for single house boilers (SHB, left) and stoves (STV, right). (NEW = new technologies, IMP= improved technologies, NOC= no control).(*for stoves NOC in 2025 there is a mistake in the underlying data)

For medium size boilers, larger than those used in single houses (both automatic and manual) no controls are taken into account in the EU Baseline. That is the case also for automatic single house boilers, since they result in efficient combustion conditions and are expected to be low-emitting.

The emissions of $PM_{2.5}$, BC and OC estimated by using the emission factors from the EMEP/EEA Guidebook, GB (based on dilution tunnel sampling) are presented in Figure 44, Figure 45 and Figure 46, together with the emissions estimated based on the Swedish emission factors, SW (based on hot flue gas measurements) already presented above.

Estimated emissions of $PM_{2.5}$ from small scale biomass combustion, based on emission factors where condensable organic matter is included are approximately double to those estimated by the Swedish emission factors (RM-GB compared to RM-SW, and CNBS-GB compared to CNBS-SW). In the BAT scenarios this discrepancy disappears (e.g. BM-BAT and RM-GB-BAT in 2050). The corresponding emission scenarios for BC and OC show similar results as for $PM_{2.5}$ (Figure 45 and Figure 46).

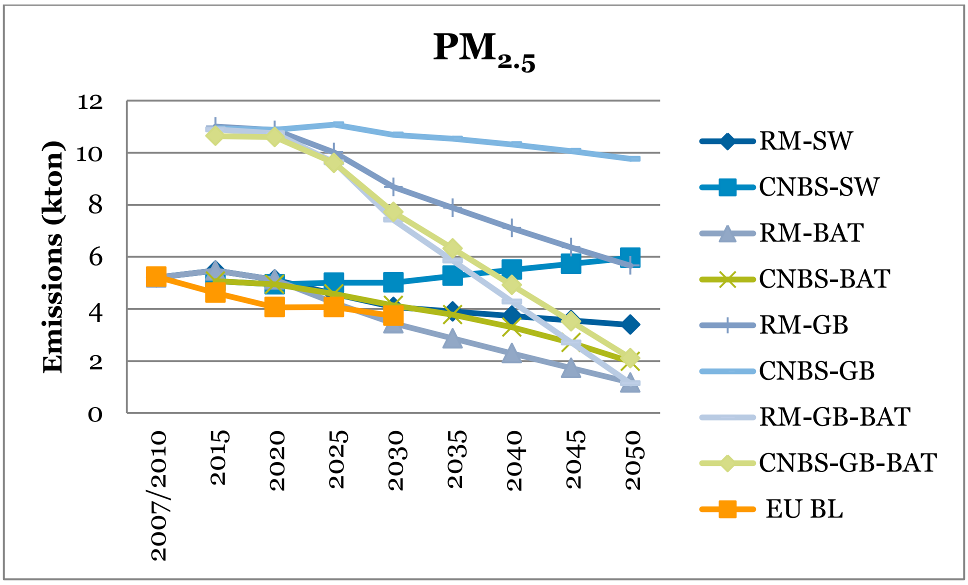


Figure 44. Estimated emissions of $PM_{2.5}$ from small scale combustion of biomass based on different scenarios of fuel use (Roadmap 2050=RM and CNBS) and different types of emission factors (SW=Swedish national factors and BG= emission factors form the EMEP/EEA Air Emission Inventory Guidebook). Estimated emissions from IIASA are shown for comparison.

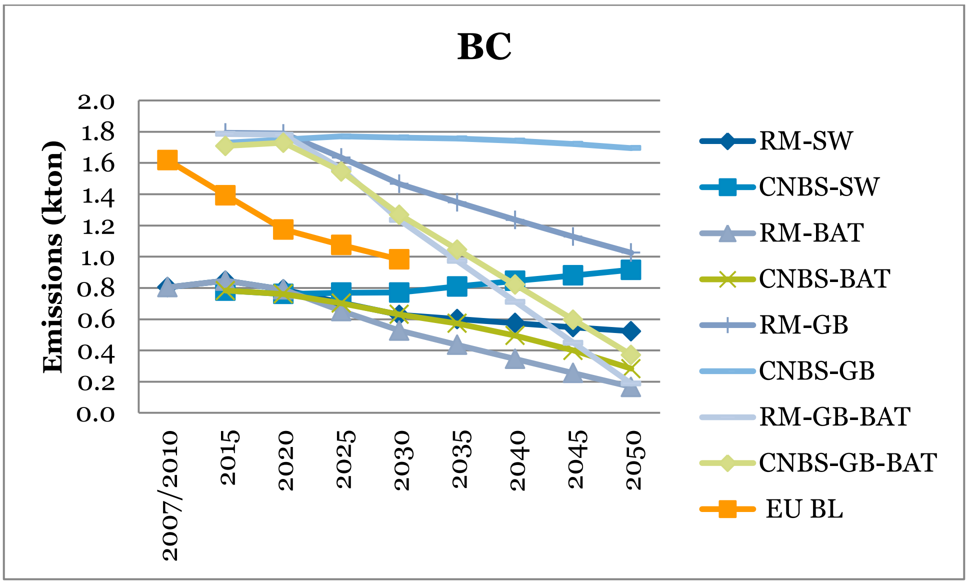


Figure 45. Estimated emissions of Black Carbon (BC) from small scale combustion of biomass based on different scenarios of fuel use (Roadmap 2050=RM and CNBS) and different types of emission factors (SW=Swedish national factors for $PM_{2.5}$ and fraction BC of $PM_{2.5}$ from GB, and GB= emission factors for $PM_{2.5}$ and BC from the EMEP/EEA Air Emission Inventory Guidebook). Estimated emissions from IIASA are shown for comparison.

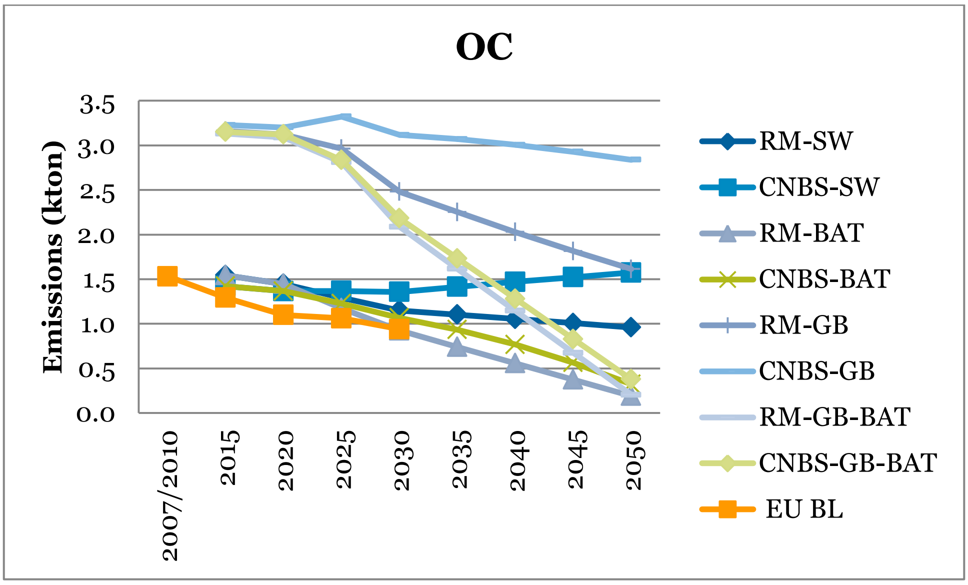


Figure 46. Estimated emissions of Organic Carbon (OC) from small scale combustion of biomass based on different scenarios of fuel use (Roadmap 2050=RM and CNBS) and different types of emission factors (SW=Swedish national factors for $PM_{2.5}$ and fraction OC of $PM_{2.5}$ from IIASA, and GB= emission factors for $PM_{2.5}$ the EMEP/EEA Air Emission Inventory Guidebook and OC-fraction of $PM_{2.5}$ from IIASA). Estimated emissions from IIASA are shown for comparison.

Estimated emissions of particles from small scale biomass combustion are strongly dependent on the type of measurement method used in the underlying information to derive emission factors, especially at inefficient combustion conditions. Estimated emissions of particles from small scale biomass combustion in Sweden can differ a factor of two depending on the set of emission factors. At modern and efficient combustion conditions (BAT) emissions of particles are reduced significantly and the problem of the set of emission factors is not important.

5.4 Scenarios for domestic transport sector (including non-road mobile machinery)

This section includes scenarios on fuel consumption and emission estimations for all types of domestic transport; air, sea, road and railways, as well as non-road mobile machinery (NRMM).

5.4.1 Fuel consumption in domestic transport

Fuel consumption 2007-2050 by type of transport and fuel in Roadmap2050 (left) and NETP-CNBS (right) are presented in Figure 47. In 2007, road traffic accounted for the major share of the domestic transport fuel consumption in Sweden; non-road mobile machinery (NRMM) being the second largest domestic transport use sector. It is obvious that there is significantly less fuel consumption expected in NETP-CNBS compared to Roadmap2050, mainly due to assumption on large share of electrified vehicles. In addition, in NETP-CNBS it is assumed that almost all remaining fuel-based transportation by 2050 is using biofuels.

For Roadmap2050 it can be seen that passenger cars, followed by heavy duty vehicles (HDV), are the main consumers of oil fuels in road transportation (Figure 48). It is also obvious that the total road transportation fuel consumption is assumed to increase from 2030 to 2050 in the Roadmap2050 scenario, the increase mainly taking place in the passenger car category.

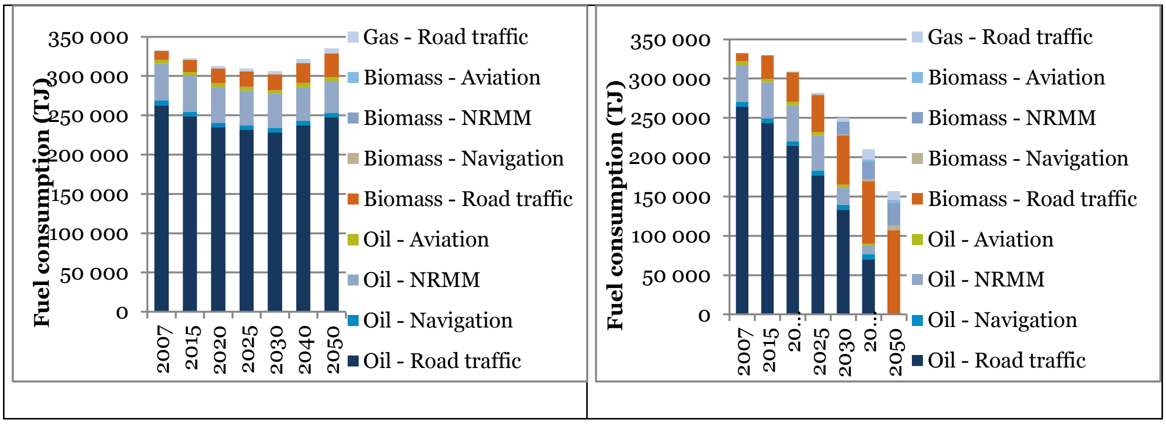


Figure 47. Fuel consumption (TJ) by type of transportation and fuel based on Roadmap2050 (left) and NETP-CNBS (right).

