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Summary

A number of measures to abate emissions of SLCPs 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 black carbon (BC) and methane (CH₄) are expected to decrease to 2030. In the future, residential biomass combustion and transport will be important sources of BC, as will agriculture and waste management for CH₄-emissions. The objective in this part of the project was to identify efficient additional measures to reduce emissions of SLCPs beyond the current emission projections. The assessment primarily covers BC and CH₄, but 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 is also included in the analysis. Both technical measures, such as filters or improved technologies, and non-technical measures, such as promoting behavioural changes favouring reduced emissions are discussed in this report.

A combined SLCP analysis using the GAINS model (and based on the ECLIPSE¹ project results for the Nordic countries) was carried out and additional technical measures for reduced SLCP emissions in the individual Nordic countries were assessed. The analysis shows that in order to reach the modelled technical emission reduction potential for black carbon, measures within the residential wood combustion sector should be prioritized. Among the efficient technical measures are replacement of older boilers and heating stoves with new appliances, installation of ESP (electrostatic precipitator) and high-efficiency dedusters, and fuel switch from wood logs to pellets. 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 EUR 6/VI on 100% of road diesel transport is most important.

The 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. Further emission reductions can be achieved by speeding up the diesel vehicle fleet renewal to EUR 6/VI.

For methane, the large part of the 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 (primarily in Norway and Denmark).

Full realization of the SCLP emission reduction strategy in 2030 in the Nordic countries would bring significant health benefits² for the whole Europe (> 60,000 life years gained) – and reduced climate impact (by ~14 Million tons CO₂ equivalents).

¹ <http://eclipse.nilu.no/>

² Health benefits are estimated with the Alpha RiskPoll model.

As is evident from the combined SLCP analysis a number of different technical measures aimed at various emission sources are needed to reduce SLCP and reach the technical emission reduction potentials. 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 CH₄ the agricultural sector and waste management are the most important sources, followed by oil and gas production, particularly for Norway. In addition to the technical measures in the model, general technical 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 (CH₄).

A literature review of possibilities beyond existing measures was performed for each of the important SLCP emission sources. Also instruments that are existing, planned, or possible to implement to promote abatement measures are discussed. Where available, the costs and cost efficiency of measures are presented.

Residential biomass combustion contributes, and will in the future contribute a large share of Nordic BC and PM_{2.5} emissions according to current projections. There are differences between the Nordic countries both in the contribution from residential combustion to national emissions, and in which instruments and measures to abate emissions are already applied. There are also differences in existing technical solutions and practices. As a result of this, relevant and efficient “additional measures” may be different depending on country. Emission limit regulations and eco-labelling of combustion equipment are likely to have a future impact on emission. Subsidies on replacing older equipment have previously resulted especially in Denmark in rather cost-efficient emission reductions. Aside from such economic instruments, Norway’s perhaps most important measure is to introduce emission limits for new stoves. In Finland, a large share of residential biomass burning equipment are masonry heaters, which are not readily replaced and hence information campaigns to ensure correct practices are identified as the most efficient way in order to decrease emissions. Information campaigns for correct use and maintenance of wood burning equipment is a common and important non-technical measure as correct use and maintenance can have a significant impact on the emission levels. Technical measures such as replacing residential wood burning equipment with low-emitting technologies can also significantly reduce emissions from residential biomass combustion.

On-road and non-road vehicles and machinery emissions of BC are according to current projections expected to decrease in the future, but still to contribute a significant part of the total Nordic emissions. Technical measures are similar irrespective of country, and in principle consists of renewal and modernisation of the vehicle fleet (EUR 6/VI), as well as use of diesel particle filters (DPF).

Agriculture contributes, and will contribute a large share of total emissions of CH₄ also in the future. Abatement measures are available to reduce emissions of CH₄ from ruminant enteric fermentation, from manure management (including biogas production), and also the possibility to reduce the number of animals (and thus also the

CH₄ emissions) following measures to promote behavioural changes towards less meat consumption. Several of the measures discussed are already present to a smaller or larger degree in the Nordic countries, but the applications could be extended. The situation differs between the Nordic countries, and the potential for relevant additional (or extended measures) may vary.

The most efficient way to reduce methane emissions from livestock is anaerobic digestion of manure followed by production of biogas. This measure has methane emission reduction efficiency of up to 80%. With the possibility to upgrade biogas to vehicle fuel, it provides triple benefits – reduces methane emissions from the agricultural sector, replaces fossil fuels in transport systems with biofuels, and decreases the need for mineral fertilizer use due to better nitrogen availability in the digested slurry.

In waste management methane is emitted from previously deposited organic waste in landfills, from management of currently produce waste, and from waste water treatment. Emissions of CH₄ from waste are expected to decrease in the future, mainly due to the existing ban of landfilling of organic waste. Emissions from waste treatment will however remain a significant CH₄ emission source. Generally, anaerobic treatment of organic waste, and of waste-water sludge, with gas recovery and upgrade systems is an efficient methane emission measure.

Waste prevention and separate collection with subsequent recycling is an example of a measure combining efficient infrastructure with information campaigns to promote behavioural changes. From all the waste fractions, food waste is of particular interest from methane perspective – good practices to reduce food waste is being developed and shared at the EU level.

Landfill gas collection, recovery and upgrade systems are established methods to reduce methane emissions. Gas recovery rates can be significantly (up to 90%) increased by applying micrometeorological methods based on continuous measurement and evaluation of methane fluxes to optimize landfill performance. Another efficient measure for landfill emissions is bio-cover – a multi-layer covering system consisting of inert and compost materials, reducing CH₄-emissions by 79–94%.

Oil and gas production and transmission are important sources of methane emissions primarily in Norway among the Nordic countries. The largest sources of methane in the oil and gas system are from venting and fugitive emissions (leaks). Already today several techniques to abate CH₄-emissions are implemented in Norway. Technical and operational abatement measures considered as best practices, with potentially high methane emission-reducing effect include: flaring instead of venting, extended recovery and utilization (rather than venting) of associated gas, and improved control and reduction of unintended fugitive emissions and leaks from production processes and from transmission and storage.

The Nordic countries share many similarities, but there are also differences in national conditions, in which SLCP sources contribute most to national emissions, and which 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. The GAINS-model analysis and the literature review presented in this report could serve as a starting point for assessing measures to abate SLCP, as a group of pollutants, originating from very different emission sources.

Preface

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

The overall objective of the project is to improve the Nordic emission inventories of Short Lived Climate Pollutants (SLCP). The first phase of the project presented an analysis of the status of knowledge (TN2015:523³). In the second phase an emission measurement program was implemented, where the objective was to expand the knowledge and to develop well documented and reliable emission factors for SLCP and PM_{2.5} from residential wood combustion (TN2017:570⁴).

This report presents the results from the third task in the project, an assessment of efficient measures to abate SLCP emissions in the Nordic countries.

The work has been excellently guided by a project steering group with participants from the Nordic countries as well as from the Nordic Council of Ministers.

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³ <http://norden.diva-portal.org/smash/record.jsf?pid=diva2:807348>

⁴ <http://norden.diva-portal.org/smash/record.jsf?pid=diva2:1174670>

1. Background and introduction

The overall objective of the project is to improve the Nordic emission inventories of Short Lived Climate Pollutants (SLCPs), which is a group of substances comprising black carbon (BC) or soot, tropospheric ozone (O_3), methane (CH_4), and hydrofluorocarbons. O_3 is formed in atmospheric chemical reactions involving CH_4 , nitrogen oxides (NO_x), carbon monoxide (CO), non-methane volatile organic compounds (NMVOC) and sunlight. The SLCPs have, in comparison to the long lived greenhouse gases such as carbon dioxide (CO_2) and nitrous oxide (N_2O), a short residence time in the atmosphere.

As a first step a Background analysis was performed (Kindbom *et al.* 2015, TN2015:523⁵) to summarise current Nordic knowledge, emission inventories and emission levels, and to lay the basis for the emission measurement program which was performed in the second phase of the project (Kindbom *et al.* 2017, TN2017:570⁶). As described in the background analysis, residential biomass combustion is identified as a major source for SLCP emissions in the Nordic countries. The measurement program, covering different residential biomass combustion appliances, showed that the levels of emissions can vary substantially depending on technology and on operational conditions.

In this step of the project, the objective was to identify efficient measures to reduce emissions of SLCPs beyond the current emission projections.

The primary goal in the project was to improve the knowledge regarding black carbon (BC) emissions. BC is part of particulate matter ($PM_{2.5}$), and most of the earlier reported or implemented measures are focusing on $PM_{2.5}$. Reduction of $PM_{2.5}$ emissions is therefore also included in the analyses in this report. Furthermore, to propose efficient measures to reduce SLCPs, not only BC ($PM_{2.5}$) should be taken into account. Measures targeting only BC or $PM_{2.5}$ emissions might not always be the most cost-effective if reduction of SLCPs as a group is considered. Thus, also measures abating CH_4 emissions were included in the assessment.

The principle in this project was that the measures need to be additional to those already considered in the current national projections. The effects of the already existing measures and legislation are included in the national projections, which are referred to as “with existing measures” (WEM). To reduce emissions further, additional measures or actions were explored. Both technical measures, such as filters or improved technologies, and non-technical measures, such as promoting behavioural changes favouring reduced emissions are discussed in this report.

As a background the current national projections of BC, $PM_{2.5}$ and CH_4 are presented, showing the future emission levels expected with existing measures taken into

⁵ <http://norden.diva-portal.org/smash/record.jsf?pid=diva2:807348>

⁶ <http://norden.diva-portal.org/smash/record.jsf?pid=diva2:1174670>

account. A general overview of recent EU policy instruments that will impact future SLCP emissions, as well as a review of key measures to abate BC and CH₄ emissions based on a literature review is provided.

A combined SLCP model analysis show that for BC the most important sources targeted for abatement measures in the Nordic context are residential biomass combustion, on-road and non-road diesel vehicles and machinery. For CH₄ the agricultural sector and waste management are the most important sources, followed by oil and gas production, particularly for Norway.

A literature review of possibilities beyond the existing measures is presented for PM_{2.5} and BC from residential biomass combustion and on road and non-road vehicles and machinery. Measures targeting CH₄ are presented for oil and gas production as well as for the agricultural and the waste sectors. Also instruments that are existing, planned, or possible to be implemented to promote abatement measures are discussed. Where available, the costs and cost efficiency of measures are presented.

2. Nordic SLCP emission sources

Important SLCP and PM_{2.5} sources in the future

The aggregated national projections in the Nordic countries show that total Nordic emissions of PM_{2.5}, BC and CH₄ are all expected to decrease to 2030 with existing measures in place. Residential combustion is expected to remain as the most important source for PM_{2.5} and BC. Emissions of PM_{2.5} and BC from vehicles (road transport and off-road vehicles and machinery) are expected to decrease in the future, especially for BC, but will still contribute significantly to the total emissions. CH₄-emissions from solid waste treatment are projected to decrease due to the ban on landfilling of organic waste, and the recovery of methane as biogas. Remaining projected emissions from waste treatment are however still significant. Emissions from agricultural sources remain high and their relative importance will increase. In Norway, fugitive emissions from fuels (oil and gas production) will increase as a source of CH₄ according to the Norwegian projections.

The presently most important SLCP emission sources in the Nordic countries were identified in the background report TN2015:523 (Kindbom *et al.* 2015). In order to assess relevant and efficient measures to reduce future emissions, consideration needs to be taken to the expected future emissions according to the national emission projections. National projections are developed with existing measures (WEM), which include the expected effects of already existing measures and legislation as well as those agreed to be implemented. Measures to reduce emissions beyond the WEM projections would be additional.

