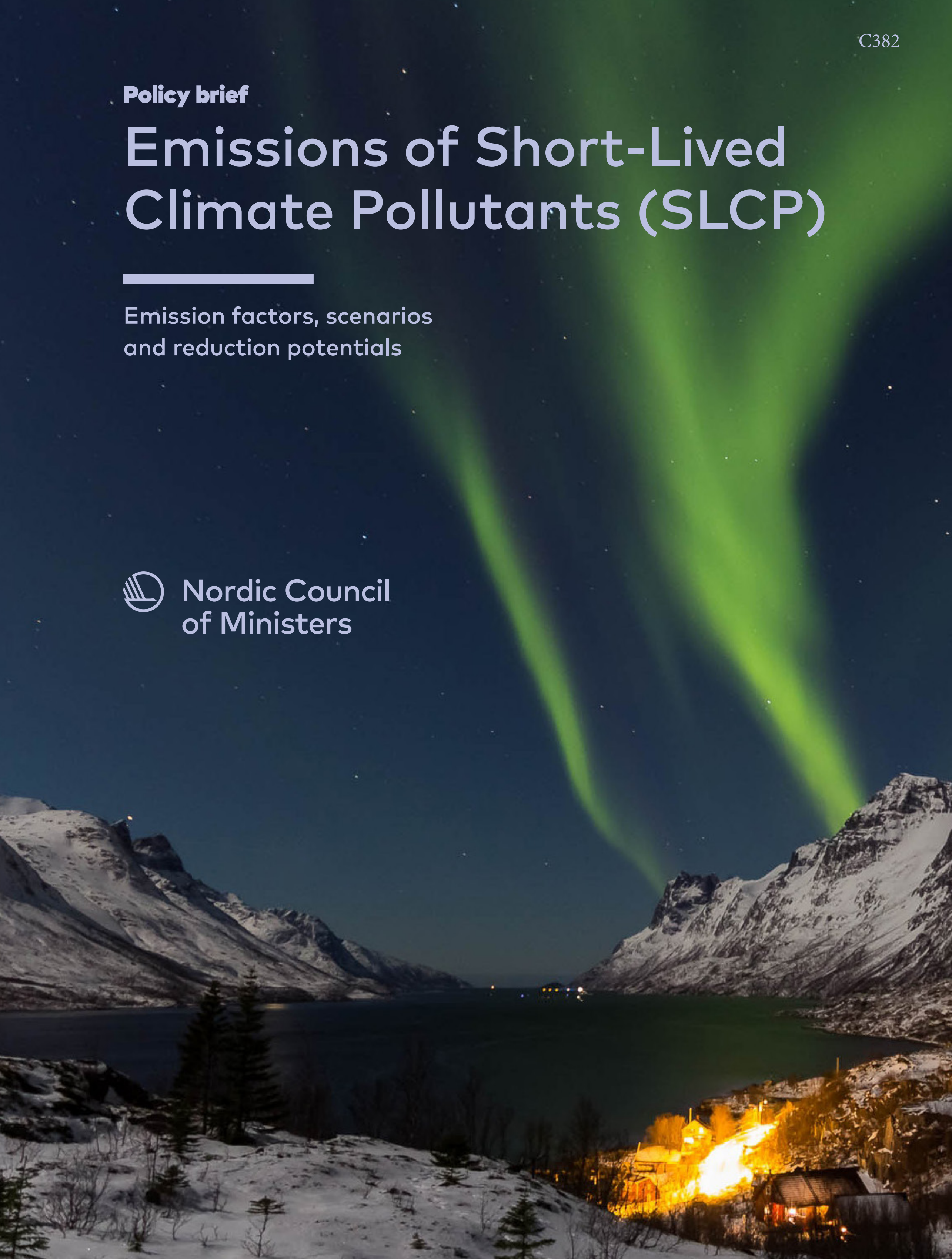
C382

Policy brief

Emissions of Short-Lived Climate Pollutants (SLCP)

Emission factors, scenarios and reduction potentials

Nordic Council of Ministers



Policy Brief: Emissions of Short-Lived Climate Pollutants (SLCP)
Emission factors, scenarios and reduction potentials

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PHOTO: UNSPLASH

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PHOTO: SCANPIX

Emission factors, scenarios and reduction potentials

The overall objective of this project was to improve the Nordic emission inventories of short-lived climate pollutants (SLCP) with a focus on Black Carbon (BC). It is commonly known that emissions of SLCP have a negative impact on climate, air quality and human health. BC is known as soot, which is the dark, light-absorbing part of the particles. There has been an increasing attention and interest especially in the role of BC in climate change and the possibilities to slow down the on-going temperature increase by reducing emissions of BC and other SLCPs. Emission reductions of BC can also have a regional effect on climate change, for example in the sensitive Arctic region.