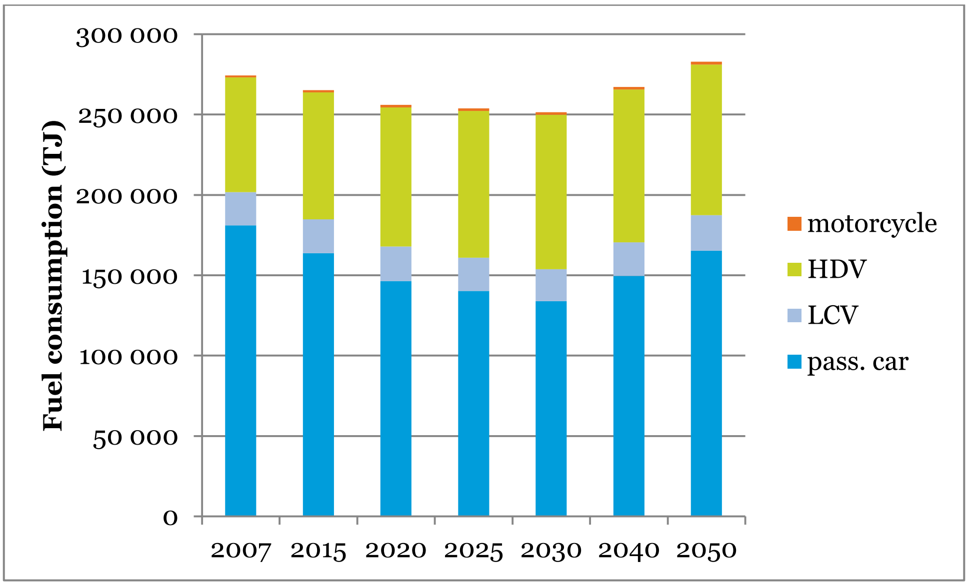


Figure 48. Fuel consumption (TJ) for road transportation based on Roadmap 2050. (HDV=Heavy Duty Vehicles, LCV= Light Commercial Vehicle)

5.4.2 Emissions from domestic transport

Emission scenarios for $PM_{2.5}$, BC, OC, NO_X, NMVOC and Hg from domestic transports are presented in Figure 49 to Figure 54. For all pollutants, except for Hg, and regardless of scenario, large emission reductions are expected up to 2030. In Figure 49 to Figure 51 it can also be seen that are only minor differences in particulate matter emissions ($PM_{2.5}$, BC and OC) from domestic transport (including non-road mobile machinery, NRMM) between Roadmap2050 and NETP-CNBS, given the same EFs. The slightly lower emissions 2050 for NETP-CNBS are due to the lower total fuel consumption.

From Figure 49 it is obvious that EU baseline (EU BL) IEFs are significantly higher for $PM_{2.5}$ compared to Swedish national EFs (SW), which can be traced back to higher EFs for gasoline NRMM in households.

EU baseline emission data (EU BL-EU BL) are on comparable levels with the RM-SW scenario on $PM_{2.5}$ and BC emissions (Figure 49 and Figure 50, respectively). However, for OC (Figure 51) EU baseline emission data shows significantly higher emission levels all years due to high estimates of OC from gasoline NRMM in households.

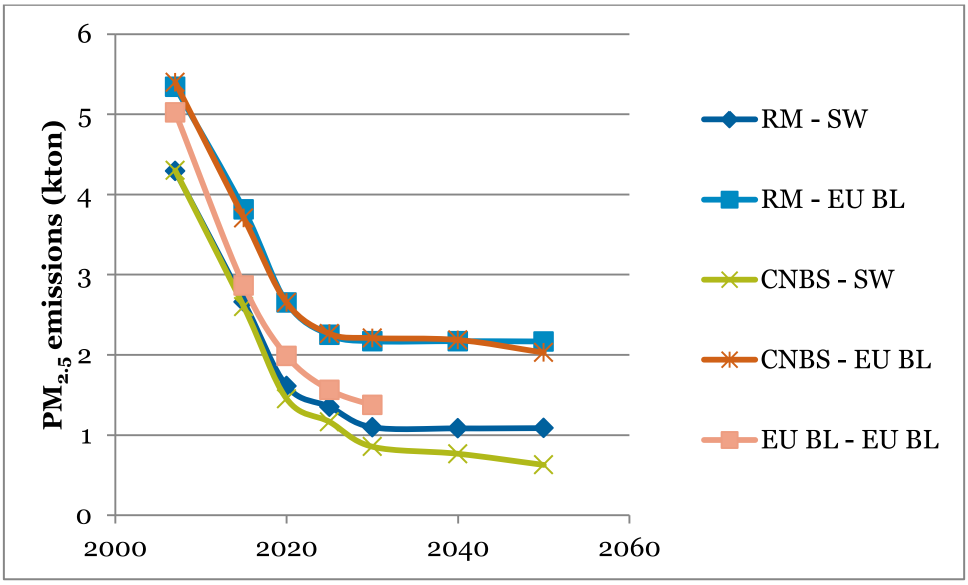


Figure 49. Estimated emissions of $PM_{2.5}$ from domestic transport in the different scenarios.

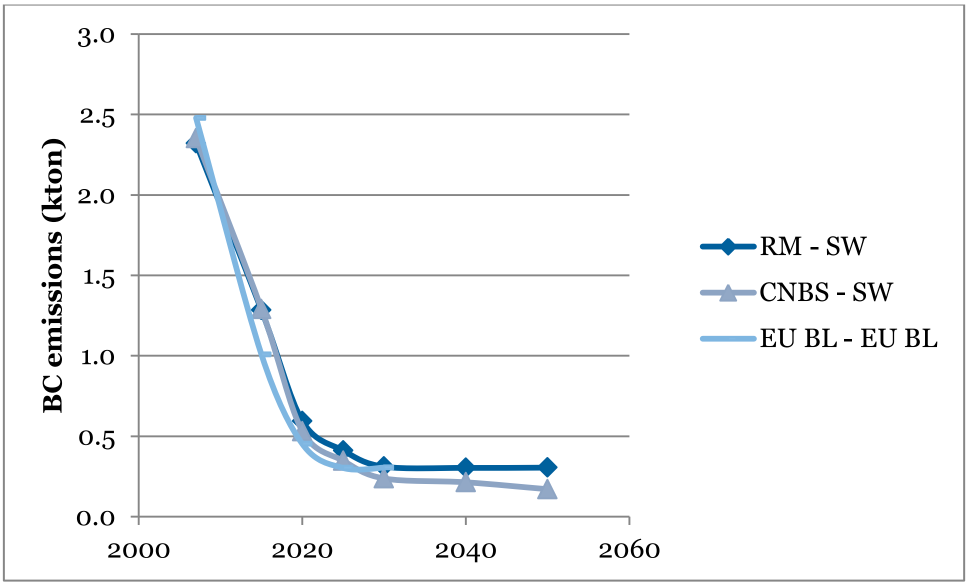


Figure 50. Estimated emissions of BC from domestic transport in the different scenarios.

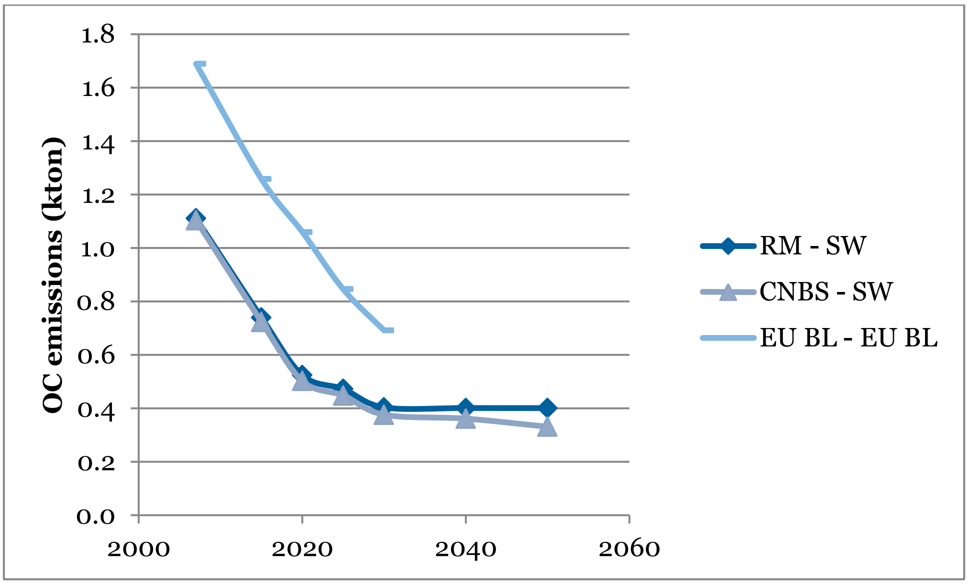


Figure 51. Estimated emissions of OC from domestic transport in the different scenarios.

For NO_X and NMVOC emissions (Figure 52 and Figure 53, respectively), all scenarios show similar results until 2030. After 2030 the NETP-CNBS indicate a slight decrease in emissions compared to Roadmap2050 due to reduced fuel consumption.

Hg emissions from domestic transports (Figure 54) almost solely stem from heavy fuel oil (HFO) used in shipping. The EU Directive (2012/33/EU) will most likely lead to significantly reduced use of HFO. As the consequences of the EU directive has been taken into account in the NETP-CNBS scenario it shows large Hg emission reductions until 2020 compared to the Roadmap2050 scenario.

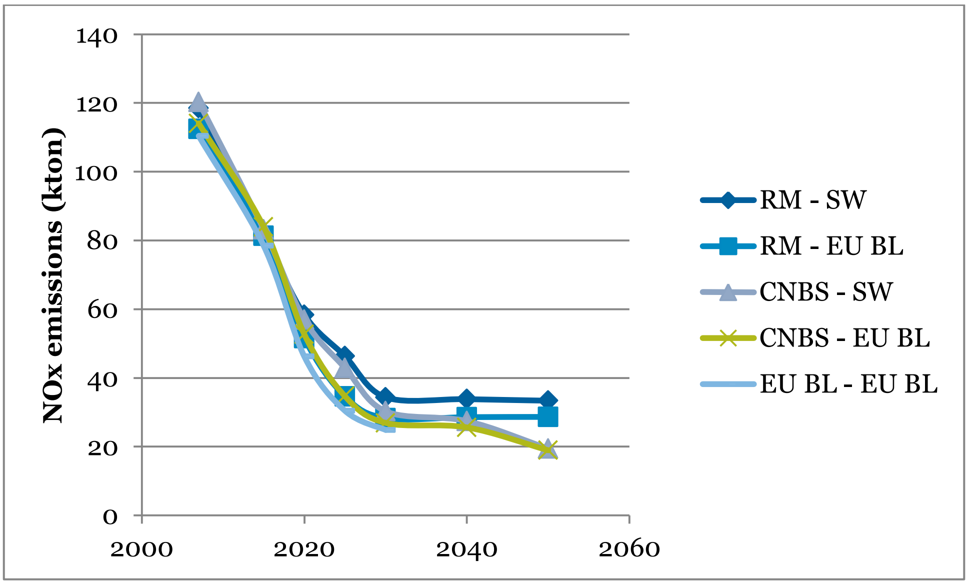


Figure 52. Estimated emissions of NO_X from domestic transport in the different scenarios.

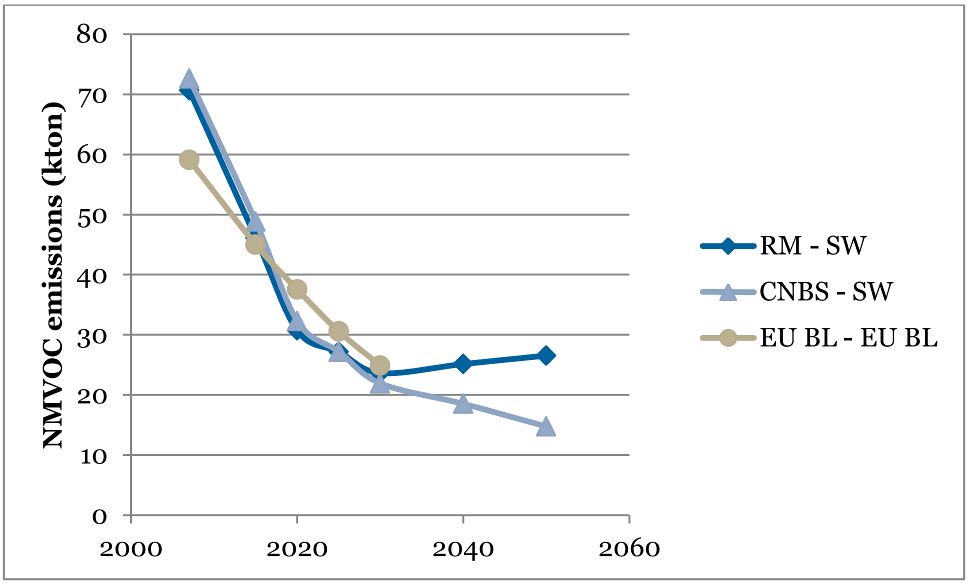


Figure 53. Estimated emissions of NMVOC from domestic transport in the different scenarios.