2.1 Present and future sources of PM_{2.5}, BC and CH₄

The Nordic emission inventories show that the largest source of BC and PM_{2.5} emissions is residential combustion, which contributes more than 40% of the Nordic BC and PM_{2.5} emissions (Kindbom *et al.* 2015).

In Figure 1 and Figure 2 the development of the officially reported Nordic PM_{2.5} and BC emissions from 2005–2015 and projected emissions to 2030 are presented as sums for all the Nordic countries. The disaggregation of sources in the figures is adapted to the aggregation level of the reporting of projections, which is less detailed than in annual emission inventories. This means that emissions from residential combustion are reported aggregated with stationary and mobile combustion in commercial, institutional, agriculture, forestry and fishing.

The current Nordic projections of PM_{2.5} and BC emissions show a decrease from 2015 to 2030. The contributions of (important) sources remains similar: residential combustion dominates and road transport is still significant, as is the diverse group of energy production, combustion in industry and fugitive emissions.

In 2015, the emissions of PM_{2.5} from residential combustion in the Nordic countries were about 44 Gg or 48% of the total Nordic PM_{2.5} emissions. For BC the estimated emissions from residential combustion were 6.5 Gg, 43% of the Nordic total emissions. Road transport contributes significantly to the BC emission (around 15% in later years).

Figure 1: Nordic emissions of PM_{2.5} (Gg) 2005–2015 and projections to 2030

Figure 2: Nordic emissions of black carbon, BC (Gg) 2005–2015 and projections to 2030

The aggregated Nordic CH_4 emissions are dominated by the agriculture and waste sectors (Figure 3). These sectors together contributed more than 85% to the total CH_4 emissions in 2015. Agriculture is the single largest source, contributing almost to 65% of the CH_4 emissions. In the projections of CH_4 for 2030 the total emissions are expected to decrease, mainly due to decreasing emissions from the waste sector while emissions of CH_4 from agriculture remain high.

Figure 3: Nordic emissions of methane, CH₄ (Gg) 2005–2015 and projections to 2030

The aggregated Nordic projections (Figure 1, Figure 2 and Figure 3) show that total emissions of PM_{2.5}, BC and CH₄ are all expected to decrease by 2030. Residential combustion is expected to remain as the most important source for PM_{2.5} and BC also in 2030. Emissions from vehicles (road transport and off-road vehicles and machinery) are expected to decrease in the future, especially for BC. For methane, emissions from solid waste are projected to decrease due to the ban on landfilling of organic waste, and also the recovery of methane as biogas. Emissions from agriculture remain high.

2.1.1 Denmark

Emissions of PM_{2.5} and BC in Denmark are dominated by residential wood combustion. Emissions from residential wood combustion increased from 2000 to 2008 due to increased fuel consumption that negated the development in technology. In the projection the wood consumption is expected to remain relatively constant and due to the continuous replacement of older stoves and boilers with more modern technologies the emissions are projected to decrease significantly.

Figure 4: Emissions of PM_{2.5} (Gg) in Denmark 2005–2015 and projections to 2030

Figure 5: Emissions of BC (Gg) in Denmark 2005–2015 and projections to 2030

The CH₄ emission in Denmark is dominated by agriculture and waste. In 2013 the two sectors accounted for 93.7% of the total CH₄ emission. The share has been increasing from 88.4% in 2000 due to decreasing emissions from energy production and industry and fugitive emissions from fuels. In the projection the share is expected to increase slightly to 94.5% in 2025. The further increase is due to reductions in emissions from other stationary combustion (residential wood combustion) and fugitive emissions from fuels. The emission from the waste sector is decreasing driven by the ban of land-filling organic waste, while the emission from agriculture is projected to increase.

Within agriculture, enteric fermentation is the largest source and cattle is the dominant animal category. The emission from enteric fermentation is mainly correlated to the number of cattle and the emission has been decreasing in the historic years, due to a reduction in the number of cattle. In the projection period a slight increase is projected due to an increase in the number of cattle. The emission from manure management has increased historically due to a shift from traditional solid based animal waste management systems to slurry based systems with higher emissions. The emission from manure management is expected to decrease in the future. The reasons for the decrease is the increased use of manure for biogas production as well as other technologies put in place to reduce emissions, e.g. acidification of slurry.

CH₄ emissions from the waste sector are expected to continue a steady decrease caused by a reduction in emissions from solid waste disposal on land. The latest projection does not take into account the effect of biocovers expected to be implemented as a measure to reduce CH₄ emissions. Emissions from other waste are mainly from composting and this source is expected to increase. The emission from anaerobic digesters using organic waste is not included in the figure.

Figure 6: Emissions of CH₄ (Gg) in Denmark 20015–2015 and projections to 2030

2.1.2 Finland

The projections for 2020, 2025 and 2030 are calculated by the national air pollutant scenario tool FRES (Karvosenoja 2008) for other sectors than transport, which is calculated by GAINS, and agriculture, which is calculated by the national Nitrogen Model (Grönroos 2009). Altogether, four scenario versions are available: the baseline, GAINS, low-C and maximum feasible reductions.

The projections are based on existing legislation and legislation to be implemented in the target years, and include:

- the EU IED requirements with national transitional plans;
- EUR 6 standards for vehicles;
- reduced SO₂ emissions due to national decree for energy production units less than 50 MW;
- national energy and climate strategy update in 2013 for fuel use in 2020 and 2030.

The largest future source of PM_{2.5} and BC is small scale combustion, where the level of emissions is estimated to stay at the present level until 2020. By 2030 emissions are projected to decrease due to reduced need for heating through growing energy efficiency of buildings resulting from tightened building codes. The impact of the Ecodesign Directive is estimated to be rather low due to the long operating life of equipment already including accumulation and having moderately low particle emissions. Small decrease in emissions can be expected by 2030 due to renewal of equipment, especially for sauna stoves. Continuing already implemented information campaigns on correct user practices in small combustion are estimated to result in further reductions, and would be efficient especially in urban areas.⁷

Exhaust emissions of PM_{2.5} and BC from road transport, other transport and off-road machinery are decreasing due to renewal of the car and vehicle fleet and will continue to decrease when EUR 5–6 techniques become more common. From road dust the emissions of PM_{2.5} reflect the development of transport volumes and cannot efficiently be abated⁸, although efficient maintenance and cleaning of roads, especially in urban areas, have a decreasing impact on emissions.

From energy production, due to efficient combustion and end-of-pipe technologies, emissions of PM_{2.5} are estimated to stay low compared to the volume of fuel use, however, although the emission reductions required in the EU IED impact the emission levels in 2010–2020, increase in combustion of biofuels increases particle emissions.

⁷ The development of user practice of each of the combustion equipment types and user profiles for the equipment types are included in the projections: user induced errors (incorrect filling of the device malfunctions in lighting the fire, restricted air flow and low quality of wood result in bad combustion with excessive amount of unburned components and high particle emissions). Estimation of bad combustion emissions is based on measurements and expert judgements. (Savolahti et al 2015).

⁸ Development in the design of studded tyres has already reduced emissions, while some municipalities have considered restrictions on their use in urban areas. However, restrictions on the use of studded tires may also risk road safety outside urban areas. (www.hel.fi; www.autoliitto.fi; www.liikennesuunta.fi).

The foreseen steep decrease in combustion of coal is not reflected in emissions because coal is combusted in large combustion plants where particle emissions are low due to efficient combustion and abatement technique.

Projected emissions from industry reflect activity levels and no large changes to current levels are included in the scenarios.

Figure 7: Emissions of PM_{2.5} (Gg) in Finland 2005–2015 and projections to 2030

Figure 8: Emissions of BC (Gg) in Finland 2005–2015 and projections to 2030

CH₄ emissions are projected to develop as presented in Figure 9. Small scale wood combustion, transport and fugitive emissions from fuels are small sources while agriculture and waste dominate projected emissions.

No measures are expected for agriculture where the emissions depend on the number of animals, which already has steadily decreased due to closure of small farms and increase in animal sizes due to structural changes in agriculture.

CH₄ emissions from waste handling have decreased by a third from the 1990s due to improvements in waste handling methods. All further emission reductions for methane are foreseen to concentrate in the waste sector where the ban for biodegradable waste to be deposited on landfills will have a large impact on emissions. Also methane generated at landfills will be recovered.

Figure 9: Emissions of CH₄ (Gg) in Finland 2005–2015 and projections to 2030

2.1.3 Iceland

Figure 10 and Figure 11 show the development of emission estimates for PM_{2.5} and BC between 2005–2015. Iceland presently does not produce any national projections for PM_{2.5} and BC. The emission estimates for these pollutants is based on a limited number of emission sources and cannot be considered complete as of now. The emission estimates are therefore expected to change somewhat as the inventory for these pollutants become more complete. Currently reported PM_{2.5} emissions are shown in Figure 10 and some of the sources of PM_{2.5} emissions are commercial fishing, metal production (ferroalloys and aluminium production), road transport and waste incineration. The fluctuations in the current emission estimates are mainly due to fluctuations in metal production and fluctuating use of oil in commercial fishing. Total current BC emission estimates are shown in Figure 11 and some sources are road transport, mobile combustion in industries, commercial fishing, waste incineration and metal production (ferroalloys and aluminium production). The emission estimates trend shown in Figure 11 is subject to changes in the inventory as it becomes more complete, as previously mentioned.

In Iceland, emissions from residential biomass combustion have not been estimated as of today and in contrast to other Nordic countries, the great majority of residences uses either geothermal district- or electric heating, suggesting a much lower impact of residential combustion of biomass on total national SLCP emissions than in the other Nordic countries. In addition, the small population of Iceland compared to other Nordic countries suggests, overall, a very small impact of the Icelandic residential combustion of biomass on total Nordic SLCP emissions. The PM_{2.5} emissions presented under residential combustion in Figure 10 does therefore not include residential combustion and the source of the PM_{2.5} is entirely from the fishing fleet.

Figure 10: Emissions of PM_{2.5} (Gg) in Iceland 2005–2015, from presently estimated sources

Figure 11: Emissions of BC (Gg) in Iceland 2005–2015, from presently estimated sources

Emission estimates for CH₄ in Iceland are dominated by enteric fermentation in the agricultural sector and by biodegradation processes at solid waste disposal sites in the waste sector (Figure 12). Projections for these emissions are provided in the biennial report to the UNFCCC⁹ and are based on a reduction in emissions from waste disposal sites. These projections were made in 2013 for the submission of the 6th national communication and 1st Biennial report and used global warming potentials from the 2nd Assessment report¹⁰, as stated in the biennial report. These projections therefore need revision and updating based on new emission estimates and updated global warming potentials.

Figure 12: Emissions of CH₄ (Gg) in Iceland 2005-2015 and current projections to 2030

2.1.4 Norway

Emissions of PM_{2.5} and BC in Norway are dominated by residential wood combustion. PM_{2.5} and BC emissions from residential wood combustion increased from 2000 to 2003 due to increased fuel consumption. For the years 2004 to 2009 the fuel consumption was relatively constant while the emissions of PM_{2.5} and BC decreased due to the fact that a larger amount of the wood was burnt in stoves with modern technologies. In 2010 there was a peak in fuel consumption and emissions. Since 2010 consumption and emissions have decreased. According to the Norwegian emission projections, which take current legislation into account, the national total emissions of BC will be lower in 2030 compared to today. The trend, however, is different for different sources. Emissions from road traffic are expected to decline significantly. From other mobile sources reductions are also expected, but to a lesser extent than from road traffic. Emissions from Other sectors which include residential combustion of biomass are expected to increase. These emissions in relative terms will increase in importance.