Reduced emissions of BC would benefit both climate change mitigation and human health. The adverse effects on human health from exposure to particulate matter have long been recognized. Recent assessments suggest that BC as a component of $PM_{2.5}$ (particles with an aerodynamic diameter smaller than 2.5 μm) is associated with health effects from both short-term (daily) variations in BC concentrations, as well as long term average BC exposure.

Nationally estimated emissions of SLCPs and $PM_{2.5}$ are reported annually to international conventions. $PM_{2.5}$ and BC [and also non-methane volatile organic compound (NMVOC) and carbon monoxide (CO)] are included in the emission reporting program under the UNECE Convention on Long Range Transboundary Air Pollution (CLRTAP), while methane (CH_4) is reported to the United Nations Framework Convention on Climate Change (UNFCCC). There are uncertainties associated with reported emission inventories, especially of $PM_{2.5}$ and BC. For robust assessments of climate and health impact, as a basis for considering actions and measures to reduce emissions, uncertainties in the emission inventories need to be reduced and the comparability between the countries' inventories need to be improved. A better understanding of $PM_{2.5}$ composition is essential for the assessment of climate benefits of emission reduction actions since components of $PM_{2.5}$, such as organic carbon (OC), can have a cooling effect on the climate.

A good enough understanding of the sources and the magnitude of emissions of SLCPs and $PM_{2.5}$ is a prerequisite to be able to take effective action, in prioritising measures to abate climate change and/or health effects, and also to be able to evaluate if the actions have had desired effect.


PHOTO: KARIN BEATE NØSTERUD

Highlights and summary of results

1 Residential wood combustion is a major source of $PM_{2.5}$ and BC emissions in the Nordic countries, both today and in the future.

2 Emission factors were developed in the emission measurement programme for $PM_{2.5}$, EC(BC), OC, CH_4, NMVOC and CO for various combustion technologies used in residential biomass combustion in the Nordic countries. Ratios were developed for increased emissions at poor combustion conditions compared with normal combustion conditions.

3 Scenarios using the new emission factors show that reduced emissions from residential wood combustion can be achieved by modern technologies and through improved user skills in operating the combustion equipment.

4 Modelling the technical SLCP reduction potential, including all relevant emission sources (not only residential biomass combustion), show that full realization of the modelled SLCP emission reduction strategy in 2030 in the Nordic countries would save more than 60 000 life years in Europe and reduce the climate impact by about 14 million tons CO_2 equivalents.

PHOTO: UNSPLASH

Policy implications and recommendations

Improved emission inventories

Nordic emission inventories of residential biomass combustion are not yet fully comparable due to differences in the details of the calculations and different measurement methodologies underlying the national emission factors. Further improvement in the national data of applied technologies and the related emissions are needed to serve as a sufficiently reliable basis for policy development and actions. National studies to improve knowledge about the user behaviour are essential as the operation of the combustion equipment impacts emissions. The emission factors developed in this project, including ratios for poor combustion, contribute to a better knowledgebase for developing more comparable emission inventories, taking national conditions into account. Future regular updates of emission factors are needed to follow technical developments.

Reducing emissions from residential biomass combustion

Measures aimed at reducing emissions from residential biomass combustion are key in the strategies for additionally reduced emissions of SLCP and $PM_{2.5}$ in the Nordic countries in the future. Effective information campaigns to educate users in proper combustion behaviour are important. In addition, there are incentives to introduce policies to facilitate early scrapping of old combustion technologies and replace with modern low-emitting equipment.

Strategies and measures for reduced emissions of SLCPs

The Nordic countries share many similarities, but there are also differences in national conditions, and in what actions and measures are already implemented. To identify the most efficient additional measures to reduce SLCP emissions nationally, each individual country needs to do a country specific analysis.