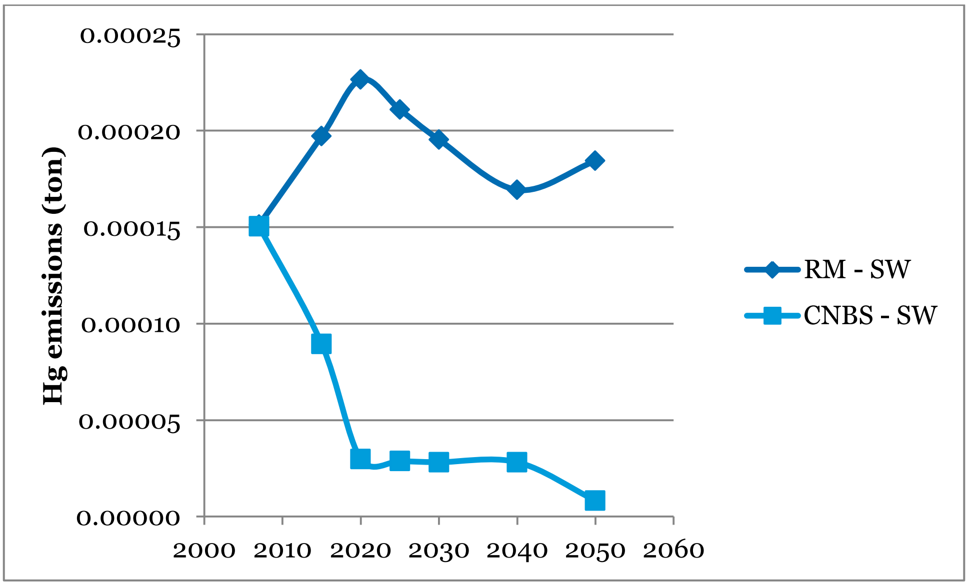


Figure 54. Estimated emissions of Hg from domestic transport in the different scenarios.

6 Emission scenario results – International transport

This section describes scenarios for international transport.

6.1.1 Fuel consumption in international transport

In Figure 55 below the fuel consumption 2007-2050 in international aviation and international navigation based on Roadmap2050 (left) and NETP-CNBS (right) is presented. It can be seen that the majority of fuels are used by marine vessels. In Roadmap2050, no introduction of biofuels is expected, whereas in NETP-CNBS, all fossil fuels are assumed to be replaced by biofuels by 2050. In NETP-CNBS, the total fuel consumption 2050 is slightly lower compared to Roadmap2050 (149 PJ and 158 PJ, respectively).

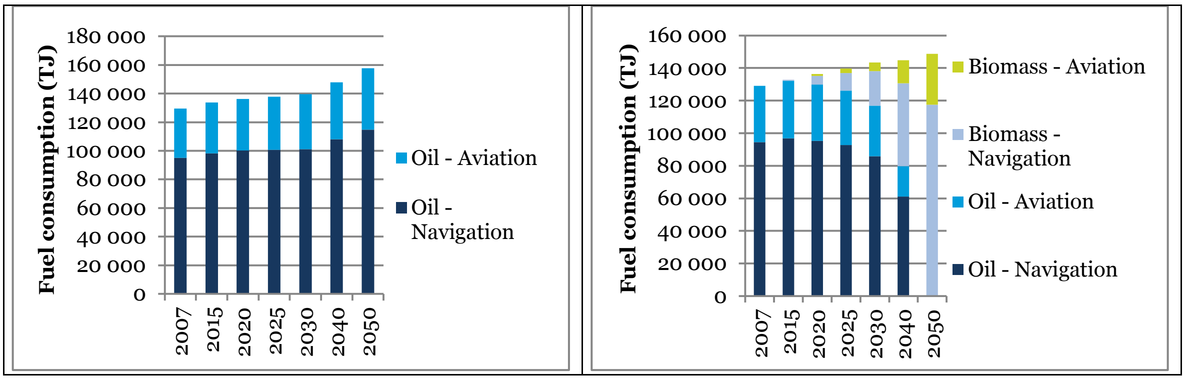


Figure 55. Fuel consumption (TJ) by type of international transportation and fuel based on Roadmap2050 (left) and NETP-CNBS (right).

6.1.2 Emissions from international transport

$PM_{2.5}$, BC, OC, NO_X, NMVOC, Hg emissions based on Roadmap2050 (RM) and NETP-CNBS using Swedish national EFs (SW) are presented in Figure 56 to Figure 61.There are significant differences in emission levels for all pollutants, except NMVOC, due to the forthcoming phase out of HFO (from 2015) which is not taken into account in Roadmap2050. This affects all pollutants except NMVOC significantly. The same EFs are applied for oil fuels and biofuels in the two scenarios. No EU baseline emission data has been extracted for international transport.

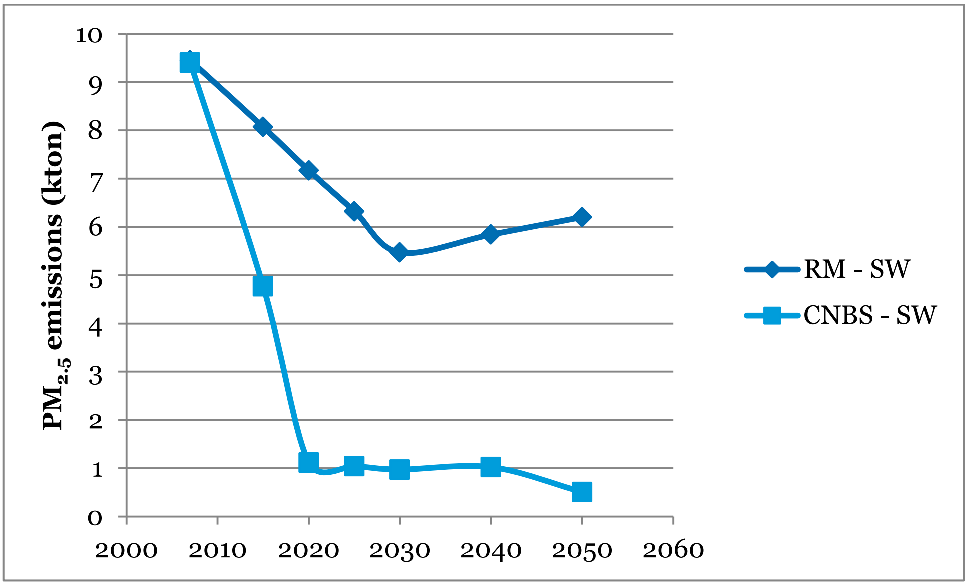


Figure 56. Estimated emissions of $PM_{2.5}$ from international transport in the different scenarios.

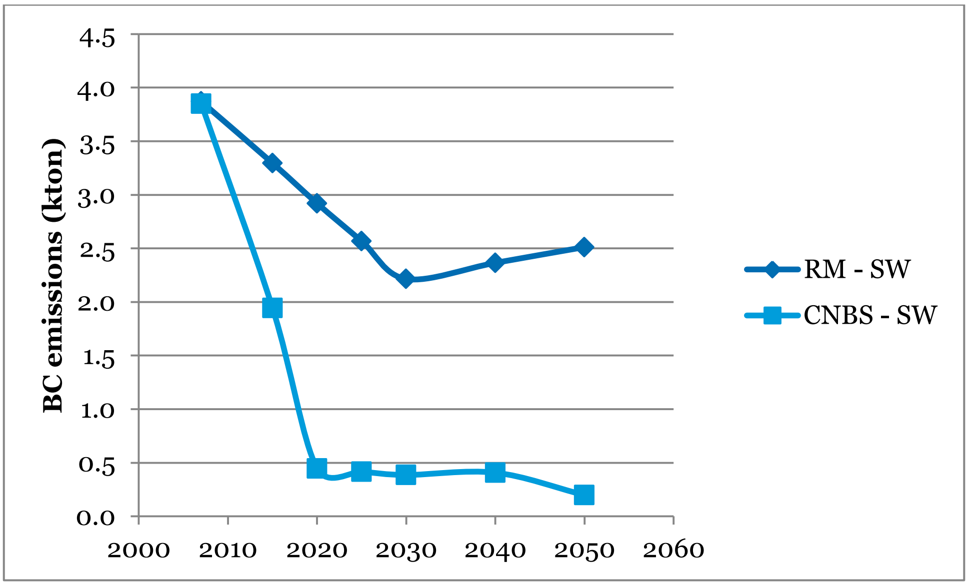


Figure 57. Estimated emissions of BC from international transport in the different scenarios.

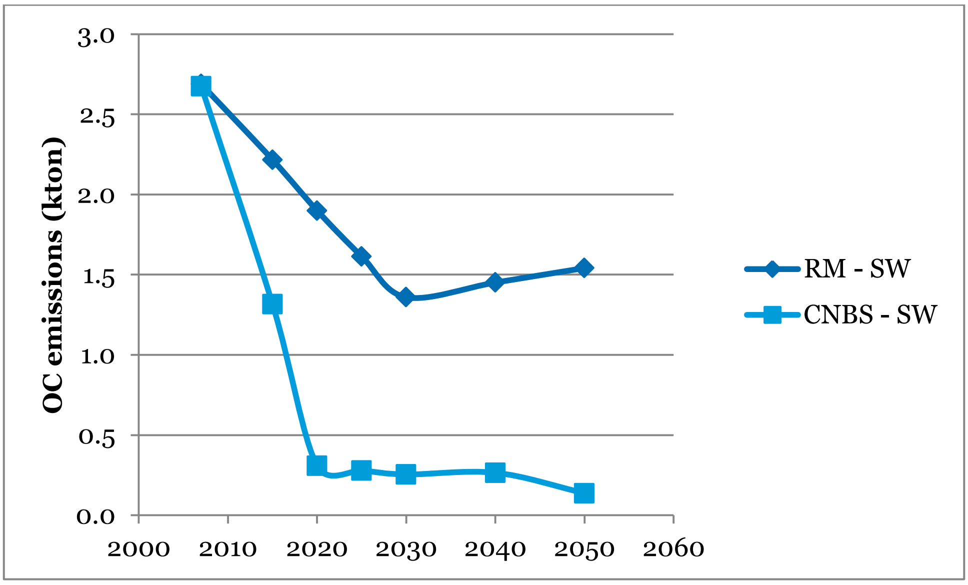


Figure 58. Estimated emissions of OC from international transport in the different scenarios.