⁹ https://unfccc.int/files/national_reports/biennial_reports_and_iar/submitted_biennial_reports/application/pdf/iceland_biennial_report_2nd.pdf

¹⁰ http://unfccc.int/files/national_reports/annex_i_natcom/submitted_natcom/application/pdf/nc6_br1_isl.pdf

Figure 13: Emissions of PM_{2.5} (Gg) in Norway 2005–2015 and projections to 2030

Figure 14: Emissions of BC (Gg) in Norway 2005–2015 and projections to 2030

The agricultural sector, together with the waste sector, are the main emission sources for CH₄ in Norway today. In the future the agricultural sector and fugitive emissions from fuels (included in "Other" in Figure 15) are expected to be the main emission sources for CH₄ in Norway. CH₄ from the agricultural sector is reduced slightly to 2020 and increased slightly to 2030 according to the projections. Agriculture will thus be of relatively greater importance for emissions of CH₄ in the future. In the projection the emissions from industrial processes and fugitives emissions from fuels is projected to increase. The emission from the waste sector is decreasing driven by the ban of land-filling organic waste.

Figure 15: Emissions of CH₄ (Gg) in Norway 2005–2015 and projections to 2030

2.1.5 Sweden

According to the Swedish emission projections, which take current legislation into account, the national total emissions of PM_{2.5} and BC will be lower in 2030 compared to today (Figure 16 and Figure 17). The trend however, varies for different sources.

Emissions of PM_{2.5} and BC from combustion of fuels in road traffic are expected to decline to 2030, while PM_{2.5} emissions from road abrasion remain higher, resulting in a smaller relative decrease in PM_{2.5} than in BC from road traffic in total. Decreases in emissions are due to the expected renewal of the vehicle fleet and that the energy efficiency of the fleet is assumed to continuously improve due to the EU CO₂ requirements. From other mobile sources reductions are also projected, but from a lower level of emissions and to a lesser extent than from road traffic.

Emissions of PM_{2.5} and BC from residential combustion are expected to remain at about the same level as at present, why these emissions in relative terms will increase in importance.

Figure 16: Emissions of PM_{2.5} (Gg) in Sweden 2005–2015 and projections to 2030

Figure 17: Emissions of BC (Gg) in Sweden 2005–2015 and projections to 2030

The agricultural sector is the main emission source for CH₄ in Sweden, both today and in the future (Figure 18). CH₄ from the agricultural sector is reduced only slightly to 2030 according to the projections, while emissions of CH₄ from the waste sector are predicted to be reduced to a greater extent. Agriculture will thus be of relatively greater importance for emissions of CH₄ in the future.

The decrease in CH₄ emissions from agriculture to 2030 is mainly due to declining numbers of dairy cows as productivity increases. The development of product prices and continuous adaptation to EU agricultural policy regulations are contributing to lower projected emissions. Emissions from waste decrease largely due to the ban on landfilling organic waste, and recovery of methane as biogas. Furthermore, a tax on depositing waste in landfills was introduced in 2000.

The projections take into account and include an expected slight increase in CH₄ emissions due to biogas production from landfills and from sludge from waste water treatment plants. The latest Swedish emission projection for the agricultural sector, however, doesn't take into consideration anaerobic treatment of manure, although anaerobic treatment (and biogas production) from manure already exists. Swedish national instruments as well as relevant EU instruments considered in the baseline projection for greenhouse gases, including CH₄, are summarized in the latest greenhouse gas projection report.¹¹

Figure 18: Emissions of CH₄ (Gg) in Sweden 2005-2015 and projections to 2030.

¹¹ Report for Sweden on assessment of projected progress, March 2017.

<https://www.naturvardsverket.se/upload/miljoarbete-i-samhallet/uppdelat-efter-omrade/klimat/prognoser-for-Sveriges-utslapp/prognoser-for-Sveriges-utslapppreport-sweden-assessment-projected-progress-2017.pdf>

3. Policies and measures to reduce SLCP emissions

Policies and measures to reduce SLCP emissions

In order to assess and identify additional measures to abate BC and CH₄ emissions, beyond existing measures, a review of some recent EU-instruments with the potential to impact future emissions was done. Several policy instruments targeting particulate matter and methane emissions have recently (or will soon) enter into force, and will thus influence national regulations and legislation in the Nordic countries.

Furthermore, key measures from international literature was reviewed, with a particular focus on those targeted towards reduced BC emissions from biomass combustion and on road and non-road transport, as well as on CH₄ emissions from agriculture and waste. The studied measures are both technical and non-technical and a number of these measures are to varying degrees already applied in the Nordic countries.

3.1 Policy instruments to promote abatement measures

Policy instruments can be of different types, such as laws and regulations, economic instruments or in the form of education and information. Examples of different types of policy instruments are presented in Table 1 (Energimyndigheten, 2014, ACAP, 2014). Economic instruments can be for example taxes, subsidies or grants, while information campaigns can be targeted towards improved user practices or information on health aspects. A measure is a practice, technology or process that will reduce emissions.

Table 1: Examples of different types of instruments

Economic instruments	Regulatory instruments	Information instruments	Research and development
Taxes	Laws and regulations	Information/ awareness raising	Research funding
Tax deductions	Emission limit values	Guidance	Development support
Fees/charges	Technology requirements, standards, certification	Education	Demonstration support
Grants/subsidies	Long-term agreements	Guidelines (technical, policy)	Technology procurement
Deposits	Environmental classification	Influencing public opinion	
Market based trading systems			

3.2 Key SLCP measures from the literature

In the international literature covering measures to reduce emissions of SLCPs on the global scale, there are some key measures and certain emission sectors that recur. These measures are summarised for example in UNEP/WMO (2011), UNEP (2011), and in WHO (2015). In the report on the revision of the NEC directive (2016/2284/EU) measures for reduction of particulate matter emissions in urban areas are presented.

The key sectors listed in those reports are residential combustion and the transport sector, with measures to primarily reduce BC emissions (Table 2), and the agricultural and waste sectors to reduce emissions of methane (Table 3). Additionally, measures for reducing methane emissions from extraction/production of fossil fuels (oil and gas) as well as BC emissions from some industrial sectors are included. The relevance for the Nordic countries of the measures listed in the tables was considered.

Table 2: Key black carbon (BC) abatement measures

Measure	Sector
Standards for the reduction of particles from diesel vehicles (including particle filters) equivalent to EUR 6 for on road and off road vehicles	Transport
Elimination of high-emitting vehicles in on-road and off-road vehicles (renewal of fleet)	
Pellet stoves and boilers, using fuel made from recycled wood waste or sawdust, to replace current wood-burning technologies in the residential sector in industrialised countries	Residential

Note: Measures may also affect co-emitted compounds.

Source: UNEP (2011) and UNEP/WMO (2011).

Table 3: Key methane (CH₄) abatement measures

Measure	Sector
Extended recovery and utilization, rather than venting, of associated gas and improved control of unintended fugitive emissions from the production of oil and natural gas	Extraction/production and transport of fossil fuels
Reduced gas leakage from long-distance transmission pipelines	
Separation and treatment of biodegradable municipal waste through recycling, composting and anaerobic digestion as well as landfill gas collection with combustion/utilization	Waste management
Upgrading primary wastewater treatment to secondary/tertiary treatment with gas recovery and overflow control	
Control of CH ₄ emissions from livestock, mainly through farm-scale anaerobic digestion of manure from cattle and pigs	Agriculture

Source: UNEP (2011) and UNEP/WMO (2011).

In 2015 WHO ¹² published an updated assessment of health risks and cost-effective abatement measures, where some are the same or similar to those in UNEP/WMO (2011) and UNEP (2011), but where also some non-technical measures have been introduced. Measures relevant for Nordic countries are listed in Table 4.

¹² <http://who.int/phe/publications/climate-reducing-health-risks/en>

Table 4: Cost effective abatement measures for BC and CH₄ (WHO, 2015)

Measure	Sector	SLCP
Improved vehicle technologies, e.g. diesel particle filters, fuel-type innovations	Transport	BC
Shifting to low-emission modes of travel, e.g. walking/cycling		
Journey avoidance and route optimization		
Improving the management of livestock manure: cooling or covering manure sources, separating solids from liquids, and more precisely timing of manure applications to crop lands	Agriculture	CH ₄
Shifting to low-GHG diets by reducing (human) consumption of animal products		
Reducing the amount of food waste in the production chain		
Reducing the amount of waste, especially food waste in the consumption chain	Waste and wastewater treatment	CH ₄
Methane recovery at landfills and waste water treatment plants		
Recovery and use of methane (control of fugitive emissions). Flaring is a measure to decrease methane emissions but it increases BC emissions	Oil and gas	CH ₄

In the process of the revision of the Directive on National Emission Ceilings (NEC), several amendments of the text proposed by the European Commission were made. One of the text versions (amendments adopted by the European Parliament on 28 October 2015) contained a list of possible measures for urban areas focused on reduction of emissions of NO_x and particulate matter from transport and residential combustion. Both technical and non-technical policies and measures were included. In the revised NEC Directive (EU 2016/2284) the list has been eliminated; however, a summary of available efficient measures and instruments to abate particulate matter and black carbon in European urban areas remains in the Directive text.

Table 5: Instruments to reduce Particulate Matter and BC emissions in urban areas

Measure	Sector
<p>Sustainable urban mobility plans including measures such as low emission zones, congestion pricing, parking controls, speed limits, car sharing schemes and roll-out of alternative charging infrastructure</p> <p>Promotion of modal shift to increase the use of cycling, walking and public transport</p> <p>Sustainable urban freight plans such as the introduction of consolidation centres plus measures to encourage a shift of regional freight from road to electric rail and water</p> <p>Ensure emissions from construction are minimised by introducing and enforcing policies to reduce and monitor construction dust, and set emissions limits for Non Road Mobile Machinery (NRMM)</p> <p>Revision of vehicle taxation rates in recognition of the higher real-world emissions from diesel cars and gasoline direct injection vehicles to encourage sales of less polluting vehicles</p> <p>Public procurement and fiscal incentives to encourage early uptake of ultra-low emission vehicles</p> <p>Support for retrofit of UNECE REC Class IV particulate filters on diesel machines, trucks, buses and taxis</p> <p>Regulate emissions from construction machines and other non-road mobile machinery operating in densely populated areas (including through the retrofit)</p>	Transport
<p>Using the planning system to address emissions from new development and boiler systems; retrofit energy efficiency measures to existing buildings</p> <p>Retrofitting schemes to promote the replacement of old domestic combustion installations with better home insulation, heat pumps, light fuel oil, new wood pellet installations, district heating or gas</p> <p>Economic and fiscal incentives to encourage the uptake of low emitting heating appliances</p> <p>Banning of solid-fuel burning in residential areas and other sensitive areas to protect the health of vulnerable groups including children</p> <p>Awareness raising campaigns and alerts</p>	Residential combustion

Source: Amendments adopted by the European Parliament on 28 October 2015 on the proposal for a directive of the European Parliament and of the Council on the reduction of national emissions of certain atmospheric pollutants and amending Directive 2003/35/EC, Amendment 108.

3.3 Recent EU policy instruments with a potential to influence future SLCP emissions

This chapter presents some recent policy instruments in the EU which are important from the SLCPs' point of view. The material is not fully comprehensive, but indicates that for the major emission sources there is ongoing work at the EU level to introduce regulations to reduce emissions. These target emissions from residential biomass combustion via new requirements under the Ecodesign Directive (EC Directive 2009/125¹³). There is also a new regulation on emission limits for non-road mobile machinery (EU Regulation 2016/1628). The revised NEC directive (2016/2284/EU¹⁴) with revised national emission ceilings also includes ceilings for PM_{2.5}. In addition, the EU Common Agricultural Policy (CAP) targets, among other things, methane emissions from agriculture, and in the IE directive (2010/75/EU¹⁵), waste treatment from large agricultural

¹³ DIRECTIVE 2009/125/EC OF THE EUROPEAN PARLIAMENT AND OF THE COUNCIL of 21 October 2009 establishing a framework for the setting of ecodesign requirements for energy-related products.