Glossary

SLCP is a group of substances comprising black carbon (BC), tropospheric ozone (O_3), methane (CH_4), and hydro fluorocarbons. O_3 is formed in atmospheric chemical reactions involving CH_4, nitrogen oxides (NOx), carbon monoxide (CO), non-methane volatile organic compound (NMVOC) and sunlight. The SLCPs have, in comparison to the long lived greenhouse gases (e.g. carbon dioxide (CO_2) and nitrous oxide (N_2O)), a short residence time in the atmosphere.

BC, Black Carbon, commonly known as soot, is the dark, light absorbing part of the particles. BC is measured by optical methods. BC mainly consist of EC, Elemental Carbon, which is measured by thermal methods. In the literature EC and BC are usually treated as equal, even though this is not completely true.

OC, Organic Carbon, refers to the carbon content in $PM_{2.5}$ that is not BC/EC or carbonate carbon (CO_3 carbon). OC can have a cooling effect on the climate.

$PM_{2.5}$ is particles with an aerodynamic diameter smaller than 2.5 µm. Emitted $PM_{2.5}$ consists of BC/EC, organic matter (including OC) and inorganic compounds.

Residential biomass combustion is an important source of SLCP and $PM_{2.5}$ – and data are uncertain

As can be seen in figure 1 and 2, residential combustion is a significant source for $PM_{2.5}$ and BC emissions in the Nordic countries and contributes more than 40 percent of the total Nordic emissions. Road traffic is also a large contributing emission source to $PM_{2.5}$ and BC. Figure 3 shows that the agriculture and waste sectors are the most important sources for methane (CH_4) emissions. In the national emission projections – taking existing legislation and measures into account – total emissions of $PM_{2.5}$, black carbon (BC) and methane (CH_4) are expected to decrease by 2030. Residential combustion will, however, still be the most important source of $PM_{2.5}$ and BC, as will agriculture and waste management be for CH_4 emissions. The national emission inventories of $PM_{2.5}$ and BC from residential biomass combustion are not fully comparable between the Nordic countries, partly due to different measurement methodologies underlying the national emission factors (hot flue gas, dilution tunnel) and partly due to the details of the inventory, such as the technologies used. As residential biomass combustion is such a dominating source of $PM_{2.5}$ and BC emissions in the Nordic countries, the present uncertainties and knowledge gaps need to be reduced in order for the emission inventories to serve as a sufficiently reliable basis for policy development and actions.

Figure 1: Emissions of $PM_{2.5}$ in the Nordic countries 2005–2015 and projections to 2030. Gg=kilotonne.

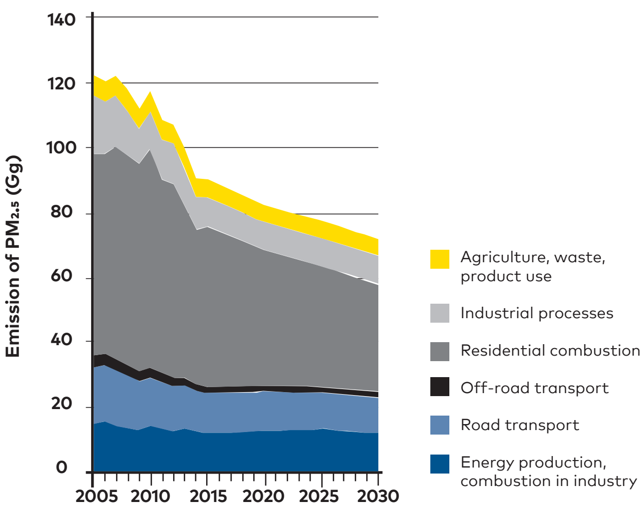


Figure 2: Emissions of black carbon (BC) in the Nordic countries 2005–2015 and projections to 2030