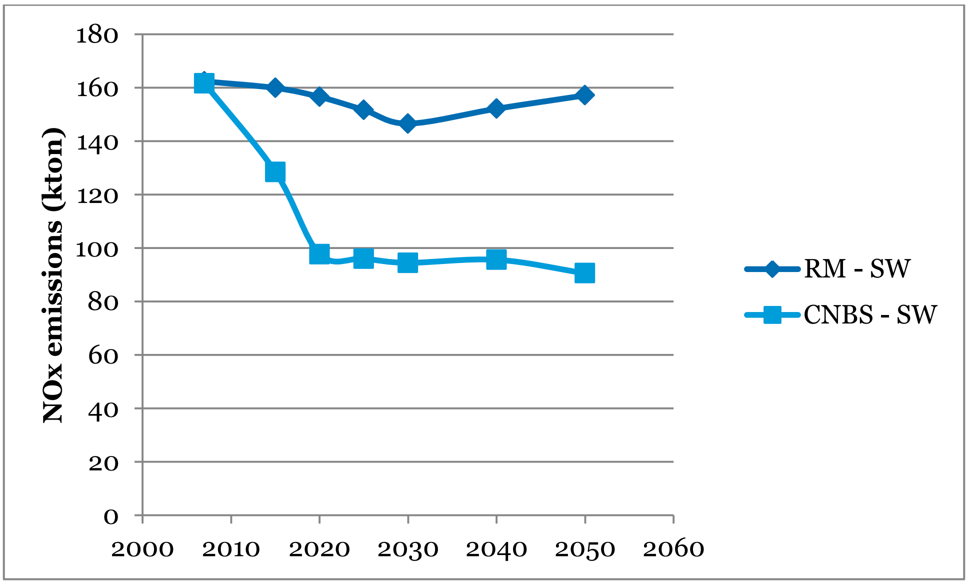


Figure 59. Estimated emissions of NO_X from international transport in the different scenarios.

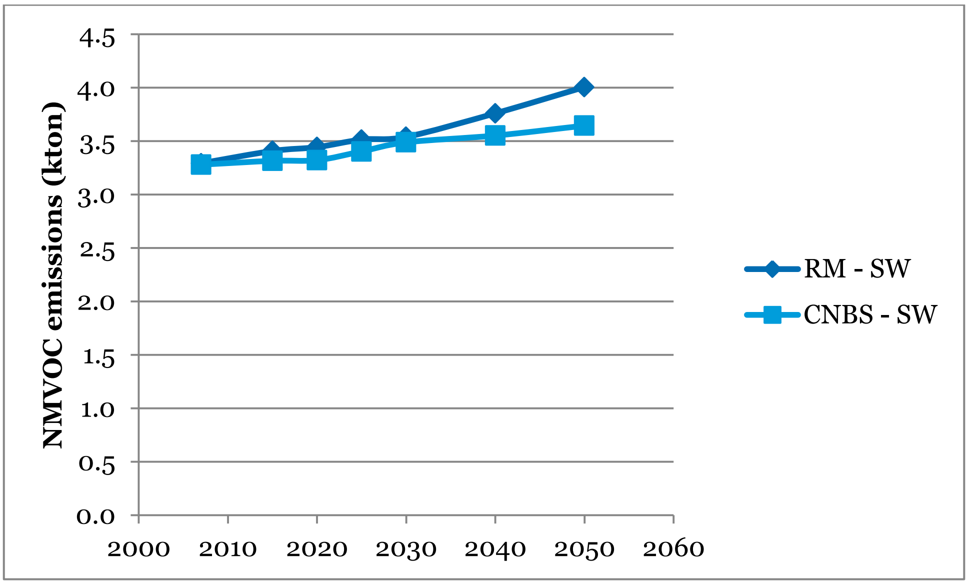


Figure 60. Estimated emissions of NMVOC from international transport in the different scenarios.

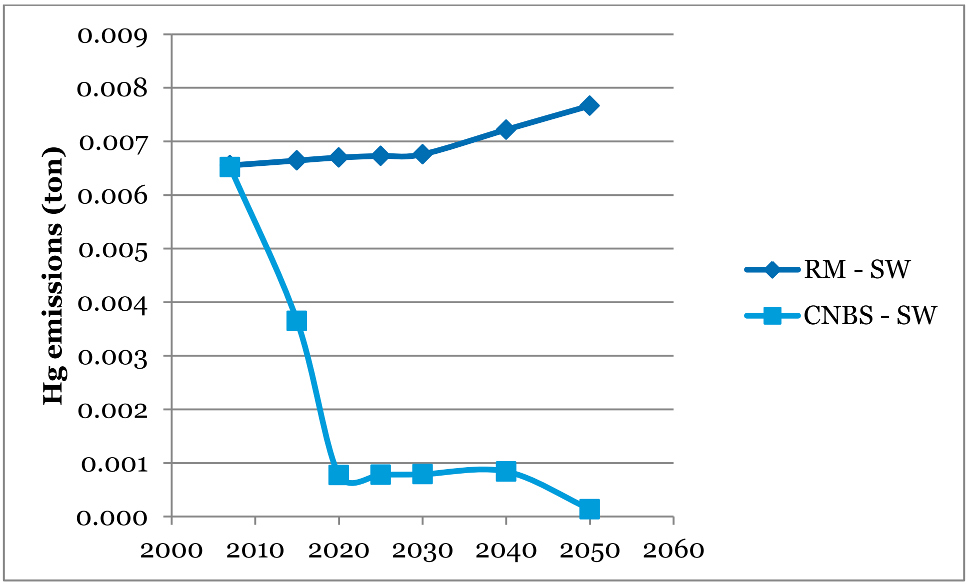


Figure 61. Estimated emissions of Hg from international transport in the different scenarios.

7 Biomass as a resource

In several parts of the world, competition on productive areas of forest and land-use is becoming more and more intense and natural resources are at risk of being drained for short term profit and capitalization. E.g. in Brazil, large areas of Amazonas' rainforest has been cut down to make way for different types of crops (sugarcane for ethanol production, coffee, soybeans, etc.). The production of sugarcane for ethanol production has been questioned in terms of meeting the environmental and social sustainability criteria (see for instance Staffas et al, 2013), which could lead to limitations on the availability of liquid biofuels as a renewable resource to the EU in the future. However, the amount of ethanol imported from Brazil to Sweden or ethanol produced based on imported biomass feedstock from Brazil has decreased significantly in 2012 compared to previous years. According to the Swedish Energy Agency (2013a), in 2012, biomass feedstock for ethanol from Brazil and several other countries accounted only for 13.5% of the Swedish import, which was a significant decrease compared to previous years. Instead the use of biomass feedstock from Sweden and other EU countries has increased in recent years. In 2012, about 31% of the Swedish ethanol consumption was produced based on Swedish feedstocks (predominantly wheat and corn) (Swedish Energy Agency, 2013a). For production of FAME (Fatty Acid Methyl Ester) in 2012, most of the feedstocks (predominantly rapeseed) came from EU countries (Lithuania and Denmark the largest contributors), whereas hydrotreated vegetable oil (HVO) is mostly based on tall oil from the domestic kraft pulp processes.

The EU Renewable Energy Directive (2009/28/EC) states, for example, that by 2020, 20 % of final energy consumption should come from renewable sources, that no biofuels should come from carbon rich or bio-diverse land, and that compliance with environmental and social sustainability criteria has to be reported for imported biofuels.. In 2012, on average 14% of gross final energy consumption/use in EU countries (EU28) came from renewable energy sources (Eurostat, 2014). A major share of the renewable energy in EU28 in 2012 stems from solid biomass fuels (about 47%), whereas liquid biofuels accounted for about 9% (Eurostat, 2014). From 2004, the use of liquid biofuels in EU28 has increased by a factor of six from about 89 PJ to about 658 PJ in 2012. To reach the 20% renewable energy goal by 2020, the use of liquid biofuels is likely to further increase in the EU.

7.1 Biomass use for energy purposes in Sweden

In 2012, most of the biomass supply and use for energy purposes in Sweden stem from domestic biomass production (Swedish Energy Agency, 2013a). However, statistics on supply of solid biomass through import is not fully covering all sources as private traders may transport fuels across borders without being part of the official trade statistics. E.g. in the Swedish energy balances, no import or export of solid biomass is reported (Swedish Energy Agency, 2013a), but according to the Swedish Pellet Association (2014), in 2012, about 491 kton (or 8 PJ) biomass pellets were imported.

Emission estimations for the energy sector reported for Sweden to the UNFCCC and CLRTAP are based on the use of fuels covered by the Swedish Energy Agency's various fuel consumption surveys. In 2012, about 279 PJ[3] of biomass was used for energy purposes in Sweden (Swedish EPA, 2014). Solid biomass used for power and heat production and in small scale combustion accounted for the major part of the biomass use (about 181 PJ). The industry, mainly pulp and paper industry, accounted for about 73 PJ[3] of biomass use in 2012. Remaining 25 PJ were used as biofuels in road transportation, mainly as FAME (Fatty Acid Methyl Esters) (9 PJ), ethanol (8 PJ), HVO (5 PJ) and biogas (3 PJ) (Swedish Energy Agency, 2013a). In addition, some minor amounts of ETBE (Ethyl Tert-Butyl Ether) and DME (Dimethyl ether) were used.

In Table 7 the biomass use (PJ) in 2007 and biomass use scenarios in 2020, 2030 and 2050 based on Roadmap2050 and NETP-CNBS, respectively, are presented. It can be seen that in 2050 the biomass use in NETP-CNBS (593 PJ) is assumed to be significantly higher than in Roadmap2050 (294 PJ). This is mainly due to assumptions on much higher liquid biofuel use in transports (domestic and international).

[3] This figure excludes black liquor.

Also for small scale combustion in 2050, NETP-CNBS (72 PJ) points to a higher biomass consumption compared to Roadmap2050 (44 PJ).

In the NETP-CNBS, about 159 PJ biomass as total primary energy supply is assumed to be imported. Remaining amounts of biomass, about 434 PJ (excluding black liquor from pulp and paper processes), are assumed to be supplied by the domestic market.

It is apparent that the availability of domestically produced and imported biomass could restrict a pathway to phase out the use of fossil fuels for combustion in Sweden by 2050.

Table 7. Biomass fuel consumption (PJ) in Sweden 2007-2050 by sector based on the Roadmap2050 and NETP-CNBS scenarios.

Scenario	Sector	Biomass fuel consumption for energy purposes (PJ)*				
		2007	2020	2030	2040	2050
Roadmap2050	Power and heat production	103	122	126	128	130
Roadmap2050	Industry	70	81	85	87	89
Roadmap2050	Small scale combustion	50	55	50	47	44
Roadmap2050	Domestic transport	11	19	20	25	30
Roadmap2050	International transport	0	0	0	0	0
Roadmap2050	**Total**	**235**	**276**	**281**	**288**	**294**
NETP-CNBS	Power and heat production	103	139	136	124	124
NETP-CNBS	Industry	70	81	85	91	103
NETP-CNBS	Small scale combustion	49	53	60	65	72
NETP-CNBS	Domestic transport	10	38	81	107	146
NETP-CNBS	International transport	0	6	26	65	149
NETP-CNBS	**Total**	**233**	**317**	**388**	**452**	**593**

* Excluding black liquor

Most of the harvested wood in Sweden is used for non-energy production purposes. At present, about 90% (or 600 PJ) of total extracted biomass (stem wood, bark and GROT (branches and tops)) is used for wood products (Swedish Forest Industries, 2013). Main wood products in Sweden are paper, pulp and other wood products (e.g. plywood). However, wood chips and saw dust as by-products from the sawmill industry are used as fuels, either non-processed or as pellets and briquettes. According to the Swedish Forest Industries (2013), about one fifth of total domestically harvested biomass is used as primary or secondary fuel for energy purposes in Sweden.

Already today there is a potential to use more domestically harvested biomass for energy purposes. Below, estimations of the potential of harvested biomass output based on CLEO project *Strategies for future forest management* is described. It presents the theoretical possibility to increase the extraction of different tree segments (stems, stumps, etc.). It is not within the scope of this study to make scenarios on how the stem and bark may be used for different purposes (wood products, primary or secondary fuels) up to 2050.

7.2 CLEO project harvested biomass output

A tree consists of roots, stump, stem, branches and top (Swedish abbreviation GROT). GROT and stumps is solid biofuel suitable for large scale combustion, but is also expected to be a potential feedstock for liquid and gaseous biofuels. Today, about 50-60% of the tree's total biomass is extracted at a typical harvest (Staffas et al, 2013).

In Hellsten et. al. (2014), the CLEO project *Strategies for future forest management* on total gross amount of harvested biomass output (stems wood, bark, branches and tops (GROT) and stumps) from three scenarios are presented (Business as usual - BUS, Medium Biomass Removal - MBR and High Biomass Removal - HBR). In this study the HBR scenario has been used to give an indication on the theoretical upper range on domestic biomass fuel production.