¹⁴ EU (2016). DIRECTIVE (EU) 2016/2284 OF THE EUROPEAN PARLIAMENT AND OF THE COUNCIL of 14 December 2016 on the reduction of national emissions of certain atmospheric pollutants, amending Directive 2003/35/EC and repealing Directive 2001/81/EC.

¹⁵ DIRECTIVE 2010/75/EU OF THE EUROPEAN PARLIAMENT AND OF THE COUNCIL of 24 November 2010 on industrial emissions (integrated pollution prevention and control).

facilities are regulated. The proposed revisions of waste regulations included under the EU Circular Economy Package also target SLCPs.

3.3.1 *The Ecodesign Directive*

Future emissions of BC and ozone precursors from residential biomass combustion (solid fuel boilers and space heaters (stoves) using solid fuels) will be affected by the new requirements under the Ecodesign Directive which were adopted in August 2015 (EU 2015/1185¹⁶, EU 2015/1186¹⁷, EU 2015/1189¹⁸). The requirements will take effect in 2020 for new solid fuel boilers and in 2022 for new stoves (space heaters). According to the new regulations the Ecodesign Directive proposes minimum requirements for seasonal space heating energy efficiency. It also includes emission limits for particulate matter (where BC is a component) and for the ozone precursors carbon monoxide (CO), organic gaseous compounds (OGC) and nitrogen oxides (NOx).

3.3.2 *Emission limits for non-road mobile machinery (NRMM)*

Emissions from non-road mobile machinery engines are regulated in the Non-Road Mobile Machinery regulation which applies as of 1 January 2017 (EU 2016/1628, "NRMM Regulation").¹⁹ The NRMM Regulation defines emission limits for non-road mobile machinery engines for different power ranges and applications. It also lays down the procedures, which engine manufacturers have to follow in order to obtain type-approval of their engines – which is a prerequisite for placing the engines on the EU market. The NRMM²⁰ covers a large variety of combustion engines installed in machines ranging from small handheld equipment, construction machinery and generating sets, to rail-cars, locomotives and inland waterway vessels.

3.3.3 *National Emission Ceilings (NEC) directive*

The revised National Emission Ceilings (NEC) Directive (2016/2284/EU) entered into force on 31 December 2016²¹. It sets national emission reduction commitments for Member States and the EU for the years 2020 and 2030 for five air pollutants: nitrogen oxides (NOx), non-methane volatile organic compounds (NMVOCs), sulphur dioxide

¹⁶ COMMISSION REGULATION (EU) 2015/1185 of 24 April 2015 implementing Directive 2009/125/EC of the European Parliament and of the Council with regard to ecodesign requirements for solid fuel local space heaters.

¹⁷ COMMISSION DELEGATED REGULATION (EU) 2015/1186 of 24 April 2015 supplementing Directive 2010/30/EU of the European Parliament and of the Council with regard to the energy labelling of local space heaters.

¹⁸ COMMISSION REGULATION (EU) 2015/1189 of 28 April 2015 implementing Directive 2009/125/EC of the European Parliament and of the Council with regard to ecodesign requirements for solid fuel boilers.

¹⁹ REGULATION (EU) 2016/1628 OF THE EUROPEAN PARLIAMENT AND OF THE COUNCIL of 14 September 2016 on requirements relating to gaseous and particulate pollutant emission limits and type-approval for internal combustion engines for non-road mobile machinery, amending Regulations (EU) No 1024/2012 and (EU) No 167/2013, and amending and repealing Directive 97/68/EC.

²⁰ https://ec.europa.eu/growth/sectors/automotive/environment-protection/non-road-mobile-machinery_sv

²¹ <https://www.eea.europa.eu/themes/air/national-emission-ceilings/national-emission-ceilings-directive>

(SO₂), ammonia (NH₃) and fine particulate matter (PM_{2.5}). PM_{2.5} was included in the revised directive in addition to the four other pollutants included already in the earlier legislation. These pollutants contribute to poor air quality, leading to significant negative impacts on human health and the environment. The reduction commitments agreed for 2030 are designed to reduce the health impacts of air pollution by half compared to emission levels in 2005.

The revised directive introduces a number of new requirements for the Member States, including the reporting of emissions of black carbon (BC), if available. Furthermore, the Directive requires that the Member States draw up National Air Pollution Control Programmes to be reported by 1st April 2019 and every four years thereafter. In the proposal for the new directive that was adopted on 28th October 2015²² there is a list of measures in urban areas for reducing particulate matter and black carbon emissions which Member states are encouraged to consider for inclusion into their National Air Pollution Control Programmes. The list of measures for urban areas is focused on transport and residential combustion (see Table 5).

3.3.4 EU Common Agricultural Policy (CAP)

The EU Common Agricultural Policy, CAP, targets among other things controlling methane emissions from the agricultural sector. The CAP has rather recently undergone a revision for a period covering 2014–2020. The reform was focused on delivering more effective policy instruments designed to improve the sustainability of the agricultural sector over time. While in the nineties CAP policies were mainly product based, by the end of 2013 94% of the financial support was decoupled from production and targeted towards producer support and consideration of the environment (EC, 2013).

The recognized need for improved environmental performance through more sustainable methods is, within the new CAP, developed into a new greening architecture and more flexible implementation mechanisms. 30% of the budget for each Rural Development program is reserved specifically for voluntary measures beneficial for the environment and for climate change (EC, 2013). This encompasses measures such as promoting anaerobic treatment of manure with biogas production, and other advanced methods to reduce methane emissions.

To facilitate adaptation of new technologies, there are training and innovation programs organized within the European Innovation Partnership "Agricultural Productivity and Sustainability" (EIP-AGRI). One of the focus groups within this partnership has specifically been working on the issue of reducing cattle livestock emissions in a cost-effective way. The tasks of the group included identification and comparison of different management practices and strategies for reducing emissions from cattle, with consideration of their cost-effectiveness and emission reduction efficiency, as well as stimulating the knowledge and the use of best management practices. Main findings of this

²² <http://www.europarl.europa.eu/news/en/news-room/20151022IPR98807/Air-quality-MEPs-approve-new-national-caps-on-pollutants>

work are summarized in their final report, “Reducing emissions from cattle farming” (EIP-AGRI, 2017).

3.3.5 *The Industrial Emission Directive and update of the BAT Reference Document (BREF) for waste treatment*

The Industrial Emission Directive (2010/75/EU) is relevant as an instrument regulating both the agricultural and waste sectors. Farm-yard manure is classified as waste, and thus large facilities treating more than 50 tons of manure and/or other organic waste per day are regulated by the IED and have to apply BAT-conclusions (2010/75/EU). The BAT Reference document for Waste Treatment currently undergoes a revision. The latest draft of the document (BREF for Waste Treatment, 2015) addresses anaerobic, aerobic and mechanical treatment of biological waste and discusses, among other things, possibilities to reduce methane emissions from biogas production.

3.3.6 *Waste Framework Directive and the Directive on Landfill of Waste*

In December 2015, the European Commission adopted a Circular Economy Package, which includes proposals on revised legislation for waste, amending the Waste Framework Directive (2008/98/EC) and the Directive on the Landfill of Waste (99/31/EC). These proposals set even stricter targets for decreased landfill and enhance further reductions of methane emissions from landfills, already significantly reduced within the implementation of the old Landfill Directive (99/31/EC). Some of the key elements of the waste proposals directly affecting methane emissions are as follows (EU Circular Economy Package):

- Limitation of the landfilling of municipal waste to 10% by 2030.
- A ban on landfilling of separately collected waste.
- Separate collection of bio-waste²³ where technically, environmentally and economically practicable.
- Encouragement of measures to increase recycling, including composting and digestion of bio-waste.
- Promotion of economic instruments to discourage landfilling.
- Promotion of food waste prevention, monitoring and assessment of the implementation of food waste prevention measures.

²³ Bio-waste is defined as biodegradable garden and park waste, food and kitchen waste from households, restaurants, caterers and retail premises, comparable waste from food processing plants and other waste with similar biodegradability properties that is comparable in nature, composition and quantity.

3.4 National policy plans and climate legislation

All Nordic countries have national climate legislation, climate policy plans or climate objectives in place. Out of the SLCPs, at least methane is affected by the national climate policies. National policies and measures targeting greenhouse gases (including methane) are available in the National communications and Biennial reports submitted to the UNFCCC²⁴. Norway has in addition an action plan specifically targeting SLCP.

3.4.1 Norwegian action plan for emissions of SLCPs

The Norwegian Environment Agency, on behalf of the Ministry of the Environment, has performed a holistic assessment of climate, health and environmental effects of Norwegian emissions of short-lived climate forcers (SLCFs), proposed measures and instruments for reducing such effects by 2030 and reviewed the need for further monitoring of these components. The proposal for an action plan was published on 6th December 2013 (Norwegian Environment Agency, 2014). The proposed action plan identifies 18 measures to reduce SLCPs. BC and CH₄ are targeted, as they account for 93% of SLCP emissions in Norway.

Table 6 shows a list of the cost effectiveness and the emission reduction effectiveness of all measures in the Norwegian action plan for short lived climate pollutants (SLCP). Cost effectiveness includes both climate effect and health effect. When calculating the cost effectiveness of the different measures, the impact from climate effect or the health effect varies greatly. The climate effects of the measures differ a lot, and only 8 of the 18 measures have a health effect.

The focus is on the most important emission sources. Out of the 18 different measures six affect the transport sector and increased use of DPF, diesel particle filters. There are two measures on domestic heating, where one is to accelerate introduction of new technology stoves and the other is improved combustion practices.

²⁴ http://unfccc.int/national_reports/national_communications_and_biennial_reports/submissions/items/10268.php

Table 6: Assessment matrix in the Norwegian action plan for short lived climate pollutants (SLCP)

Measure	Primary component reduced	Climate effect in kilotonnes of CO ₂ eq (GTP ₁₀ , Norway/yr)	Health effect in NOK million/yr	Cost effectiveness in NOK/tonne	Instrument
1 Reduced food waste	Methane	221	-	-4686	Information and outreach
2 Accelerated introduction of new stoves and pellet burners	BC, OC	318	808	-2433	Financial support combined with information and outreach
3 Energy efficiency in parts of industry	BC, OC	183	54	-1255	Financial support (ENOVA) combined with information and outreach
4 Transition from red to white meat	Methane	781	-	-593	Information and outreach (consumer side) Financial support (production side)
5 Improved combustion practices, inspection and maintenance	BC, OC	94	222	-208	Inspection, information and outreach
6 Reducing the filling need and use of HFCs with low climate effect	HFCs	137	-	14	Regulatory requirement
7 Retrofitting of diesel particle filters (DPFs) on construction machinery*	BC, OC	314	133	67	Regulatory requirement, low emission zones
8 Increased recycling of NMVOCs and methane when loading crude oil off-shore	NMVOCs, methane	101	-	71	Regulatory requirement, possible financial start-up support
9 Retrofitting and phasing in of DPFs on coastal vessels	BC	367	-	104	Regulatory requirement combined with financial support
10 Phasing in and retrofitting DPFs on fishing boats	BC	143	-	171	Regulatory requirement combined with financial support
11 Monitoring leak control and containment of HFCs	HFCs	445	-	236	Inspection/audit and supervision of the regulations
12 Retrofitting and phasing in of DPFs on mobile rigs	BC	171	-	465	Regulatory requirement and financial support
13 Conversion to Freiland process in the silicon carbide industry	CO	128	-	533	Regulatory requirement combined with financial support
14 Retrofitting of DPFs on light vehicles*	BC	226	216	589	Regulatory requirement combined with financial support. Low emission zones
15 Phasing in biogas from manure on buses	BC, methane	380	61	1591	Financial support
16 Retrofitting of DPFs on tractors	BC	224	-	2538	Regulatory requirement combined with financial support
17 Phasing in biogas from food waste on buses	BC, methane	110	81	3169	Financial support
18 Retrofitting of DPFs on heavy vehicles*	BC	54	17	18514	Regulatory requirement combined with financial support

Note: *Measure that could give an increase in NO₂ that reduces the positive health effects of the BC reductions.