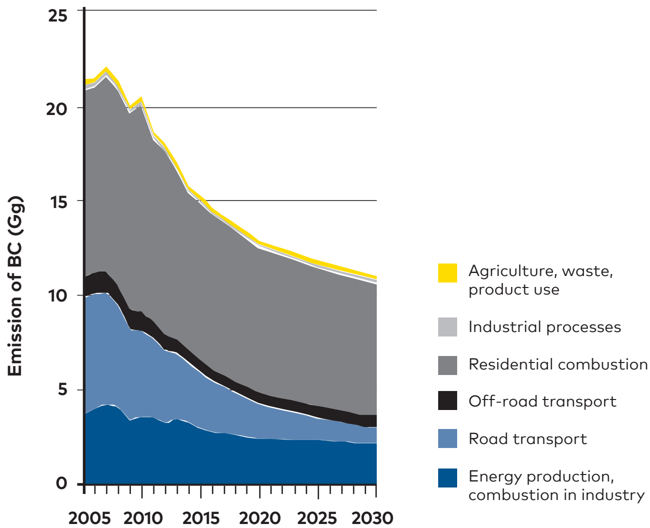
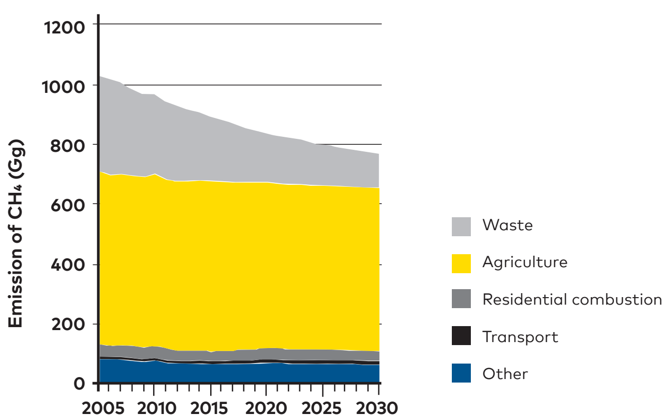


Figure 3: Emissions of methane (CH_4) in the Nordic countries 2005–2015 and projections to 2030.



Factors influencing estimated emissions from residential biomass burning

Emissions from residential biomass combustion are estimated by multiplying activity data (amount of fuel combusted) with appropriate emission factors. In the detailed national inventories, the activity data covers different technologies and their shares of the biomass fuel, in addition to technology specific emission factors that are based on national measurements or international default values. Uncertainties in estimated emissions arise both from uncertainties in emission factors and in activity data.

Emission factors are influenced by:

- Emission measurement method for deriving emission factors
- Combustion technology, e.g. older or modern equipment
- Operational conditions, poor combustion conditions give higher emissions
- Fuel quality, e.g. moisture

Emission measurements were conducted on residential biomass burning appliances common in the Nordic countries. During the project it was understood that there are substantial differences in the stock of residential biomass burning technologies between the five Nordic countries. The measurement program provided SLCP and $PM_{2.5}$ emission factors for several types of residential biomass combustion technologies (stoves and boilers), both for standard combustion conditions and at poor user behavior (inefficient combustion conditions). Measurements were made using EN standards for boilers and for stoves, and also the Norwegian standard for stoves. Sampling for $PM_{2.5}$, EC and OC were in all cases done in a dilution tunnel (i.e. sample including condensables) and not in hot flue gases.

Activity data are compiled based on statistics, modelling and expert assumptions

Activity data consists of:

- Fuel amount used in each combustion technology
- Share of fuel combusted under ”poor combustion conditions”

Activity data collection can be challenging and the Nordic countries use information from regular or intermittent surveys, in some countries in combination with modelling based on energy demand (fuel consumption) and expected lifetimes of equipment (combustion technologies). It is not uncommon with insufficient information from the surveys, for example regarding fuel used in different combustion technologies. Information on user behavior can for example be based on dedicated studies and/or interviews with chimney sweepers. Expert judgement and assumptions are an integral part of activity data.

A new set of emission factors for residential biomass burning technologies

Key findings

- In general, the measured older stoves and boilers show higher emission levels than modern ones
- Poor combustion increases emission levels significantly
- Elemental Carbon (EC) and $PM_{2.5}$ do not correlate (no "fixed" share $EC/PM_{2.5}$)
- Elemental Carbon (EC) least affected by poor combustion conditions

The emission measurement program provided emission factors for $PM_{2.5}$, EC, OC, CH_4, NMVOC and CO. In the measurement program, also the influence from common user mistakes leading to poor combustion, including firing with moist fuel or at part load, was investigated.

The technologies tested were grouped according to similarities in technology and emission levels when developing the

Figure 4: Measured emission factors for different boilers under standard (good) combustion conditions.

Four different modern wood boilers (blue), two old technology wood boilers (red), three pellet technologies (grey) and a wood chip boiler.