Note that agriculture residues are not included in the study.

The estimated potential annual extraction of harvested biomass in Sweden 2020, 2030, 2040 and 2050 according to the High Biomass Removal (HBR) scenario from CLEO project *Strategies for future forest management* is presented in Table 8. An average conversion factor of 18 GJ/ton harvested biomass has been applied (based on Strömberg, 2008). In total 2050, the HBR biomass potential amounted to about 1338 PJ, including stem wood and bark, GROT and stumps. The HBR scenario indicates that the theoretical potential of GROT and stumps extraction in 2050 is about 447 PJ. Note that stumps are presently not harvested and used for energy purposes to large extent due to economical, technical and sustainability limitations.

As seen in the previous section the estimated use of biomass for energy purposes for NETP-CNBS (Table 7) (excluding black liquor) 2050 is 593 PJ. Without taking economical, technical, social or sustainable implementation limitations into consideration, the HBR scenario indicate that there is a theoretical potential to cover a significant part of the future national biomass need through domestic biomass fuel production. For more information on restrictions, limitations and uncertainties regarding the use of GROT and stumps as biomass fuel in Sweden, see for example Swedish Energy Agency (2013b) and Strömberg (2008).

Table 8. Estimated potential future annual extraction of domestic biomass 2020-2050 (PJ) based on the High Biomass Removal (HBR) scenario from CLEO project *Strategies for future forest management*.

Type of harvested biomass	HBR annual extraction (PJ)			
	2020	2030	2040	2050
Stem wood and bark	679	745	819	891
GROT (branches and tops)	187	188	208	228
Stumps	173	191	203	219

The price of harvesting, producing and using the forest biomass residues (branches and tops (GROT), and stumps) as fuel in relation to forest industry by-products (bark, wood chips, saw dust, black liquor, etc.) influences the level of biomass output in Sweden (Staffas et. al., 2013). In order to create incentives for increased biomass extraction for energy purposes there is a need for compatible prices for forest biomass residues for fuel use.

7.3 Other studies on future biomass production and use in Sweden

There are several recent studies available on scenarios for future potential production and use of biomass as fuel in Sweden. Below short summaries of the studies are presented. Based on the information on these studies, it is obvious that the magnitude of future production and use of biomass fuels in Sweden is uncertain.

In Hansson and Grahn (2013), a number of scenarios on the present and future potential of renewable liquid road fuel production and use in Sweden were compiled via the literature and by personal communication with various producers. The study points to a wide range of possible future scenarios. For 2020 and 2030, it was estimated that renewable fuels could account for about 25-58 PJ and 47-108 PJ, respectively. The amount of domestically produced biofuels in 2020 and 2030 were estimated to 18-47 PJ and 47-94 PJ, respectively.

According to Ecotraffic (2013), in 2030, there will be need for about 72 PJ of liquid biofuels for transports in Sweden. It was estimated that the technical potential 2030 for domestically produced biofuels for transports could be 307 PJ. It was thus concluded that the theoretical potential of producing biofuels in Sweden 2030 exceeds the estimated need.

In Staffas et al (2013), a compilation of 24 biomass resource assessments for Sweden were presented. For 2030, the biomass energy potentials roughly ranged to about 500-700 PJ (including fuel wood, stem wood, stumps, primary and secondary residues, and black liquor). Too few data was available and presented for 2050 to be included here.

8 Discussion and conclusions

The main conclusions of this CLEO study are:

- Emissions of fossil-related carbon dioxide in Sweden could be reduced by increased substitution of fossil fuel by biomass fuels
- Increased use of biomass fuels may lead to conflicts of interests between the Swedish environmental objectives, “Clean Air” and ”Reduced Climate Impact”
- The magnitude of future particulate matter (PM) emissions is largely dependent on the end use sector, the combustion and emission abatement technology, and the type and quality of biomass used
- There is a need for further studies on the current stock and use of existing small scale combustion appliances in Sweden along with technology specific Swedish PM emission factors

In this study, Swedish emission scenarios have been developed based on fuel consumption from the Swedish Roadmap2050 (reference scenario) and IEA Carbon-Neutral high Biomass Scenario (NETP-CNBS) with Swedish national emission factors and BAT (Best Available Technology) emission factors. In addition, emission data from the EU commission baseline have been used as a comparison. The study has focused on analyzing the results for particulate matter (PM) emissions ($PM_{2.5}$, BC and OC) but NO_X, NMOVC, Hg (and to some extent CH_4) emissions are also included.

The results show that national total (excluding international transport) PM emissions 2007-2030 are expected to decrease significantly in all scenarios, primarily due to reductions in the domestic transport sector. Moreover, this study indicates that PM emission trends 2030-2050 largely would depend on the end use sector, the combustion and emission abatement technology, and the type and quality of biomass used in Sweden.

In 2007 (i.e. the emission scenario base year), the largest contribution to national total PM emissions (excluding international transport) reported to the CLRTAP stems from small scale combustion, followed by domestic transport. Consequently, the most significant differences in the PM emission scenarios to 2050 could be found in the small scale combustion sector. The future emissions of particles from small scale combustion are highly dependent on the type of future combustion technologies. Assuming future technologies comparable to current conditions, an increased use of biomass would lead to increased emissions of particles. On the other hand, a transition to modern appliances, comparable to automatic pellets boilers, would lead to substantial PM emission reductions, also under assumptions of increased biomass fuel consumption (i.e. NETP-CNBS). The technology of combustion appliances thus largely determines the level of PM emissions from small scale biomass combustion, as inefficient combustion conditions lead to higher emissions. PM emissions are however also significantly affected by firing conditions and the quality of biomass fuel. Older and improperly used wood log boilers or stoves are expected to emit significantly more PM emission than do modern, more technically advanced and well maintained boilers and stoves. An increased use of appliances that restrict the possibility of ineffective firing habits (e.g. automatic pellet boilers, advanced wood log boilers) may significantly reduce the PM emissions.

The results in this study indicate that PM emissions from transport, except for navigation, in Sweden are not dependent on type of fuel used, but primarily on abatement technology (vehicle emission standards, EURO standards). Hence, increased use of biofuels would not significantly affect the PM emission from transport, under the assumption that they are replacing fossil fuels. In all scenarios, PM emissions from transport (excluding navigation) are expected to decease significantly until 2030, due to improved abatement technologies in modern vehicles and machineries, and stay more or less levelled until 2050. Currently, for domestic and international navigation, the PM emissions are strongly correlated with the amount of heavy fuel oil (HFO) used. The implementation of EU and global agreements on SO_X emission limitations will most likely lead to a rapid switch from the use of HFO to low-sulphur marine gas oil (LSMGS) inside the Sulphur Emission Control Areas (SECAs), affecting not only SO_X emissions, but also leading to significantly reduced PM and NO_X emissions.

For power and heat production and industry, the analysis shows that replacing fossil fuels with solid biomass may cause higher PM emissions unless improved abetment technologies are installed. The increase in PM emissions would mainly occur for power and heat production if waste used as fuel is replaced by solid biomass due to the stricter standards for installed emission abetment techniques when using waste as fuel. Implementing BAT in power and heat production and industry could lead to lower PM emissions, also under assumptions of increased biomass use. However, due to substantial uncertainties in the relevant national EFs for PM emissions from these sources, as indicated above, in this study, we do not draw any conclusions on the magnitude of the possible reductions.

Power and heat production plants in Sweden use both solid and liquid biomass fuels. The historic data from Roadmap2050 shows that the major part of biomass consumption consists of solid biomass fuels. The use of liquid biomass fuels in this sector has increased over time and may continue to do so in the future. However, the Roadmap2050 scenario does not assume large increase in liquid biomass up to 2050. As solid biomass fuels have significantly higher EF than do liquid biomass fuels it would be interesting to investigate the impact on air pollutants of increased use of liquid biomass in this sector.

Up until 2025 there are relatively small differences in PM emission scenarios based on Roadmap2050 with national EFs compared to emission data from the EU baseline for Sweden (available up to 2030). The differences in emissions could be explained by the differences in underlying activity data and methodological issues between the two emission scenario estimation approaches. However, the gap in PM emission increases 2025-2030 for all PM fractions ($PM_{2.5}$ BC and OC), and it would be of interest to further study the driver of these expanded differences.

In this study, the results from CLEO project *Strategies for future forest management* High Biomass Removal scenario (HBR) are used to analyze if the potential for increased use of biomass for energy purposes could be harvested from the Swedish forest by 2050. The analysis indicates that there is a theoretical potential to fulfill most of the needs also at assumptions of a high biomass use scenario (i.e. the NETP-CNBS). In particular, the potential to harvest GROT (branches and tops) and stumps could account for a majority of the increased biomass output. However, their production costs and technical properties in relation to other biomass products and by-products will likely determine the future domestic biomass output in Sweden.

8.1 Discussion on the reliability of results

An emission scenario should not be seen as a prediction or a forecast but rather as an image of the future given certain criteria. The outcome of a scenario may be considered highly unlikely during present circumstances, but could help to shape future political and technical pathways. However, a scenario could be considered to be more or less reliable depending on the various elements underpinning the calculations. In any scenario study there are several sources of uncertainties in scenario outputs: uncertainties in quantities (e.g. EFs based on measurements), uncertainties due to biases in the model structure that could lead to omission or double counting of emission sources, and uncertainties that arise from assumptions (e.g. economic drivers underpinning certain production data trends, or high availability of biomass fuels).

In this study, no quantified uncertainty analysis has been performed. However, the results are likely less reliable for certain sectors and parameters than for others, e.g. small scale biomass combustion and non-road mobile machinery (NRMM).

For small scale biomass combustion, as mentioned above, there are uncertainties in the level of estimated PM emissions due to different existing emission measurement methods to derive emission factors. Compared to EU countries using emission factors for PM based on dilution tunnel measurements, the Swedish reported PM emission from small scale combustion of biomass may be significantly lower since they are based on emission factors derived from hot flue gas measurements. Another contribution to the uncertainties in emission from the small scale biomass combustion sector is the lack of sufficiently detailed knowledge of the type and extent of use of existing small scale combustion appliances in Sweden. With current knowledge, technology specific estimations of emissions are not possible. This also implies that it is not possible to estimate future potentials for emission reductions based on solid knowledge of current conditions, but rather on assumptions and expert judgments regarding the present conditions and technology stock. However, the uncertainty in emission factors for modern, technically advanced appliances for small scale combustion is relatively low as efficient combustion conditions lead to smaller variation in emission measurements, regardless of measurement method. Hence, the results for the BAT scenarios for 2050 can be considered reliable given the assumptions made in this study on the high future implementation rate of modern burners.

Moreover, for NRMM (non-road mobile machinery) the future implementation of stricter emission standards and regulations is uncertain and thus the phase-out scheme of older machinery is not as reliable as for e.g. road traffic vehicles.

Generally, as the emission scenarios are based on historic data, any scenario is more reliable closer to the base year than in 2050.

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Appendix A NETP-CNBS energy scenario data

Table A 1. Total energy supply 2010-2050 by energy carrier based on NETP-CNBS. (More detailed NETP-CNBS data by sector has been used in this study.)

Energy carrier (PJ)	**2010**	**2015**	**2020**	**2025**	**2030**	**2040**	**2050**
Coal	104	91	77	63	44	17	10
Oil	692	506	507	463	409	237	80
Gas	61	41	48	47	45	44	41
Nuclear	631	609	674	674	602	609	747
Hydro	239	236	238	243	252	252	252
Biomass* and waste	498	615	653	681	738	787	828
Other renewables	13	32	46	67	120	160	189
Net import of electricity	7	9	-34	-50	-76	-94	-133
Sum	**2 246**	**2 138**	**2 208**	**2 187**	**2 134**	**2 011**	**2 013**
Biomass net imports	-	*23*	*14*	*58*	*81*	*148*	*159*

***Note that these figures included black liquor used in industrial processes (around 150-200 PJ annually) and thus are excluded from calculations made in this study.**

Appendix B Emission factors

The EFs presented below for 2040 and 2050 (in *italics*) for stationary combustion are estimated in this study by extrapolating the 2030 values. As mentioned previously in this report, this assumption may lead to overestimation of emissions in several cases and thus caution should be taken when analyzing the absolute values for emission estimations for 2040 and 2050. For transport (excluding road transport), a quick review of the EFs was made within this study.