Light blue=low, medium blue=moderate, dark blue=high.

Cost effectiveness (NOK/tonne CO₂ eq reduced); high=<0, moderate=0–600, low=>600.

Climate effect (annual reduction in kilotonnes CO₂ eq); high>400, moderate=200–400, low=<200.

Health effect (annual health benefit in NOK million); high>100, moderate=50–100, low=<50.

The column for instruments, the colour describes the degree of emission reduction effectiveness.

Source: From Norwegian Environment Agency (2014).

4. Efficient SLCP measures – a GAINS model analysis

Efficient SLCP measures – a GAINS model analysis

ECLIPSE project results applied for the Nordic countries indicate that in order to reach the emission reduction potential for black carbon, measures within the residential wood combustion sector should be prioritized – in particular, replacement of older boilers and heating stoves with new appliances, installation of ESP and high-efficiency dedusters, and switch to pellets. Measures aimed at residential combustion can reduce BC emissions in 2030 by 3.7 kt – this is about 79% of the estimated total BC emission reduction potential in the Nordic countries. Further emission reductions can be achieved by speeding up vehicle fleet renewal so that most of the diesel vehicles are EUR 6/Vl.

For methane, the large part of the emission reduction potential lies within the waste management and wastewater treatment sector, oil and gas industries, and gas distribution networks.

Full realization of the 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 a reduced climate impact (by ~14 Million tons CO₂ equivalents).

According to a Swedish study, the most cost-effective measures to reduce emissions of SLCP from a climate perspective are measures targeting residential biomass combustion (increased share of pellets replacing wood logs) in addition to anaerobic digestion and CH₄ recovery from manure (biogas). These results are well in line with the results from the ECLIPSE project applied for the Nordic countries.

GAINS²⁵ is an integrated assessment model, an extension of the RAINS²⁶ 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 (Amann *et al.* 2011). 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 (IIASA 2017) 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.

²⁵ GAINS = Greenhouse Gas - Air Pollution Interactions and Synergies.

²⁶ RAINS = Regional Air Pollution Information and Simulation.

4.1 SLCP in GAINS – assessment for the Nordic countries based on the results of the ECLIPSE study

In recent years, a comprehensive global analysis of SLCP emissions, effects and measures has been conducted within the ECLIPSE study (Stohl *et al.* 2015a, Stohl *et al.* 2015b, and Klimont *et al.* 2017). The overall goal of the ECLIPSE project was to develop and assess effective global emission abatement strategies for short-lived climate pollutants in order to provide sound scientific advice on measures that mitigate climate change and improve air quality at the same time (ECLIPSE 2017).

ECLIPSE is the most recent GAINS-based analysis taking an integrated, combined approach to SLCP mitigation with consideration of both climate and health perspectives. However, as a global study, it does not focus on individual countries. For the purposes of this project, we used ECLIPSE-based scenarios to analyze SLCP mitigation options and reduction potentials in the Nordic countries (see methodological details in Annex 1, including description of the differences between our analysis and the original ECLIPSE study).

The analysis was done by investigating baseline scenario emissions, emissions in the SLCP mitigation scenario as well as abatement measures available in the model, for each of the emitting sectors. We have identified key SLCP measures relevant for the five Nordic countries and assessed their contribution to the total emission reduction potentials. We have further estimated climate effects, emission reduction costs and health-related benefits attributable to air quality improvements – from emission reductions in each of the Nordic countries separately and in all five of them in total.

4.1.1 Scenarios

A *baseline* scenario implies efficient enforcement of committed legislation. This means that for future years the baseline scenario only includes measures already agreed and integrated in the current and planned legislation. Baseline scenarios in GAINS are updated on a regular basis to reflect new knowledge. In our analysis we use the most recent publically available baseline – *ECLIPSE_V5a_CLE_base*, finalized in 2015. It covers the period from 1990 to 2050 in five year intervals (IIASA 2017).

The SLCP mitigation scenario (hereinafter – *SLCP-MIT**) exemplifies a climate-optimized SLCP reduction (Stohl *et al.* 2015a). In the mitigation scenario, instead of current legislation measures, a set of reduction technologies has been implemented which for each single measure results in a reduction of total climate forcing. It considers the change in emissions of all substances included in the GAINS model. The climate forcing values are in this case based on GTP₂₀²⁷ (IIASA 2017). The measures are assumed to be implemented between 2015 and 2030. This scenario reflects the SLCP mitigation strategy that maximizes co-benefits and limits trade-offs between climate mitigation and air quality improvement by comprising a full set of measures beneficial for both (Stohl *et al.* 2015b).

²⁷ GTP₂₀= Global temperature potential with time horizon of 20 years.

Detailed descriptions of the measures for BC and methane that are available in the GAINS model can be found in Kupiainen & Klimont 2004 and Höglund-Isaksson *et al.* 2016, respectively.

By emission reduction potential in the current analysis we mean the emission difference between the baseline scenario and the SLCP-MIT* scenario. Below, we summarize emission reduction potentials for each country, and identify relevant abatement measures, choosing from those available in the GAINS model.

4.1.2 ECLIPSE results regarding SLCP in the Nordic countries

Figure 19 below illustrates CH₄ and BC emission trends in the baseline scenario as well as emission reduction potentials identified within the ECLIPSE project for all the Nordic countries in total. This figure illustrates that without additional measures, methane emissions would increase by ~50 kt between 2015 and 2030, and amount to ~1 Mt in 2030. By applying additional reduction measures, it is possible to reduce emissions down to 0.8 Mt (the lowest possible emissions are shown by the black line starting 2015). Baseline BC emissions are assumed to be decreasing from ~17 kt in 2015 to ~9 kt in 2030; with additional measures it is possible to achieve the level of ~4.5 kt in 2030. Sectors with significant emission reduction potentials in 2050 are marked as dotted areas – for methane it is mainly waste management, and for BC – residential combustion.

Figure 19: Emissions and emission reduction potentials in the Nordic countries according to ECLIPSE (IIASA 2016, Klimont 2017)

For the purposes of our project, we derive similar results for each particular Nordic country, choosing 2030 for more detailed analysis of the emission reduction potentials.

Furthermore, we identify relevant sector-specific measures to reach the minimum possible level of emissions in 2030.

4.2 Analysis of emission trends and reduction potentials

4.2.1 Methane-emission trends, measures and reduction potentials

Figure 20 below shows current and projected methane emissions in the Nordic countries in the baseline and in the *SLCP-MIT** scenarios. For comparison, emissions according to the national reporting and national emission projections are displayed²⁸.

Figure 20: CH₄ emissions in the Nordic countries, kt

According to the baseline scenario methane emissions will slightly increase in Sweden, Norway and Finland between 2015 and 2030, while in Iceland and in Denmark a decrease is expected. Emission reduction potentials in 2030, the difference between the baseline and *SLCP-MIT** in 2030, range from 5 kt in Iceland to ~100 kt in Denmark.

²⁸ In this report, we do not analyze the discrepancies between the reported and GAINS-modelled emissions. Those might be very country-specific and usually arise from differences in emission factors, application rates of technologies assumed, allocation of activities, information sources used, etc.

In Annex 2, the baseline emissions are presented by country and sector – the figures show in which sectors emissions are expected to be reduced due to already implemented instruments, without additional measures. Agriculture and waste management are significant emissions sources in all Nordic countries; in Sweden, Finland and Iceland they both are dominating, while in Norway and Denmark the second largest methane emission source (after agriculture) is oil and gas industries. Emissions from agriculture are expected to increase by 2–13% between 2015 and 2030 in all Nordic countries. Emissions from oil and gas production and distribution sector in Denmark and Norway are expected to decrease. Relative changes in the emissions from waste and wastewater treatment range from -38% to 16%.

Potential emission reductions down to the SLCP-MIT* levels imply extended application of additional measures. A detailed overview of all methane measures available in the GAINS model (including cost estimates, where available) has been published by Höglund-Isaksson *et al.* (2016). These measures are presented in Table 7, where key measures identified within the ECLIPSE project (Stohl *et al.* 2015b) are marked with italics.

Table 7: Methane abatement measures in GAINS

Sector	Available measures
Coal mining	<i>Pre-mining degasification</i> Oxidation of ventilation air methane (VAMOX) <i>VAMOX combined with improved ventilation system</i>
Oil and gas production	<i>Extended recovery and utilization of associated gas</i> <i>Good practice – leakage control</i>
Oil refinery	Extended flaring of waste gas
Consumer gas distribution networks	Doubled control frequency <i>Replacement of grey cast iron networks</i>
Livestock	Feed additives and feed management Breeding: – to enhance feed efficiency and reduce CH ₄ emissions – to increase productivity and maintain health and fertility Vaccination against methanogenic bacteria Farm-scale anaerobic digestion of farms with minimum size 100 LSU
Agricultural waste burning	<i>Effective ban on open burning of agricultural waste</i>
Municipal solid waste	<i>Separate collection and anaerobic digestion of food waste for biogas production</i> Household and large-scale composting of food waste Incineration of mixed waste Landfilling with recovery and flaring/utilization of landfill gas <i>Separate collection and recycling of paper waste</i>
Industrial solid waste	<i>Incineration with energy recovery</i> Landfilling with recovery and flaring/utilization of landfill gas Recycling of wood board production
Wastewater	<i>Anaerobic treatment with or without biogas recovery</i>

Source: Höglund-Isaksson *et al.* (2016).

In Table 8, the key measures and their contribution to the emission reduction potential of methane in the Nordic countries are presented. Several of these key measures appear to be relevant for the Nordic countries. The relative contribution from these key measures to methane emission reduction potentials in the Nordic countries is estimated at 64–85% for the year 2030.

Table 8: Key mitigation measures for methane identified within the ECLIPSE project (Stohl et al. 2015b) and the related emission reductions in the Nordic countries in 2030 = difference between baseline and SLCP-MIT* scenarios (own analysis)

Key measure as in Stohl et al. 2015b	Emission reduction potential in the Nordic countries (related to baseline emissions), kt				
	Norway	Sweden	Denmark	Finland	Iceland
Recovery and use of associated gas in oil and gas industries rather than venting and flaring	0*	No activity	43.5	No activity	No activity
Reducing emissions from unintended leaks during gas extraction	0*	No activity	0*	No activity	No activity
Reducing (oxidizing) ventilation air methane emissions released during hard coal mining	1.6	No activity	No activity	No activity	No activity
Hard and brown coal – pre-mining emissions – degasification	1.4	No activity	No activity	No activity	No activity
Replacement of grey cast iron distribution network in the gas distribution systems	13.1	0.8	0	0.9	No activity
Municipal waste – waste paper separation, collection and recycling ²⁹	5.3	1.7	1.4	3.5	2.2
Municipal food waste separation, collection and treatment in biogasification plants ³⁰	2.5	1.0	0.2	0.8	0.8
Recovery and incineration of industrial solid waste	9.3	0.8	0.4	3.3	0.7
Anaerobic treatment of wastewater with gas recovery, upgrading and use	3.5	24.5	22.1	18.8	0.5
% of total emission reduction potential of the mitigation scenario	82%	64%	67%	71%	85%

Note: *Zero emission reduction potential due to high levels of abatement measures (good practice, gas recovery) in the baseline scenario.