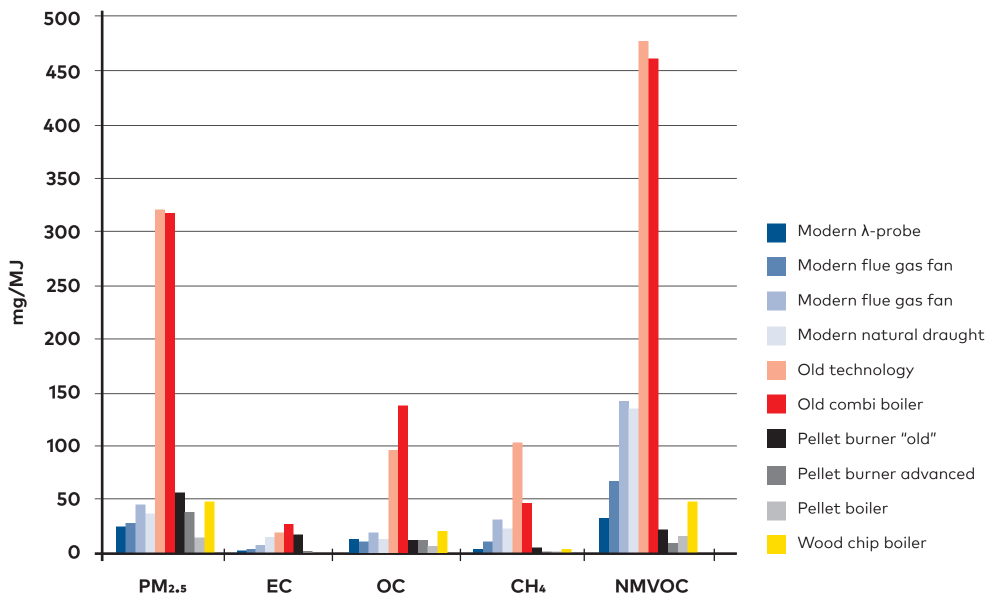
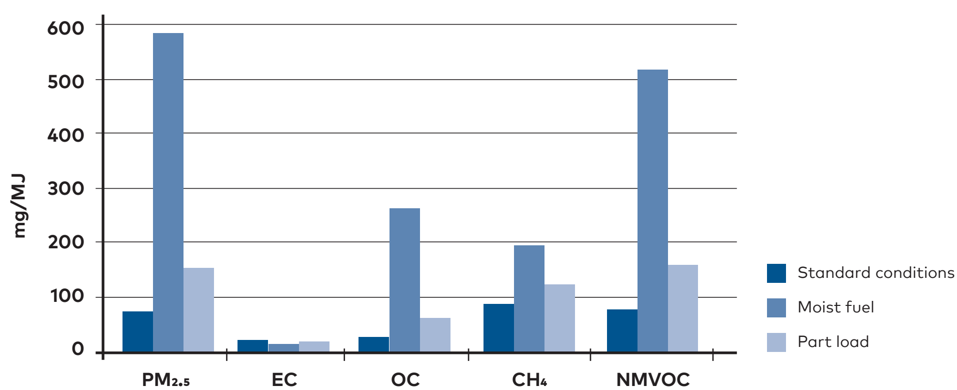


Figure 5: Measured emission factors for modern stoves under different combustion conditions.

Standard conditions (good combustion), moist fuel and part load (poor combustion conditions).



emission factors. In a national emission inventory, lack of detailed information on technologies is a common situation. The emission factor results were thus adapted and aggregated to be useful in a national inventory. To enable the use of the measurement results reflecting emissions at different combustion conditions, ratios between emissions at poor combustion conditions and at standard combustion conditions were calculated. These ratios can be used in national emission inventories together with information on the national share of poor combustion.

In general, the measurement results showed that older technologies exhibited higher emission levels than more modern types of equipment. As can be seen in figure 4, traditional log wood boilers had emission levels that were in the order of 5–10 times higher (depending on pollutant) than for the modern log wood boilers and the pellets technologies. Among the stoves the difference between older and modern technologies was not as large, where up to two times higher emission levels were measured from the traditional tiled and masonry stoves and an older type of iron stove, compared to the modern wood stoves.

Poor combustion conditions increased emission levels. In the boilers part load combustion conditions increased the emissions between 2–6 times, and moist fuel generally increased the emission levels by a factor of 1.5–2.