Emission factors for stationary combustion (excluding small scale biomass combustion)

$PM_{2.5}$

Table B 1. Swedish national $PM_{2.5}$ emission factors for stationary combustion (excluding small scale biomass combustion) used in the latest projection submission to the CLRTAP. The EFs 2040 and 2050 (in *italics*) are estimated in this study by extrapolating the 2030 values.

Fuel category	Fuel	Sector	PM2.5 (g/GJ)						
			2007	2015	2020	2025	2030	*2040*	*2050*
Biomass	Landfill gas	Power and heat production, industry	0.1	0.1	0.1	0.1	0.1	*0.1*	*0.1*
	Other biomass	Industry	28.0	28.0	28.0	28.0	28.0	*28.0*	*28.0*
		Power and heat production	24.5	24.5	24.5	24.5	24.5	*24.5*	*24.5*
	Tall oil	Power and heat production, industry	2.0	2.0	2.0	2.0	2.0	*2.0*	*2.0*
	Wood fuel	Industry	28.0	28.0	25.2	23.8	22.4	*22.4*	*22.4*
		Power and heat production	24.5	24.5	22.0	20.8	19.6	*19.6*	*19.6*
Coal	Blast furnace gas, Coke oven gas, Steel converter gas	Power and heat production, industry	1.0	1.0	1.0	1.0	1.0	*1.0*	*1.0*
	Coke	Industry	21.0	21.0	21.0	21.0	21.0	*21.0*	*21.0*
	Coking coal, Other bituminous coal	Industry	9.0	9.0	9.0	9.0	9.0	*9.0*	*9.0*
	Coking coal, other bituminous coal	Power and heat production	16.6	16.6	16.6	16.6	16.6	*16.6*	*16.6*
	Other solid fuels, Other not specified fuels	Power and heat production, industry	35.0	35.0	35.0	35.0	35.0	*35.0*	*35.0*
	Peat	Power and heat production, industry	24.5	24.5	22.0	20.8	19.6	*19.6*	*19.6*

Fuel category	Fuel	Sector	PM2.5 (g/GJ)						
			2007	**2015**	**2020**	**2025**	**2030**	***2040***	***2050***
Gas	Natural gas	Power and heat production, industry	0.1	0.1	0.1	0.1	0.1	*0.1*	*0.1*
		Small scale combustion	0.5	0.5	0.5	0.5	0.5	*0.5*	*0.5*
Oil	Gas works gas	Power and heat production, industry	0.1	0.1	0.1	0.1	0.1	*0.1*	*0.1*
		Small scale combustion	0.5	0.5	0.5	0.5	0.5	*0.5*	*0.5*
	Gas/diesel oil	Power and heat production, industry	2.0	2.0	2.0	2.0	2.0	*2.0*	*2.0*
		Small scale combustion	3.0	3.0	3.0	3.0	3.0	*3.0*	*3.0*
	Kerosene	Power and heat production	2.0	2.0	2.0	2.0	2.0	*2.0*	*2.0*
	LPG	Power and heat production, industry	0.1	0.1	0.1	0.1	0.1	*0.1*	*0.1*
		Small scale combustion	0.2	0.2	0.2	0.2	0.2	*0.2*	*0.2*
	Refinery gases, Other petroleum fuels	Power and heat production, industry	35.0	35.0	35.0	35.0	35.0	*35.0*	*35.0*
	Residual fuel oil	Power and heat production, industry	8.3	8.3	8.3	8.3	8.3	*8.3*	*8.3*
		Small scale combustion	12.5	12.5	12.5	12.5	12.5	*12.5*	*12.5*
Waste	Waste		0.8	0.8	0.7	0.7	0.6	*0.6*	*0.6*

Table B 2. Low and high TSP (Total Suspended Particles) BAT EFs from EMEP/EEA Guidebook 2013 (Table 6-1). Based on this information, an average $PM_{2.5}$ BAT EF of 5 g/GJ was applied for all fuels and boilers in this study.

Fuel category	New or existing plant	Boiler size or technology (MWth)	Emission factor (g/GJ)	
			Low	High
Coal	new	50-100	1.8	7.2
		100-300	1.8	7.2
		>300	1.8	7.2
	existing	50-100	1.8	10.9
		100-300	1.8	10.9
		>300	1.8	10.9
Wood fuels	new	50-100	1.9	7.7
		100-300	1.9	7.7
		>300	1.9	7.7
	existing	50-100	1.9	7.7
		100-300	1.9	7.7
		>300	1.9	7.7
Oil	new	50-100	1.4	5.7
		100-300	1.4	5.7
		>300	1.4	2.8
	existing	50-100	1.4	8.5
		100-300	1.4	7.1
		>300	1.4	5.7

NO_X

Table B 3. Swedish national NO_X emission factors for stationary combustion (excluding small scale biomass combustion) used in the latest projection submission to the CLRTAP. The EFs 2040 and 2050 (in italics) are estimated in this study by extrapolating the 2030 values.

Fuel category	Fuel	Sector	NO_X (g/GJ)						
			2007	2015	2020	2025	2030	*2040*	*2050*
Biomass	Tall oil	All consumption	130	130	100	100	100	*100*	*100*
	Landfill gas	Gas turbine/diesel power generation	50	50	40	40	40	*40*	*40*
	Landfill gas	Other consumption	50	50	40	40	40	*40*	*40*
	Wood, wood waste	Industry	80	80	80	80	80	*80*	*80*
	Wood, wood waste	Power plants and district heating	60	60	60	60	60	*60*	*60*
	Other biomass	All consumption	110	110	110	110	110	*110*	*110*

Fuel category	**Fuel**	**Sector**	**NO_X (g/GJ)**						
Coal	Carbide furnace gas	All consumption	100	100	100	100	100	*100*	*100*
	Coke oven gas	All consumption	30	30	30	30	30	*30*	*30*
	Blast furnace gas	All consumption	30	30	30	30	30	*30*	*30*
	Steel converter gas	All consumption	30	30	30	30	30	*30*	*30*
	Coking coal, other bituminous coal	Mining industry	550	550	550	550	550	*550*	*550*
		Cement industry	250	250	250	250	250	*250*	*250*
		Lime industry	200	200	200	200	200	*200*	*200*
		Power plants and district heating	80	80	80	80	80	*80*	*80*
		Other consumption	150	150	150	150	150	*150*	*150*
	Coke	All consumption	150	150	150	150	150	*150*	*150*
	Peat	All consumption	70	70	70	70	70	*70*	*70*
	Other solid fuels	All consumption	100	100	100	100	100	*100*	*100*
	Other not specified fuels	All consumption	100	100	100	100	100	*100*	*100*
Gas	Natural Gas	Gas turbine/diesel power generation	50	50	40	40	40	*40*	*40*
		Other power plants and district heating, and industries	50	50	40	40	40	*40*	*40*
		Other consumption	40	40	32	32	32	*32*	*32*
Oil	Gas/diesel oil	Gas turbine/diesel power generation	200	200	160	160	160	*160*	*160*
		Other consumption	50	50	40	40	40	*40*	*40*
	Residual fuel oil	Mining industry	650	650	520	520	520	*520*	*520*
		Cement industry	250	250	200	200	200	*200*	*200*
		Gas turbine/diesel power generation	150	150	120	120	120	*120*	*120*
		Other industries, power plants and district heating	60	60	48	48	48	*48*	*48*
		Other consumption	100	100	80	80	80	*80*	*80*
	LPG, kerosene	Power plants, district heating and industries	70	70	56	56	56	*56*	*56*
		Other consumption	50	50	40	40	40	*40*	*40*
	Gas works gas	Power plants, district heating and industries	70	70	56	56	56	*56*	*56*
		Other consumption	50	50	40	40	40	*40*	*40*
	Methane	All consumption	50	50	40	40	40	*40*	*40*
	Petroleum coke	Cement industry	250	250	250	250	250	*250*	*250*
		Other consumption	150	150	150	150	150	*150*	*150*
	Refinery oil	All consumption	60	60	48	48	48	*48*	*48*
	Other petroleum fuels	All consumption	100	100	80	80	80	*80*	*80*
	Refinery gases	All consumption	30	30	30	30	30	*30*	*30*

Waste	Municipal Solid Waste	Industry	90	90	90	90	90	*90*	*90*
		Other consumption	50	50	50	50	50	*50*	*50*

NMVOC

Table B 4. Swedish national NMVOC emission factors for stationary combustion (excluding small scale biomass combustion) used in the latest projection submission to the CLRTAP. The EFs 2040 and 2050 (in italics) are estimated in this study by extrapolating the 2030 values.

Fuel category	Fuel	Sector	2007	2015	2020	2025	2030	*2040*	*2050*
Biomass	Ethanol	Industry	20	20	20	20	20	*20*	*20*
Biomass	Landfill gas	Power and heat production	2	2	2	2	2	*2*	*2*
Biomass	Landfill gas	Industry	1	1	1	1	1	*1*	*1*
Biomass	Other biomass	Power and heat production, Industry	20	20	16	16	16	*16*	*16*
Biomass	Tall oil	Power and heat production, Industry	3	3	3	3	3	*3*	*3*
Biomass	Wood fuels	Power and heat production, Industry	20	20	16	16	16	*16*	*16*
Coal	Carbide furnace gas	Industry	2	2	2	2	2	*2*	*2*
Coal	Coke	Industry	8	8	4	4	4	*4*	*4*
Coal	Coke oven gas, Blast furnace gas, Steel converter gas	Power and heat production, Industry	2	2	2	2	2	*2*	*2*
Coal	Coking coal	Power and heat production	5	5	4	4	4	*4*	*4*
Coal	Coking coal	Industry	8	8	4	4	4	*4*	*4*
Coal	Other non-specified	Power and heat production, Industry	2	2	2	2	2	*2*	*2*
Coal	Other solid fuels	Power and heat production, Industry	2	2	2	2	2	*2*	*2*
Coal	Peat	Power and heat production, Industry	50	50	40	40	40	*40*	*40*
Gas	Natural Gas	Power and heat production	2	2	2	2	2	*2*	*2*
Gas	Natural Gas	Industry, Small scale combustion	1	1	1	1	1	*1*	*1*
Oil	Diesel Oil	Power and heat production, Industry	2	2	2	2	2	*2*	*2*
Oil	Domestic Heating	Power and heat	2	2	2	2	2	*2*	*2*

Fuel category	Fuel	Sector	2007	2015	2020	2025	2030	2040	2050
	Oil	production, Industry							
Oil	Domestic Heating Oil	Small scale combustion	6	6	6	6	6	6	6
Oil	Gas works gas	Industry, Small scale combustion	1	1	1	1	1	1	1
Oil	Kerosene	Power and heat production	2	2	2	2	2	2	2
Oil	LPG	Industry, Small scale combustion	1	1	1	1	1	1	1
Oil	Methane etc.	Industry	1	1	1	1	1	1	1
Oil	Other petroleum fuels	Power and heat production, Industry	2	2	2	2	2	2	2
Oil	Petroleum coke	Industry	8	8	8	8	8	8	8
Oil	Refinery gas	Industry	2	2	2	2	2	2	2
Oil	Refinery oil	Industry	3	3	3	3	3	3	3
Oil	Residual Fuel Oil	Power and heat production, Industry	3	3	3	3	3	3	3
Oil	Residual Fuel Oil	Small scale combustion	6	6	6	6	6	6	6
Waste	Solid waste	Power and heat production	5	5	4	4	4	4	4

Emission factors for transport (including non-road mobile machinery)

$PM_{2.5}$

Table B 5. Swedish national $PM_{2.5}$ (implied) emission factors (IEF) for road transport used in the latest projection submission to the CLRTAP. EFs for all other vehicle categories and fuels are assumed as not applicable.