Total emission reduction potential for methane in the Nordic countries, according to our estimates, is 234 kt. This is slightly higher than ~200 kt implied in Figure 19 above illustrating aggregated results from the original ECLIPSE project. The reason for this discrepancy is that the most recent updates of emissions in the European countries done in connection with the EU reference scenario development (EC 2016) are not introduced in the GAINS module used for our analysis (Höglund-Isaksson 2017). That means that although the key emitting sources (agriculture, waste

²⁹ This measure is supposed to replace landfilling of municipal paper waste, not the fraction being incinerated (0% in Iceland and Finland and 7–39% in other Nordic countries).

³⁰ This measure is supposed to replace composting and landfilling of municipal food waste, not the fraction being incinerated (0% in Iceland and 31–76% in other Nordic countries).

management, and oil and gas industry) and sectors with high emission reduction potentials (waste and wastewater treatment, oil and gas industries, and gas distribution networks) seem to be identified correctly, numbers on emissions and emission reduction potentials in Table 8 and Figure 20 should be considered as indicative.

4.2.2 *BC and PM_{2.5} – emission trends, measures and reduction potentials*

Current and projected emissions of BC and PM_{2.5}, both as in nationally reported inventories and projections and modelled in the baseline and *SLCP-MIT** scenarios, are presented in Figure 21 and Figure 22, respectively. Available national projections indicate a decrease of particle emissions between 2015 and 2030 in all Nordic countries due to already agreed legislation. The modelling results for the baseline scenario show the same decreasing trend for black carbon whereas PM_{2.5} emissions are estimated to be slightly increasing for Sweden and Norway.

Emission reduction potentials, the difference between the baseline and the mitigation scenario *SLCP-MIT** (Figure 21 and Figure 22), are estimated at up to 2.2 kt for black carbon and up to 9.8 kt for PM_{2.5}.

It is important to remember that scenario *SLCP-MIT** focuses on reduction of SLCP and thus does not include a range of measures that would affect PM_{2.5} but not BC (e.g. measures in the construction industries). This means that the actual emission reduction potentials for PM_{2.5} are higher than those shown in Figure 22.

Figure 21: BC emissions in the Nordic countries, kt

Figure 22: PM_{2.5} emissions in the Nordic countries, kt

In all of the Nordic countries, except Iceland, residential combustion constitutes a substantial contribution to baseline emissions of BC and PM_{2.5}. Sectoral contribution to total BC and PM_{2.5} emissions in the Nordic countries according to the baseline scenario (see Annex 2) clearly shows that residential combustion is an important source, which is in line with the national emission inventories and projections.

In the global perspective, however, residential combustion is insignificant and none of the BC-targeting key measures identified as globally important in the ECLIPSE project concerns residential combustion (Stohl *et al.* 2015b).

In our analysis we have compiled lists of key measures targeting BC specifically for the Nordic countries. This was done by analyzing measures contributing to the emission reduction potentials – the difference between the baseline and SLCP-MIT* scenarios for each country – and identifying measures that make the largest contribution in each of the Nordic countries. The measures are presented in Table 9.

The measures in Table 9 are additional to what is included in the baseline. The key BC measures for the Nordic countries seem to be replacement of conventional residential combustion installations with more advanced equipment, EUR 6/VI control on road diesel transport, and specifically for Norway – good practice in associated gas flaring in the oil and gas industry.

Table 9: Key additional measures for BC in the Nordic countries, contributing to emission reduction potentials – difference between the baseline and SLCP-MIT* scenarios

N	Measures	BC reduction potential, kt	% of total reduction potential in the country
SWEDEN (94% of the total reduction potential)			
1	Residential combustion: for medium boilers (automatic) – HED ³¹ ; for single-house boilers (manual) – pellet boilers; for heating stoves – pellet stoves	0.81	65%
2	Industrial combustion of biomass: high-efficiency deduster	0.18	15%
3	EUR ₂₆ /VI on 93–100% of road diesel transport	0.070	6%
4	Power and district heating plants on biomass: high-efficiency deduster	0.067	5%
5	Stage 4 control for diesel-fueled agricultural and construction machinery; Stage 3B control on diesel trains; combustion modification at shipping	0.05	4%
FINLAND (99% of the total reduction potential)			
1	Residential combustion: for medium boilers (automatic) – cyclones, for medium boilers (manual) – HED; for single-house boilers (manual) – pellet boilers; for heating stoves – pellet stoves	2.01	93%
2	EUR ₂₆ /VI on 69–89% of road diesel transport	0.04	2%
3	Stage 4 control for diesel-fueled agricultural and construction machinery; Stage 3B control on diesel trains; combustion modification at shipping	0.032	1%
4	Power and district heating plants on biomass: high-efficiency deduster	0.029	1%
5	Biomass in fuel conversion sector: high-efficiency deduster	0.017	1%
NORWAY (93% of the total reduction potential)			
1	Flaring in oil and gas industries – good practice (87% removal efficiency)	0.12	62%
2	Effective ban on agricultural waste burning	0.06	22%
3	Industrial combustion of biomass: high-efficiency deduster	0.012	5%
4	Meat frying, BBQ: filters in the household kitchens	0.006	2%
5	Power and district heating plants on biomass: high-efficiency deduster	0.005	2%
DENMARK (99% of the total reduction potential)			
1	Residential combustion: for medium boilers (automatic) – HED; for single-house boilers (manual) – pellet boilers (partly – equipped with ESP); for heating stoves – pellet stoves	0.92	86%
2	Stage 4 control for diesel-fueled agricultural and construction machinery; Stage 3B control on diesel trains; combustion modification at shipping	0.08	8%
3	Effective ban on agricultural waste burning	0.03	2%
4	Mobile sources on gasoline, gas and LPG	0.02	2%
5	EUR ₂₆ /VI on 78–99% of road diesel transport	0.01	1%
ICELAND (100% of the total reduction potential)			
1	EUR ₂₆ /VI on 100% of road diesel transport	0.001	100%

³¹ HEED - high efficiency deduster with assumed removal efficiency of 99.98% (IIASA 2017).

Residential combustion of fuelwood comprises a number of installation types; not all of them are relevant for additional efficient abatement measures. The contribution from different installations to total BC emissions from residential wood combustion in four Nordic countries is presented in Figure 23 – for the baseline and for *SLCP-MIT** scenarios.

Figure 23: BC emissions (in kt) from residential combustion in four Nordic countries in 2030, by installation type, in the baseline vs. *SLCP-MIT scenarios; the differences are the emission reduction potentials**

The highest actual reduction potential is seen for manual single-house boilers (primarily Sweden and Finland), automatic medium boilers (Sweden and Denmark) and for heating stoves (Sweden, Finland and Denmark). For those installations, the following efficient measures are available in the GAINS model (removal efficiencies compared to a conventional device are given in parenthesis):

- Single-house boilers (manual): improved installation (50%), new installation (83%), pellet boiler (99.86%), pellet boiler with ESP (99.98%)
- Medium boilers (automatic): high-efficiency deduster HED (99.98%), pellet boiler (89%)
- Heating stoves: new installation (63–72%), new installation with ESP (94%), pellet stove (96%), pellet stove with ESP (99.98%).

For Norway, there is a very small difference between the baseline and the *SLCP-MIT** scenario. Measures targeting residential wood combustion do not show up as important for Norway in the analysis of key additional measures for BC (Table 9, Figure 23), resulting in comparatively low emission reduction potentials. This may be explained by the fact that the share of new and improved installations is assumed to be quite high already in the baseline, meaning that they are installed recently and would not be expected to be replaced by more advanced equipment quickly enough to influence the *SLCP-MIT** scenario to 2030. For Norway the share of new heating stoves is 70% in the baseline (see Annex 3 exemplifying residential combustion technology baseline trends in four Nordic countries). Another explanation for low reduction potentials in general may be that a large part of emission reductions is assumed to be achieved with the current legislation alone, without extra mitigation measures.

4.3 Costs and effects of additional SLCP measures in the Nordic countries

In Table 10 total estimated costs of additional SLCP measures, implemented in the *SLCP-MIT** scenario for the Nordic countries, are presented. The total incremental costs in 2030 are estimated at MEUR 1,520³². Note that measures targeting SCLPs other than BC and methane are included here as well. Costs for BC-targeting measures in the residential combustion sector are presented separately in the table. Differences in the costs for Sweden and Denmark, having rather similar emission reduction potentials for residential combustion (see Figure 23), indicate that replacement of conventional single-house boilers with pellet boilers (mitigation in Sweden) is more cost-effective than measures for heating stoves (mitigation in Denmark), in terms of EUR per ton removed BC.

Table 10: Incremental costs for SLCP measures in the Nordic countries in 2030 corresponding to full implementation of measures in the *SLCP-MIT scenario**

Country	Total baseline costs, MEUR		Total costs in <i>SLCP-MIT*</i> , MEUR		Total incremental costs of SLCP abatement, MEUR	
	All sources	Residential combustion	All sources	Residential combustion	All sources	Residential combustion
Sweden	1,540	88	1,762	148	222	60
Finland	1,416	164	1,927	614	512	450
Norway	1,755	496.8	2,099	496.9	345	0.1
Iceland	69	0	71	0	2	0
Denmark	1,172	106	1,612	288	439	182
TOTAL (5 countries)	5,952	855	7,471	1,547	1,520	692

³² Currency year 2005 is used in the cost estimates in this section.

Potential reductions of SLCP emissions would result in both improved population health and in climate mitigation. In Table 11 a partial quantification of those two positive impacts is presented. Reduced climate effects are calculated using GAINS, whereas avoided premature mortality due to reduced exposure to secondary PM_{2.5} (a consequence of SLCP mitigation) is estimated in the Alpha Risk Poll model (Holland *et al.* 2013).

Table 11: Health and climate effects resulting from emission reductions in the SCLP-MIT*scenario (additional measures are applied in the Nordic countries only)

Scenario	Premature mortality (LYL = Life Years Lost) in Europe due to PM _{2.5} . Decreases due to SLCP emission reductions (SLCP-MIT*)			Climate effects due to SLCP emission reductions in 5 Nordic countries (SLCP-MIT*), Mt CO ₂ eq.			
	1000*LYL in Europe, 2030	1000*LYL, decrease in the Nordic countries	1000*LYL, decrease in the rest of Europe	GWP100, 2030	GWP100, decrease	GTP20, 2030	GTP20, decrease
Baseline	4,246	-	-	278.4	-	335.0	-
SLCP-MIT* in Iceland only	4,246	- (*)	- (*)	278.3	0.1	334.6	0.4
SLCP-MIT* in Sweden only	4,180	3.8	62.2	276.2	2.2	328.4	6.6
SLCP-MIT* in Finland only	4,180	4.0	62.3	276.0	2.4	327.2	7.8
SLCP-MIT* in Norway only	4,181	2.9	62.1	272.9	5.5	326.7	8.3
SLCP-MIT* in Denmark only	4,179	4.6	62.5	274.9	3.5	324.8	10.2
SLCP-MIT* in 5 Nordic countries	4,176	7.0	62.7	264.6	13.7	301.8	33.3

Note: *Iceland is not included in the ARP-model.

The potential climate effect of the SLCP-MIT* scenario compared to the baseline is a reduction of 33 Mt CO₂eq (based on GTP20) or 14 Mt CO₂eq (based on GWP100). Climate effect directly depends on the amounts of emitted SLCP so the total effect from SLCP-MIT* mitigation measures in all five Nordic countries is a sum of the effects resulting from implementation of the SLCP-MIT* mitigation measures in each particular country.