For the stoves part load conditions generally increased the emission levels by 1.5–3.5 times. The measurement results suggested that modern stoves are sensitive to moist fuel, as emissions of $PM_{2.5}$ and OC were 5–8 times higher compared to emissions when firing with standard fuel, see figure 5. The results also showed that older technologies, tiled and masonry stoves, were hardly affected by moist fuel, and the emission levels were comparable to the standard fuel test cases. The higher impact from moist fuel in the modern stoves is likely due to limited capacity of the air systems in many modern stoves.

It was found that the EC emission factors did not correlate with the $PM_{2.5}$ emission factors, and that the EC emissions were less affected by moist fuel and part load conditions than most of the other pollutants. In the literature, EC emission factors are often given as percentage of $PM_{2.5}$, which according to the results in this project does not necessarily reflect reality very well.

Way forward for improved emission inventories

- Emission inventories of residential biomass combustion are sensitive to combustion technology and user behavior.
- It is important to take user behavior into account in national emission factors.
- Collection of information on the use of different technologies and the amount and quality of wood combusted in them is often challenging and resource demanding. Sufficient data and information from different sources are needed, in many cases in combination with expert estimates.
- Detailed knowledge on the amount of biomass fuel combusted in different combustion technologies is needed to enable developing more accurate emission inventories.

In addition, knowledge about user related factors that influences combustion conditions needs to be studied nationally. These include the use of moist fuel, firing conditions related to part load and management of the ignition and air flows. This information can then be used to develop country-specific shares of "poor combustion conditions" that can be used together with information on the increased emission levels during these conditions.

When comparing currently used national emission factors in the Nordic countries with those developed from the measurement program in this project, some large differences were identified, both between countries and in relation to the measurement results. There are examples of individual national emission factors that are considerably higher, or considerably lower, than the measurement results.

Differences in the emission factors between the Nordic countries were identified and the reasons behind the deviations were studied. One of the reasons for differences between the current national emission factors is that some are based on measurement results derived using different measurement standards (e.g. hot flue gases/diluted sampling, or EN standards/Norwegian standard). To compare national emission inventory results, emission factors should be presented and documented in a way that enables the use of comparable emission factor values, in addition to the details of the equipment used and the biomass consumption.

There are real differences between the Nordic countries regarding the most important technologies used for wood combustion, the user practices and the user influenced factors. The results from this project provide additional knowledge for developing emission inventories that are more comparable between the Nordic countries, taking national circumstances into account.

Potentials for reducing the health and climate impacts from residential biomass combustion

Scenarios exploring how emissions from residential biomass combustion would be affected by improvements in user related operational conditions and upgrading the equipment to modern combustion technologies were developed using the emission factors derived from the measurement program.

The scenario results (covering Denmark, Finland and Sweden) suggest that there is a realistic and technical potential to reduce the adverse health effects and, to some extent, the climate impact from future residential biomass combustion by reducing emissions of SLCPs and $PM_{2.5}$. The penetration of modern technology in residential biomass combustion and improvements in the user related operational conditions both have impacts on the emission levels in the three Nordic countries. Decreasing or increasing the amounts of biomass fuel combusted would of course also have a large effect on emissions, but this was not investigated and the total amount of biomass was kept the same in all scenarios.

The results show that:

- the estimated reduction of $PM_{2.5}$ emissions would lead to reductions in adverse health effects: about 1000 premature deaths would be avoided annually in Europe in 2035 as a result of replacing older boilers and stoves with modern equipment and using good combustion behaviour;
- the reduced climate impact resulting from reduced emissions of the short lived climate pollutants BC, CH_4, NMVOC and OC from residential biomass burning is rather modest and more of a positive side effect in addition to the reduced health effects from reducing $PM_{2.5}$ emissions. The potential emission reductions estimated in the scenarios correspond to approximately 0.1% of the projected greenhouse gas emissions from Denmark, Finland and Sweden in 2030;
- according to current national projections the use of older technology stoves and boilers in Denmark, Finland and Sweden are expected to only account for about 7% (10 PJ of 148 PJ) of total residential biomass use in 2035, see figure 6. The potential to reduce emissions from residential biomass burning by replacing those older technologies (7% of the biomass fuel) with modern equipment by 2035 can be significant, in the order of 15% for $PM_{2.5}$ and OC, 25% for NMVOC and 7–9% for BC and CH_4;
- if, in addition to replacement of older equipment, the combustion behaviour is improved from the assumed 90% up to 100% of the fuel combusted with good combustion behaviour, the potential to reduce the emissions rises to 26% for $PM_{2.5}$, 32% for OC, 35% for NMVOC, 15% for CH_4 and 8% for BC. This can be seen in figure 7.