Vehicle type	Fuel	$PM_{2.5}$ IEF (g/GJ)					
		2007	2015	2020	2025	2030	2050
Passanger car	Natural gas	0.3	0.4	0.4	0.4	0.4	0.4
Passanger car	Diesel oil	18.2	5.6	1.5	1.4	1.3	1.3
Passanger car	Ethanol	0.7	0.9	0.9	0.9	0.9	0.7
Passanger car	Gasoline	1.0	0.8	0.5	0.5	0.4	0.4

Light duty vehicle	Diesel oil	38.0	20.7	6.3	4.2	1.9	1.8
Light duty vehicle	Gasoline	3.0	2.7	1.5	1.4	1.3	1.3
Heavy duty vehicle	Natural gas	17.3	9.4	4.5	3.1	1.5	2.6
Heavy duty vehicle	Diesel oil	14.6	8.8	4.0	2.5	1.2	1.0
Heavy duty vehicle	Ethanol	5.1	3.0	1.2	0.8	0.4	0.4
Mopeds & motorcycles	Gasoline	35.0	22.8	13.1	11.9	10.7	9.4

Table B 6. Swedish national $PM_{2.5}$ emission factors for transport (including NRMM, excluding road transport) used in the latest projection submission to the CLRTAP.

Fuel	Sector	Subsector	PM2.5 (g/GJ)				
			2007	2020	2030	2040	2050
Aviation Gasoline	Aviation	Domestic	10.0	10.0	10.0	10.0	10.0
Gas/Diesel oil	Fisheries	Fisheries	22.8	21.0	21.0	21.0	21.0
	Off Road Vehicles and Working Machinery	Farming	39.2	14.7	9.8	9.8	9.8
		Forestry	22.5	3.3	1.7	1.7	1.7
		Households	12.8	23.0	18.4	18.4	18.4
		Industry	40.6	8.4	3.9	3.9	3.9
		Other	30.8	43.9	41.3	41.3	41.3
	Railways	Railways	95.7	33.0	33.0	33.0	33.0
	Navigation/Shipping	International	16.0	4.0	4.0	4.0	4.0
		Domestic	16.0	4.0	4.0	4.0	4.0
		Military	16.0	4.0	4.0	4.0	4.0
Gasoline	Navigation/Shipping	Military	90.0	90.0	90.0	90.0	90.0
		Small boats	90.0	43.0	43.0	43.0	43.0
	Off Road Vehicles and Working Machinery	Farming	93.1	68.3	67.1	67.1	67.1
		Forestry	67.3	70.9	73.8	73.8	73.8
		Households	60.6	46.4	45.7	45.7	45.7
		Industry	20.0	20.3	20.5	20.5	20.5
		Other	7.3	7.3	7.4	7.4	7.4
Jet Kerosene	Aviation	International	1.2	1.2	1.2	1.2	1.2
		Domestic	1.2	1.2	1.2	1.2	1.2
		Military	1.2	1.2	1.2	1.2	1.2
Residual Oil	Navigation/Shipping	International	104.3	53.4	53.4	53.4	53.4
		Domestic	104.3	77.7	58.5	58.5	58.5

NO_X

Table B 7. Swedish national NO_X (implied) emission factors (IEF) for road transport used in the latest projection submission to the CLRTAP. EFs for all other vehicle categories and fuels are assumed as not applicable.

Vehicle type	Fuel	NO_X IEF (g/GJ)					
		2007	2015	2020	2025	2030	2050
Passanger car	Natural gas	12	20	23	24	25	21
Passanger car	Diesel oil	213	158	140	118	95	98
Passanger car	Ethanol	80	101	111	113	116	97
Passanger car	Gasoline	141	119	63	61	58	53
Light duty vehicle	Diesel oil	372	289	220	175	127	124
Light duty vehicle	Gasoline	342	298	122	108	87	93
Heavy duty vehicle	Natural gas	991	647	431	347	251	392
Heavy duty vehicle	Diesel oil	701	457	250	162	82	71
Heavy duty vehicle	Ethanol	365	221	95	63	31	31
Heavy duty vehicle	Gasoline	712	725	740	758	775	769
Mopeds & motorcycles	Gasoline	142	137	133	126	120	100

Table B 8. Swedish national NO_X emission factors for transport (including NRMM, excluding road transport) used in the latest projection submission to the CLRTAP.

Fuel	Sector	Subsector	Region	NO_X (g/GJ)				
				2007	2020	2030	2040	2050
Aviation Gasoline	Aviation	Domestic	Cruise	356	249	142	142	142
			LTO	254	178	102	102	102
		Military		305	305	305	305	305
Gas/Diesel oil	Fisheries	Fisheries		1508	1406	1338	1338	1203
	Off Road Vehicles and Working Machinery	Farming		658	208	95	95	95
		Forestry		478	85	28	28	28
		Households		665	274	163	163	163
		Industry		583	160	60	60	60
		Other		689	430	375	375	375
	Railways	Railways		1524	549	542	542	542
	Navigation/Shipping	International		870	822	778	778	734
		Domestic		800	738	699	699	660
		Military		800	800	800	800	800
		Small boats		146	214	267	267	267
	Off Road Vehicles and Working Machinery	Farming		157	249	253	253	253
		Forestry		54	57	58	58	58
		Households		174	232	235	235	235
		Industry		137	139	140	140	140
		Other		113	113	113	113	113
Jet Kerosene	Aviation	International	Cruise	345	242	138	138	138
			LTO	275	192	110	110	110
		Domestic	Cruise	317	222	127	127	127
			LTO	227	159	91	91	91
		Military		291	291	291	291	291
Residual Oil	Navigation/Shipping	International		1630	1540	1457	1457	1375
		Domestic		1340	1237	1171	1171	1105

Revised values compared to latest projection submission to the CLRTAP in red.

NMVOC

Table B 9. Swedish national NMVOC (implied) emission factors (IEF) for road transport used in the latest projection submission to the CLRTAP. EFs for all other vehicle categories and fuels are assumed as not applicable.

Vehicle type	Fuel	NMVOC IEF (g/GJ)					
		2007	2015	2020	2025	2030	2050
Passanger car	Diesel oil	23	19	18	19	20	20
Passanger car	Gasoline	258	236	183	182	182	171
Light duty vehicle	Diesel oil	34	23	14	14	14	14
Light duty vehicle	Gasoline	530	487	315	300	278	256
Heavy duty vehicle	Diesel oil	28	17	7	5	3	3
Heavy duty vehicle	Gasoline	425	430	436	447	457	453
Mopeds & motorcycles	Gasoline	1517	1109	779	723	670	645

Table B 10. Swedish national NMVOC emission factors for transport (including NRMM, excluding road transport) used in the latest projection submission to the CLRTAP.

Fuel	Sector	Subsector	Region	NMVOC (g/GJ)				
				2007	2020	2030	2040	2050
Aviation Gasoline	Aviation	Domestic	Cruise	45	45	45	45	45
			LTO	44	44	44	44	44
		Military		44	44	44	44	44
Gas/Diesel oil	Fisheries	Fisheries		23	23	23	23	23
	Off Road Vehicles and Working Machinery	Farming		78	36	25	25	25
		Forestry		33	6	3	3	3
		Households		84	57	48	48	48
		Industry		46	15	8	8	8
		Other		127	103	99	99	99
	Railways	Railways		80	57	57	57	57
	Navigation/Shipping	International		16	16	16	16	16
		Domestic		15	15	15	15	15
		Military		15	15	15	15	15
		Small boats		6556	3114	819	819	819
	Off Road Vehicles and Working Machinery	Farming		3963	2659	2594	2594	2594
		Forestry		5055	4010	3086	3086	3086
		Households		2752	1914	1824	1824	1824
		Industry		1664	1647	1636	1636	1636
		Other		557	462	391	391	391

Jet Kerosene	Aviation	International	Cruise	16	16	16	16	16
			LTO	35	35	35	35	35
		Domestic	Cruise	40	40	40	40	40
			LTO	39	39	39	39	39
		Military		32	32	32	32	32
Residual Oil	Navigation/Shipping	International		28	28	28	28	28
		Domestic		26	26	26	26	26

Revised values compared to latest projection submission to the CLRTAP in red.

Emission factors for small scale biomass combustion

Table B 11. Swedish emission factors for small scale combustion. Data in italics for 2040 and 2050 have been extrapolated from 2030.

			NMVOC (g/GJ)					
Sector	Appliance type	Fuel type	2007/2010	2015	2020	2030	2040	*2050*
Residential	Boilers	Wood logs	300	300	270	240	*240*	*240*
		Wood chips	150	150	140	120	*120*	*120*
		Pellets	6	6	6	6	*6*	*6*
	Stoves	Wood logs	150	150	140	120	*120*	*120*
		Pellets	6	6	6	6	*6*	*6*
	Open fire places	Wood logs	200	200	200	200	*200*	*200*
Other consumption	All technologies	Biomass	300	300	270	240	*240*	*240*

			CH4 (g/GJ)					
Sector	Appliance type	Fuel type	2007/2010	2015	2020	2030	2040	2050
Residential	Boilers	Wood logs	254	240	223	203	185	168
		Wood chips	203	193	183	162	143	127
		Pellets	3	3	3	3	3	3
	Stoves	Wood logs	430	420	410	391	373	355
		Pellets	7	7	7	7	7	7
	Open fire places	Wood logs	318	318	318	318	318	318
Other consumption	All technologies	Biomass	250	250	225	200	200	200

			NOx (g/GJ)	Hg (g/GJ)
Sector	Appliance type	Fuel type	All years	All years
Residential	Boilers	Wood logs	80	0.0005
		Wood chips	80	0.0005
		Pellets	65	0.0005
	Stoves	Wood logs	80	0.0005
		Pellets	65	0.0005
	Open fire places	Wood logs	80	0.0005
Other consumption	All technologies	Biomass	80	0.0005

Table B 12. Emission factors for different biomass combustion technologies derived from the EU Baseline.

Emission factors		$PM_{2.5}$	BC	OC	VOC	CH_4
		Abated emission factor	Abated emission factor	Abated emission factor	Abated emission factor	Abated emission factor
Sector	**Technology**	**[g/GJ]**	**[g/GJ]**	**[g/GJ]**	**[g/GJ]**	**[g/GJ]**
Open fireplace	Improved	260	55	100	318	87,5
Open fireplace	New	140	43	38	190	52,5
Medium size boiler (<50MW)	Automatic, no control	69	8	9	50	10
Medium size boiler (<50MW)	Manual, no control	77	20	27	100	30
Single house boiler (<50kW)	Automatic, no control	37	3	6	15	3
Single house boiler (<50kW)	Manual, no control	372	100	130	1000	600
Single house boiler (<50kW)	Manual, improved	149	50	47	350	420
Single house boiler (<50kW)	Manual, new	74	18	21	30	12
Heating stove	No control	316	68	129	1400	200
Heating stove	Improved	117	65	23	210	40
Heating stove	New	63	19	18	70	10

For NOx, only one emission factor for small scale combustion of biomass fuel is applied, 60 g/GJ, and no abatement options are taken into account.

BC emission factors – all sectors

Table B 13. BC shares of $PM_{2.5}$ based on information from EU commission baseline for Sweden.