Health effects, on the contrary, are not necessarily proportional to emissions of primary pollutants. Mortality numbers attributable to secondary PM_{2.5} exposure depend on population-weighted concentrations of secondary particles, which are calculated using a simplified simulation of dispersion and chemical reactions that primary emissions undergo before they contribute to the concentrations of secondary particles in a specific country (note that primary emissions in the SCLP-MIT* scenario include more substances than particulate matter and methane – in particular NO_x, which contributes a lot to formation of secondary particles). This is the reason why changes in the mortality in the case of SLCP-MIT* scenario for all Nordic countries is not a simple sum of the mortality decrease resulting from emission reductions in each particular country. Life

years gained by reductions in one Nordic country vary from ~2,900 to ~4,600. If all Nordic countries implemented the SCLP reduction strategy implied in the SLCP-MIT* scenario, ~7,000 life years would be gained in 2030 in the Nordic countries, and ~69,700 – in the whole Europe. In monetary terms³³ it corresponds to saving MEUR ~405 and MEUR ~4,020, respectively. SLCP emission reductions in the Nordic countries would thus result in significant health benefits in other European countries, especially those with large population – such as UK, Germany, France, Spain, and Italy. Decreased mortality in the Nordic countries would in fact constitute only about one tenth of the positive health effects in the whole Europe.

4.4 Swedish scenario study on SLCP emission reduction potentials

In 2015 a study on SLCP emission reduction potentials and costs was performed on commission from the Swedish Cross-Party Committee on Environmental Objectives (Miljömålsberedningen) (Kindbom *et al.* 2015a). The objective of the work was to provide background information as input to the Committee in their consideration of a possible milestone target for emissions of SLCP. The study suggests that there will be technical emission reduction measures available, with a potential to reduce emissions in 2030 beyond currently projected emissions.

The starting point of the analysis was the national baseline projections to 2030, which take current legislation into account. The analysis included only technical emission reduction measures (Table 12). Behavioural changes and their possible effects were not included in the study (mainly due to lack of quantitative information).

The SLCPs included were BC, CH₄ and ozone precursors (NMVOC, NO_x). Emission reduction potentials were derived from national studies. This means that only options where relevant information for the analysis was available were included in the study. There may be other available options, and the list is non-exhaustive. Climate metrics for conversion into CO₂-equivalents were taken from IPCC, and abatement costs from IIASA or from national studies. All costs were allocated to the climate impact.

³³ To estimate health-related benefits from reduced emissions of PM_{2.5}, we use Value of Life Year (VOLY) metric. The core value of VOLY is 57 700 Euro2005 per life year lost/gained (Holland 2014).

Table 12: Technical SLCP abatement options studied – beyond national projections

Option	"SLCP" affected
1) Increased share of pellets in residential biomass combustion	BC, CH ₄ , NMVOC, NO _x
2) Biogas production from manure (CH ₄ recovery)	CH ₄
3) Coverage of manure slurry tanks	CH ₄
4) Acidification of liquid slurry	CH ₄
5) Rejuvenation of machinery	BC, NO _x
7) More 4-stroke engines in snow-mobiles	NMVOC, NO _x
8) More 4-stroke engines in small boats	NMVOC, NO _x
9) 4-stroke and electrical engines in small domestic machinery	NMVOC, NO _x
10) Product modification, solvents and products	NMVOC

According to the analysis the most cost-effective measures are increased share of pellets (replacing wood logs) in residential biomass combustion (option 1) and anaerobic digestion and CH₄ recovery from manure (biogas) (option 2), see Figure 24. The total technical emission reduction potential from the options studied is estimated at ~0.6 Mt CO₂-eq (GWP₁₀₀), about 1% of Sweden's estimated greenhouse gas emissions in 2030.

Figure 24: Indicative estimate of a Swedish emission reduction potential and emission abatement cost of the analysed technical options in the period around 2030 (climate metric GWP₁₀₀). The emission abatement potential and emission abatement cost vary significantly depending on climate metric used. In this analysis all costs are allocated to the climate impact of the options

The measures analysed are relatively expensive from a climate perspective when compared to cost levels usually discussed for measures to abate CO₂. Furthermore, the measures analysed are usually considered for improved air quality, but in this analysis, the whole cost is attributed to the climate impact of the measure. The measures analysed result in a reduced climate impact but, as a result of reduced emissions of air pollutants, also provide important synergies such as a reductions of adverse health effects.

One of the conclusions in the report is that there is no single measure or individual instrument to cost-effectively reduce emissions of SLCP beyond the expected future emissions. A combination of measures and / or instruments aimed at different types of sources is required.

5. Residential biomass combustion

Residential biomass combustion

Residential biomass combustion contributes, and will in the future contribute a large share of Nordic BC and PM_{2.5} emissions according to current projections. In order to further reduce emissions, additional measures are needed. To promote reduced emissions, the measures could include: a faster replacement of old stoves and boilers for low-emitting technologies, switching to more homogenous and cleaner-burning fuels (e.g. pellets), increased heat storage capabilities, and further developing building codes that promote energy efficiency. Additionally, education to improve user practices in residential biomass burning and maintenance of equipment are essential.

In the Nordic countries, some instruments and measures to abate emissions are already applied, but these differ between the countries. As a result of this, the relevancy and efficiency of “additional measures” may be different depending on country.

Some Nordic scenario studies on possibilities (and costs if available) for future additional reduction of BC and PM_{2.5} emissions from residential wood combustion are presented as examples.

Emission limit regulations and eco-labelling are likely to have a future impact on emission reductions as manufacturers develop equipment according to upcoming regulations and consumers demand labelled products. Subsidies on replacing older equipment have resulted especially in Denmark in rather cost-efficient emission reductions. Aside from such economic instruments, Norway's perhaps most important measure is to introduce emission limits for new stoves which probably will be updated when the Ecodesign directive is adopted. In Finland, a large share of residential biomass burning equipment are masonry heaters, which are not readily replaced and hence information campaigns to ensure correct user practices are identified as the most efficient way in order to decrease emissions.

In general, replacing fossil fuels with biomass might result in higher emissions of BC and other pollutants if combustion technology is not modernised and if combustion and equipment maintenance behaviours are not improved. Also, the need for residential wood combustion can be reduced by tightened energy efficiency requirements in building codes.

5.1 Emissions of BC and PM_{2.5} from residential combustion

In 2015 the emissions of PM_{2.5} from residential combustion in the Nordic countries were about 44 Gg or 48% of the total Nordic PM_{2.5} emissions (Chapter 1.1). For BC the estimated emissions were 6.5 Gg, 43% of Nordic total emissions.

In 2015, the source category “Other, including commercial, institutional, residential, agriculture and fishing stationary and mobile combustion” contributed to 55% of the total Nordic emissions, both for BC and PM_{2.5}. In the projections for 2030 the emissions of BC from these combined sources contributed to 64% of Nordic total emissions. For PM_{2.5} the corresponding number is 46%. The emissions of both BC and PM_{2.5} from small scale combustion (all fuels, but dominated by contribution from biomass) are expected to decrease from 2015 to 2030 for BC from 8.4 to 7 Gg (a decrease of 16%), and

for PM_{2.5} from 50 to 43 Gg (33% decrease). Even though a decrease until 2030 is expected in absolute numbers, current national projections show that the relative contribution from this source will be substantial, around 50% of the total emissions, in 2030 (Chapter 1.1).

5.2 Measures and instruments to reduce BC and PM_{2.5} from residential biomass combustion

Examples of robust opportunities for the Nordic countries to decrease emissions of BC (and PM_{2.5}) from residential biomass combustion include switching to more homogeneous and cleaner-burning fuels (e.g. pellets), a faster replacement of old stoves and boilers for low-emitting technologies, implementing inspection and maintenance schemes, introduction of more efficient stove and boiler technologies, increased heat storage capabilities (e.g. retrofit of equipment by installing accumulator tank), and further developing building codes that promote energy efficiency (Arctic Council Task Force on Short-Lived Climate Forcers 2011, ACAP 2014). Additionally, education and end user information to improve user practices in residential biomass burning is essential (see Chapter 4.3). The new Ecodesign directive requirements will in the future contribute to reduced emissions as it sets efficiency and emissions limit requirements for new products to be sold on the market. The Ecodesign requirements will take effect from 2020 for solid fuel boilers and from 2022 for local space heaters (stoves) (see Chapter 2.3.1).

In order to promote abatement measures, a number of instruments may be relevant. For residential wood combustion, ACAP (2014) exemplifies possible instruments as in Table 13.

Table 13: Example of instruments aimed at residential wood combustion

Type of instrument	Examples
Regulatory instruments	<ul style="list-style-type: none"> Policies, laws and regulations on e.g. reduction targets – Emission limits for residential wood combustion – Technology standards, certification and labelling, standardised technology tests – Restricted use during spells of poor air quality, restricted use in certain regions – Limitation on wood moisture content in wood for combustion
Economic instruments	<ul style="list-style-type: none"> Economic incentives through e.g. – Reduced value added tax – Subsidies for installation technology replacement funds – A scrapping premium or investment grant – An environmental charge on single-house boilers and stoves
Information instruments	<ul style="list-style-type: none"> Awareness raising through e.g. – Public awareness raising, information campaigns aimed at target area/group, helpdesk services – Personal communication with chimney sweeps – Technical and policy guidance for professionals and non-professionals

Source: ACAP (2014).

Existing national instruments and measures in the Arctic countries, relevant for BC emissions from residential biomass combustion were compiled via questionnaires to the countries in the ACAP (2014) report. In ACAP (2014) policy instruments in the Nordic countries are summarised as in Table 14. The voluntary Nordic Swan labelling of environmentally preferable choices can be regarded as an information instrument (ACAP, 2014, p. 64).

Table 14: Summary of national policy instruments in the Nordic countries

		Denmark	Sweden	Finland	Norway
Regulatory	Maximum allowed PM emissions from new wood stoves	National			National
Economic	Public support/subsidies for change-out				National Local
Economic	Subsidies to manufacturers for technology development	National (cost split between developer and government)			
Information	Correct use of wood stoves	National	National	National	National
Information	Information on health effects	National	National	National	National

Source: ACAP (2014).

One of the key findings in ACAP (2014) is that none of the policy instruments identified are targeted towards BC, but rather designed to reduce PM emissions. This of course reflects the increasing knowledge and concern about BC in relation to its climate impact. Other key findings are that the most well established policy instruments are PM emission limits for new stoves, and information on correct operation of wood stoves, and on health effects.

In ACAP (2014) it is pointed out that many factors influence the level of emissions from residential wood combustion. Lack of proper maintenance, the use of wet wood or improper operation and handling might result in unnecessarily high emissions even if modern, new technology equipment is used. The conclusion is thus that instruments (and measures) must target a combination of factors to achieve an efficient and cost-effective policy mix. Also, the most efficient mix may not look the same in all countries, due to national circumstances.

A review of legislation and other policy instruments in the Nordic countries, relevant for reduction of emissions of PM_{2.5} and BC from residential wood burning is presented in Levander and Bodin (2014). In the report they discuss effects and efficiencies of national Nordic emission limit regulations, incentive programs to replace old equipment, information campaigns, environmental legislation supporting reduction of residential wood burning emissions, and voluntary eco-labelling (the Swan). Also international initiatives to reduce emissions of particulate matter (and BC) are mentioned, such as the Ecodesign directive, the Convention on Long-Range Transboundary Air Pollution (CLRTAP) and its amended Gothenburg protocol, and work under the Arctic Council.

The general conclusions from the study by Levander and Bodin (2014) are that emission limit regulations and eco-labelling can play an important role in giving incentives to manufacturers of equipment to develop equipment design to further reduce emissions. Many manufacturers today develop products based on the most stringent standards in order to ensure that production will be stable for future years. It is also common that consumers actively choose eco-labelled or Swan-labelled products.