Figure 6: Projections of biomass fuel use in different combustion technology categories to 2035

(sum for Denmark, Finland and Sweden, adapted from national projections). Red circles indicate the relatively small biofuel amounts shifted from expected to modern technologies in the scenarios.

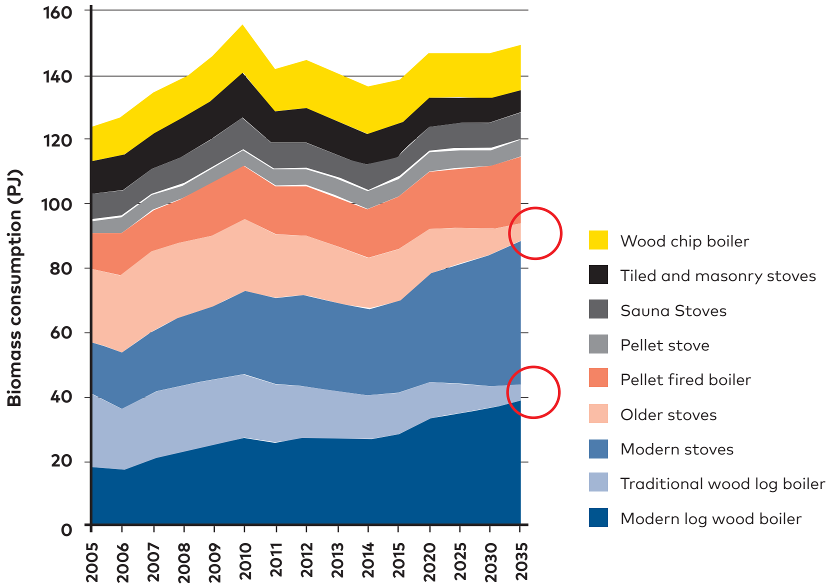
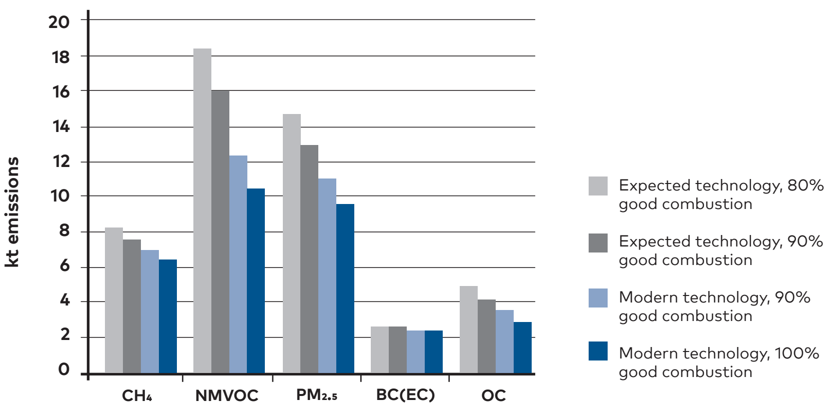


Figure 7: Estimated emissions from residential biomass combustion in Denmark, Finland and Sweden under assumptions of expected technology or modern technology and different combustion conditions.

(exchange of remaining old technology boilers and stoves for modern), and under combustion conditions ranging from 80% good combustion to 100% good combustion.



Efficient additional measures to reduce SLCP emissions

A number of measures to abate emissions of SLCPs from different emission sources are, to varying degrees, already in place in the Nordic countries. National emission projections, taking existing legislation and measures into account, show that total emissions of all SLCPs are expected to decrease to 2030. On the Nordic level, residential biomass combustion and transport will also in the future be important sources of BC, as will agriculture and waste management for CH_4 emissions. The Nordic countries share many similarities, but there are also differences in national conditions, in which SLCP sources contribute most to national emissions, and in which actions and measures are already implemented.

In order to identify efficient additional measures to reduce emissions of SLCPs beyond the current emission projections, a GAINS-model analysis was performed, including all five Nordic countries.