Sector	Fuel	Share of BC/$PM_{2.5}$ (%)				
		2010	2015	2020	2025	2030
Power and heat production	BC1	0.0%	0.0%	0.0%	0.0%	0.0%
	GAS	6.9%	6.9%	6.9%	6.9%	6.9%
	GSL	6.7%	6.7%	6.7%	6.7%	6.7%
	HC1	0.0%	0.0%	0.0%	0.0%	0.0%
	HF	13.3%	9.7%	9.7%	9.7%	9.7%
	MD	37.0%	33.9%	33.9%	33.9%	33.9%
	OS1	1.7%	1.7%	1.7%	1.7%	1.7%
	OS2	0.1%	0.1%	0.1%	0.1%	0.1%
Refineries	GAS	6.7%	6.7%	6.7%	6.7%	6.7%
	HF	9.7%	9.7%	9.7%	9.7%	9.7%
	LPG	6.7%	6.7%	6.7%	6.7%	6.7%
	MD	56.5%	56.5%	56.5%	56.5%	56.5%
Industry	BC1	0.0%	0.0%	0.0%	0.0%	0.0%
	DC	0.8%	0.8%	0.8%	0.8%	0.8%
	GAS	6.7%	6.7%	6.7%	6.7%	6.7%
	GSL	6.7%	6.7%	6.7%	6.7%	6.7%
	HC1	0.7%	0.7%	0.6%	0.6%	0.6%
	HF	9.7%	9.7%	9.7%	9.7%	9.7%
	LPG	6.7%	6.7%	6.7%	6.7%	6.7%
	MD	56.5%	56.5%	56.5%	NA	NA
	OS1	6.6%	6.6%	6.6%	6.6%	6.6%
Chemical industries	BC1	0.0%	0.0%	0.0%	0.0%	0.0%
	GAS	6.7%	6.7%	6.7%	6.7%	6.7%
	GSL	6.7%	6.7%	6.7%	6.7%	6.7%
	HF	9.7%	9.7%	9.7%	9.7%	9.7%
	LPG	6.7%	6.7%	6.7%	6.7%	6.7%
	OS1	6.6%	6.6%	6.6%	6.6%	6.6%
Paper and pulp industry	BC1	0.0%	0.0%	0.0%	0.0%	0.0%
	GAS	6.7%	6.7%	6.7%	6.7%	6.7%
	HC1	0.6%	0.6%	0.6%	0.5%	0.5%
	HF	9.7%	9.7%	9.7%	9.7%	9.7%
	LPG	6.7%	6.7%	6.7%	6.7%	6.7%
	OS1	6.6%	6.6%	6.6%	6.6%	6.6%
Other industry (e.g. cement)	GSL	19.3%	20.3%	21.5%	23.5%	25.9%
	MD	48.9%	46.5%	41.9%	37.1%	33.0%
Air	GSL	18.1%	18.1%	18.1%	18.1%	18.1%
Passenger cars	GAS	20.6%	17.8%	15.9%	15.2%	15.0%
	GSL	20.6%	17.8%	15.9%	15.2%	15.0%
	LPG	20.6%	NA	NA	NA	NA
	MD	74.5%	53.2%	25.3%	17.6%	16.7%

Light duty vehicles	GAS	17.4%	15.6%	15.4%	15.2%	15.1%
	GSL	17.4%	15.6%	15.4%	15.2%	15.1%
	LPG	17.4%	15.6%	15.4%	15.2%	15.0%
	MD	84.2%	77.8%	23.5%	20.0%	49.3%
Heavy duty vehicles	GAS	12.0%	9.8%	8.8%	8.9%	8.8%
	LPG	13.7%	10.7%	10.0%	10.0%	10.0%
	MD	68.2%	69.2%	63.0%	38.0%	17.7%
Motorcycles and mopeds	GSL	18.5%	19.8%	21.0%	22.1%	22.9%
Road abrasion	ABRASION	20.0%	20.0%	20.0%	20.0%	20.0%
Tyre&Brake	BRAKE	2.6%	2.6%	2.6%	2.6%	2.6%
Tyre&Brake	TYRE	3.6%	3.6%	3.6%	3.6%	3.6%
Railways	MD	45.6%	45.6%	45.6%	45.6%	45.6%
Domestic navigation	HF	42.8%	41.9%	NA	NA	NA
	MD	41.1%	41.0%	40.9%	40.8%	40.7%
Other transport	GSL	18.9%	19.0%	19.4%	19.9%	20.3%
	MD	46.9%	NA	NA	NA	NA
Small scale combustion (general)	FWD	31.5%	30.7%	29.3%	26.5%	26.4%
	GAS	6.7%	6.7%	6.7%	6.7%	6.7%
	HC1	19.6%	19.6%	16.5%	14.4%	10.9%
	HF	97.7%	97.7%	97.7%	97.7%	97.7%
	LPG	6.7%	6.7%	6.7%	6.7%	6.7%
	MD	97.7%	97.7%	97.7%	97.7%	97.7%
Residential	GSL	6.2%	6.2%	6.4%	6.4%	6.5%
Agriculture, forestry	GSL	19.3%	20.3%	21.5%	23.5%	25.9%
	MD	41.1%	39.8%	37.4%	36.3%	34.3%

Note: BC1 – Brown coal, peat. DC – Derived coal. GAS – Natural gas. FWD – Fuel wood direct. GSL – Gasoline. HC1 – Hard coal. HF – Heavy fuel oil. LPG – Liquefied petroleum gas. MD – Medium distillates. NA – Not available. OS1 – Biomass fuels. OS2 – Waste fuels.

OC emission factors – all sectors

Table B 14. OC shares of $PM_{2.5}$ based on information from EU commission baseline for Sweden.

Sector	Fuel	Share of OC/$PM_{2.5}$ (%)				
		2010	2015	2020	2025	2030
Power and heat production	BC1	0.1%	0.1%	0.1%	0.1%	0.1%
	GAS	74.8%	74.8%	74.8%	74.8%	74.8%
	GSL	75.0%	75.0%	75.0%	75.0%	75.0%
	HC1	0.03%	0.03%	0.03%	0.03%	0.03%
	HF	6.7%	4.1%	4.1%	4.1%	4.1%
	MD	15.4%	5.1%	5.1%	5.1%	5.1%
	OS1	0.9%	0.7%	0.7%	0.7%	0.7%
	OS2	0.03%	0.03%	0.03%	0.03%	0.03%
Refineries	GAS	75.0%	75.0%	75.0%	75.0%	75.0%
	HF	4.1%	4.1%	4.1%	4.1%	4.1%
	LPG	0.0%	0.0%	0.0%	0.0%	0.0%
	MD	8.6%	8.6%	8.6%	8.6%	8.6%
Industry	BC1	0.6%	0.6%	0.6%	0.6%	0.6%
	DC	0.0%	0.0%	0.0%	0.0%	0.0%
	GAS	75.0%	75.0%	75.0%	75.0%	75.0%
	GSL	75.0%	75.0%	75.0%	75.0%	75.0%
	HC1	0.3%	0.3%	0.3%	0.3%	0.3%
	HF	4.1%	4.1%	4.1%	4.1%	4.1%
	LPG	0.0%	0.0%	0.0%	0.0%	0.0%
	MD	8.6%	8.6%	8.6%	NA	NA
	OS1	4.5%	4.5%	4.5%	4.5%	4.5%
Chemical industries	BC1	0.6%	0.6%	0.6%	0.6%	0.6%
	GAS	75.0%	75.0%	75.0%	75.0%	75.0%
	GSL	75.0%	75.0%	75.0%	75.0%	75.0%
	HF	4.1%	4.1%	4.1%	4.1%	4.1%
	LPG	0.0%	0.0%	0.0%	0.0%	0.0%
	OS1	4.5%	4.5%	4.5%	4.5%	4.5%
Paper and pulp industry	BC1	0.6%	0.6%	0.6%	0.6%	0.6%
	GAS	75.0%	75.0%	75.0%	75.0%	75.0%
	HC1	0.3%	0.3%	0.3%	0.3%	0.3%
	HF	4.1%	4.1%	4.1%	4.1%	4.1%
	LPG	0.0%	0.0%	0.0%	0.0%	0.0%
	OS1	4.5%	4.5%	4.5%	4.5%	4.5%
Other industry (e.g. cement)	GSL	59.8%	59.2%	58.5%	56.7%	55.0%
	MD	22.2%	21.1%	19.0%	16.9%	15.0%
Air	GSL	60.4%	60.4%	60.4%	60.4%	60.4%
Passenger cars	GAS	44.5%	39.4%	36.1%	34.9%	34.7%
	GSL	44.5%	39.4%	36.1%	34.9%	34.7%
	LPG	44.5%	NA	NA	NA	NA
	MD	16.8%	20.3%	24.6%	25.6%	25.6%

Light duty vehicles	GAS	39.4%	36.1%	35.4%	34.9%	34.7%
	GSL	39.4%	36.1%	35.4%	34.9%	34.7%
	LPG	39.4%	36.1%	35.4%	34.9%	34.7%
	MD	10.6%	11.8%	29.6%	30.8%	29.8%
Heavy duty vehicles	GAS	25.7%	22.2%	20.3%	20.5%	20.4%
	LPG	29.3%	24.3%	23.1%	23.1%	23.1%
	MD	17.9%	16.9%	18.6%	27.0%	33.7%
Motorcycles and mopeds	GSL	62.2%	60.6%	58.3%	55.9%	53.9%
Road abrasion	ABRASION	100.0%	100.0%	100.0%	100.0%	100.0%
Tyre&Brake	BRAKE	46.2%	46.2%	46.2%	46.2%	46.2%
Tyre&Brake	TYRE	8.6%	8.6%	8.6%	8.6%	8.6%
Railways	MD	25.6%	25.6%	25.6%	25.6%	25.6%
Domestic navigation	HF	28.1%	26.7%	NA	NA	NA
	MD	28.3%	27.3%	26.3%	25.3%	24.6%
Other transport	GSL	60.0%	59.9%	59.7%	59.4%	59.2%
	MD	24.4%	NA	NA	NA	NA
Small scale combustion (general)	FWD	28.8%	27.4%	26.5%	25.5%	24.5%
	GAS	75.0%	75.0%	75.0%	75.0%	75.0%
	HC1	20.9%	20.9%	17.3%	14.6%	10.1%
	HF	5.1%	5.1%	5.1%	5.1%	5.1%
	LPG	0.0%	0.0%	0.0%	0.0%	0.0%
	MD	23.1%	23.1%	23.1%	23.1%	23.1%
Residential	GSL	81.4%	81.3%	81.2%	81.1%	81.0%
Agriculture, forestry	GSL	59.8%	59.2%	58.5%	56.7%	55.0%
	MD	28.9%	28.0%	26.3%	25.5%	24.1%

Note: BC1 – Brown coal, peat. DC – Derived coal. GAS – Natural gas. FWD – Fuel wood direct. GSL – Gasoline. HC1 – Hard coal. HF – Heavy fuel oil. LPG – Liquefied petroleum gas. MD – Medium distillates. NA – Not available. OS1 – Biomass fuels. OS2 – Waste fuels.

Hg emission factors – all sectors

Fuel category	Fuel	Sector	Hg (g/TJ)
			All years
Biomass	Wood fuels, Other biomass	Power and heat production, Industry	0.3
Biomass	Wood fuels	Small scale combustion	0.5
Coal	Blast furnace gas, Coke oven gas, Steel converter gas	Power and heat production, Industry	3
Coal	Coking coal, Coke	Power and heat production, Industry	3
Coal	Peat	Power and heat production, Industry	2
Oil	Diesel Oil	Power and heat production, Industry	0.1
Oil	Diesel Oil	Domestic navigation, International navigation, Fisheries, Military	0.001
Oil	Domestic Heating Oil	Power and heat production, Industry, Small scale combustion	0.1
Oil	Domestic Heating Oil	Domestic navigation, International navigation	0.001
Oil	Ethanol	Industry	0.3
Oil	Kerosene	Power and heat production, Industry	0.1
Oil	Petroleum coke	Industry	3
Oil	Refinery oil	Power and heat production, Industry	0.06
Oil	Residual Fuel Oil	Power and heat production, Industry, Small scale combustion	0.06
Oil	Residual Fuel Oil	Domestic navigation, International navigation	0.073
Waste	Solid waste	Power and heat production, Industry	1.4

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