GAINS

GAINS is an integrated assessment model, an extension of the RAINS model originally developed within the UNECE Convention on Long-Range Transboundary Air Pollution (UNECE CLRTAP) to identify and explore cost-effective emission control strategies for air pollutants. Later, the possibility to analyze greenhouse gas emissions and measures was included. The model is developed and maintained by the International Institute for Applied System Analysis – IIASA and is widely used as a unified tool for scientific analysis of economic and environmental consequences of air pollution abatement strategies and climate mitigation measures. With its broad database on abatement measures and in-built emission dispersion parameters, GAINS enables analysis of emissions, costs and health and environmental effects for relevant policy scenarios. Furthermore, a cost-optimization mode is available for determining the most cost-effective solutions to reach suggested health or/ and environmental targets.

GAINS = Greenhouse Gas - Air Pollution Interactions and Synergies.

RAINS = Regional Air Pollution Information and Simulation.

The assessment covers all relevant SLCP emission sources (not only residential biomass combustion), and primarily emissions of BC and CH_4. As BC is part of emitted particulate matter ($PM_{2.5}$) and many measures are focusing on $PM_{2.5}$, reduction of $PM_{2.5}$ emissions was also included in the analysis. Only technical measures are available in the GAINS model, including for example filters or improved technologies. Non-technical measures, such as promoting behavioural changes leading to reduced emissions, are not available in the model. The combined SLCP model analysis shows that for BC the most important sources targeted for abatement measures in the Nordic context are residential biomass combustion, and on-road and non-road diesel vehicles and machinery. For CH_4 the agricultural sector and waste management are the most important sources, followed by oil and gas production, particularly for Norway.

The results of the GAINS model analysis show that in order to reach the modelled technical emission reduction potential for black carbon, measures within the residential biomass combustion sector should be prioritized. Among the efficient technical measures are, according to the model, replacement of older boilers and heating stoves with new appliances, installation of ESP (electrostatic precipitator) and high-efficiency filters (dedusters), and fuel switch from wood logs to pellets. The technical measures in the model aimed at residential combustion can reduce BC emissions in 2030 by 3.7 kt – which is about 79% of the estimated total technical BC emission reduction potential in the Nordic countries. According to the model results, these measures would provide the highest reduction potential for BC for Denmark, Finland and Sweden, while for Norway good practice in flaring in oil and gas industries has the highest reduction potential. In Iceland the introduction of Euro 6/VI on all road diesel transport is the most important technical measure according to the model results. For methane, the large part of the technical emission reduction potential lies within the waste management and wastewater treatment sector (anaerobic treatment with gas recovery and upgrade), oil and gas industries, and gas distribution networks (different reduction potentials in different countries).

Full realization of the modelled SCLP emission reduction strategy in 2030 in the Nordic countries would bring significant health benefits for the whole Europe (> 60 000 life years gained) – and reduced climate impact (by ~14 Million tons CO_2 equivalents). In addition to the specific technical measures available in the model, more general measures such as increased energy efficiency, improved insulation of buildings, as well as non-technical measures could contribute to reduced emissions. Non-technical measures are e.g. behavioural changes such as improved user practices in residential wood combustion (BC), reduced driving in road transport (BC), and reduced meat consumption (CH_4).

Information about the project

The project, Improved Nordic emission inventories of Short-Lived Climate Pollutants was proposed by the Swedish presidency of the Nordic Council of Ministers in 2013 and approved in June 2013. All five Nordic countries have participated and contributed actively in the work. The project was financed by the Nordic Council of Ministers.

Four reports have been published from the project:

1. TN2015:523. Improved emission inventories of SLCP: Background analysis

2. TN2017:570. Emission factors for SLCP emissions from residential wood combustion in the Nordic countries

3. TN2018:530. Potentials for reducing the health and climate impacts of residential biomass combustion in the Nordic countries

4. TN2018:533. Measures to reduce emissions of Short-Lived Climate Pollutants (SLCP) in the Nordic countries

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Policy Brief: Emissions of Short-Lived Climate Pollutants (SLCP)

Emission inventories of Short Lived Climate Pollutants (SLCP), and especially of Black Carbon are uncertain and not always comparable between countries. Comparable and reliable emission inventories are essential when aiming for efficient strategies and policies for reduced emissions. The overall objective of this project is to improve the Nordic emission inventories of SLCPs.

This report presents a summary of results and highlights from four reports produced in the project. The topics cover results from a measurement programme that provided SLCP and $PM_{2.5}$ emission factors for typical Nordic residential biomass combustion technologies, it covers emission projections and efficient measures to reduce emissions of SLCPs beyond current projections, and also presents results from investigating the potentials for reducing the health and climate impacts of residential biomass combustion.