It is further concluded that subsidies programs have accelerated the replacement rates of older equipment for more modern, but the possible additional air quality effects are difficult to evaluate. Examples of estimated particle emission reductions and their costs (as compiled by Levander and Bodin, 2014) for some subsidies programs are given in Table 15. There are no subsidies in Finland for replacing combustion equipment.

Table 15: Costs of subsidies for replacement of old boilers and stoves, and estimated emission reductions*

	Grant (EUR)	Number of boilers/stoves replaced	Reduction of particulates (kg)	Kg reduced particulates/boiler or stove replaced	EUR/kg reduced particulates
Denmark	2,900,000	3,500	805,000	230	4
Norway (Oslo)	2,600,000	8,000	70,000	8	37
Norway (Bergen)	4,600,000	7,000	85,000	12	54

Note: *Processed data from Miljøstyrelsen Denmark, Oslo and Bergen municipalities Norway.

Source: Levander and Bodin (2014).

Levander and Bodin (2014) also conclude that the Nordic countries have the regulatory tools necessary to intervene in cases where wood burning results in poor air quality in individual cases (locally), but that such measures have little effect on the regional scale.

In *Denmark* several policies have been adopted to limit emissions from residential combustion. This includes the introduction of particle emission limit values for space heaters (i.e. stoves) and small scale boilers. The first emission limit values were established in 2008 and later the values have been further lowered. The effect of the regulation is however delayed due to the relatively slow replacement rate of residential wood burning appliances.

In addition to the introduction of emission limit values a scrapping scheme was enacted in 2015 that provides owners with financial support if a wood stove from before 1990 is scrapped. The programme is expected to accelerate the replacement of old stoves and has been budgeted to replace 21 000 wood stoves.

Furthermore, information campaigns have been carried out to promote better firing habits. Various instruments for reducing BC emissions from residential biomass combustion in *Norway* are presented below (ACAP, 2014)³⁴.

³⁴ https://oarchive.arcticouncil.org/bitstream/handle/11374/388/ACMMCAo9_Iqaluit_2015_ACAP_ACAPWOOD_report_web.pdf?sequence=1&isAllowed=y

Table 16: Instruments for reducing BC emissions from residential biomass combustion in Norway

Type of instruments	Timeframe	National/Local	Description
Regulatory	1998 →	National	Maximum allowed PM emissions from new wood stoves of 10 g/kg.
Economic	2006 →	National	National support scheme through Enova (public enterprise) for private households for the installation of non-fossil fuel sources of heating and/or more energy-efficient heating systems.
Economic	1998 →	Local	Grants from municipalities to residents that replace old wood stoves with newer, more cleanburning stoves.
Information		National	Information on best practices for how to operate wood stoves, on different technologies, on the health and climate effect of particles and BC are posted on the web pages of the Norwegian Environment Agency, other relevant authorities and in the media during the winter season. In 2013 this included a film on correct operation of stoves and a pamphlet.

Source: ACAP (2014).

Norwegian measures to reduce emissions from wood stoves have been driven by the desire to reduce PM emissions. Maybe the most important policy instrument in Norway is an emission limit for new stoves. This was introduced in 1998, and all stoves to be sold in the Norwegian market must be tested according to the Norwegian wood stove-testing standard, NS 3058/3059, and prove their particle emissions are less than 10 g/kg dry wood. Potential new regulations on emission limit for PM under the Ecodesign Directive will probably also lead to a change in the emission limit in Norway.

In 2001, Enova SF was established by the Norwegian government. Enova is a public enterprise that is owned by the Ministry of Petroleum and Energy. The objective of Enova is to drive the switch to more environmentally friendly and more efficient consumption of energy in Norway. Enova gives private households support for the installation of renewable sources of heating and/or more energy-efficient heating systems. This includes households that move away from direct electrical heating and households that remove heating sources using fossil fuels. The main goal of the support given to households by Enova has been to improve energy efficiency and security of supply through a more diversified heating sector. Most households investing in pellets, heat pumps, etc., previously had either electricity or oil as their main energy source for heating. In total, 21,733 households have received support from Enova's scheme from 2006 until early 2013. In addition there are local support schemes; for example Grants from the City of Oslo to residents who replace old wood stoves. To increase the proportion of clean burning stoves, Oslo residents can apply for grants from the city's climate and energy fund to replace old stoves. The grant is NOK 3,000 in central areas of the city, where air pollution is worst and the need to replace old stoves is greatest. In other areas, the grant is NOK 1,500. The measure was started in 1998 and is on-going. In the period 1998–2010, a total of NOK 16 million was granted for the replacement of 5,862 stoves.

In 2017, Norsk Energi and SINTEF Energy Research (Norsk Energi 2017) were commissioned by the Norwegian Environment Agency, to develop an action plan to reduce emissions of SLCPs from wood burning.

The following measures and instruments have been investigated:

- Advanced replacement from old (-97) to new stoves.
- Advanced replacement from old (-97) to newer and best stoves and pellet boilers.
- Improved technics for operating, new stoves.
- Inspection and maintenance, new stoves.
- Electrostatic particle cleaning, new stoves.
- Improved air supply by use of chimney fan, new stoves.

Finland has approximately 2.2 million masonry heaters and 1.5 million sauna stoves using wood fuel (Tissari, Hytönen, Sippula & Jokiniemi, 2009). The Finnish appliances are typically operated for a short time and at a high combustion rate, which is in contrast to the light-weight metal stoves used in other parts of Europe, where devices are operated at a low combustion rate to generate heat over a long period using little power. Furthermore, the Finnish appliances are often built to store heat and wood is always burned in a closed firebox and the combustion air is controlled, in contrast to open fireplaces, which are common in e.g. the USA and developing countries (Tissari *et al.*, 2009; ACAP, 2014).

Due to high heating need resulting from the climatic conditions, the combustion equipment and user skills to operate them have traditionally been advanced in Finland. Information campaigns to re-introduce the correct practices have been carried out in the last years because correct use of the combustion equipment and combustion of dry clean wood have been identified as the most efficient way to impact emission levels.

In the recent years several information campaigns have been carried out in Finland to remind users of residential combustion devices about good combustion practices. Examples of such campaigns are:

- The Ministry of the Environment, together with the Ministry of Social Affairs and Health, Capital Region Cooperation Body YTV and the Organization for Respiratory Health in Finland published in 2003 guidance for correct wood combustion practices.
- The Organization for Respiratory Health in Finland (Heli ry) organized several public events (2007) all over Finland about environmentally friendly wood combustion and health issues.
- The National Supervisory Authority for Welfare and Health (Valvira) produced a manual (2008) – Instructions for wood combustion from a health perspective.
- Helsinki Region Environmental Services Authority (HSY) organized an information campaign (2012) to promote efficient and environmentally friendly ways of using fireplaces and stoves.

The contents in the information campaigns cover commissioning and maintenance of the equipment, good practices in operating the air flow, use of good quality, size and amount of wood, lighting of fire, frequency and temperature of combustion, interaction with other heating systems and ventilation.

Maintenance of combustion equipment has considerable impact on emission levels. Soot accumulating in the walls of the combustion equipment also acts as insulation and reduces heat transfer. Regular removal of dust and ashes from the combustion chamber and regular sweeping of chimney, soot box, rods, canals and connection pipes is necessary to keep emission levels low.

National legislation in Finland, relevant for emissions from residential combustion includes:

- The Neighbourhood Act (26/1920) states that households shall not be used in a way that causes excessive stress to the neighbourhood with harmful substances like soot, filth, dust, smells, etc.
- The Health Protection Act (763/1994) is aimed at preventing, reducing and removing factors in the environment that might present health hazards. The person in charge is obligated to rectify the situation. The Act also covers smell, dust and smoke.
- The Environmental Protection Act (86/2000) and the Waste Act (1072/1993): Municipalities can issue their own regulations concerning small scale combustion. Following an inspection, the municipal authority can regulate the use of a stove or even prohibit its use.
- The Public Order Act (612/2003) authorizes the municipalities to regulate the use of solid fuels in specific areas.

In Finland, there are also tightened building regulations aimed at decreased demand for energy. The building regulations include energy effectiveness requirements i.e. the demand for better insulation to minimize the transfer of cold/heat by conduction, convection and/or radiation. In Finland new houses were required to have 30% more insulation since 2010 and from 2012 an additional 20%. In a low-energy building heat losses may not be more than 85% of a comparison heat loss value. The low-energy and passive houses need substantially less energy for heating and in many cases make traditional stoves oversized. It is common that excessive energy in relation to the actual heating need is produced through a combination of different energy systems (e.g. geothermal energy, solar panels). In a passive house the heating energy demand is a quarter of that of a traditional house (on coastal Southern Finland 20 kWh/m³/a, in Middle Finland 25 kWh/m³/a and in Northern Finland 30 kWh/m³/a).

For healthy operation, low energy and passive houses need specific ventilation, heat recovery³⁵ and thermal storage³⁶ system solutions. Better insulation also leads to

³⁵ Air heat pumps (save 30–40% of heating energy in small houses).

³⁶ Hot water storage, building structures, masonry walls.

more airtight buildings, which causes negative indoor pressure and thus impacts the techniques used in stoves. The so called n50 number that describes airtightness needs to be 0.6 l/h or less.

In Sweden there is, besides information campaigns, also a new national instrument targeting residential biomass combustion. New building rules from Boverket^{37, 38} introduce some of the new requirements under the Ecodesign directive earlier than according to the EU legislation³⁹. On July 1, 2017, the requirements for emissions from residential solid fuel boilers were tightened. The new requirements are relevant when installing combustion equipment in new or existing buildings, and when replacing a boiler or room heater with a new one. Furthermore, the minimum efficiency requirements, i.e. the lowest efficiency that the solid fuel boilers and room heaters may have, are introduced. According to the transitional rules the amendment means that the older provisions may be applied for another year after the amended rules came into force. However, as of 1st July 2018, the new tightened requirements will apply for building permits and notifications coming into the building boards.

The new emission limit requirements are published in Boverkets byggregler (BBR), section 6:74⁴⁰. For solid fuel boilers it is the same emission limit requirements as in the Ecodesign directive (except for NOx), which means that there is an earlier introduction than according to Ecodesign (where they apply from 2020).

For room heaters, no requirements regarding emission limits are introduced in the Swedish building rules at this stage other than for CO. In the new requirements under the Ecodesign directive, to apply from 2022 for room heaters, emission limits for particulate matter and OGC (organic gaseous carbon) and NOx are included.

In Sweden there are also examples of local initiatives and guidelines. As an example, guidelines have been established in a partnership between all municipalities in the Skåne region, where the aim is to facilitate the handling of residential biomass combustion issues at the municipal environment and building offices. The guidelines include a table with four types of areas in which various types of technologies and fuels are deemed appropriate or not for new installations (Table 17) (Miljösamverkan Skåne).

³⁷ http://www.boverket.se/contentassets/aga584aaoe564c8998d079d752f6b76d/konsoliderad_bbr_bfs_2011-6.pdf

³⁸ <https://info.boverket.se/BBR/PDF/BFS2017-5-BBR-25.pdf>

³⁹ <http://www.boverket.se/sv/om-boverket/publicerat-av-boverket/nyheter/skarpta-utslappskrav-for-fastbranslepannor-och-rumsvarmare/>

⁴⁰ http://www.boverket.se/contentassets/aga584aaoe564c8998d079d752f6b76d/konsoliderad_bbr_bfs_2011-6.pdf

Table 17: Guidelines for approving new installations in different types of local areas

New installation	Area 1	Area 2	Area 3	Area 4
Basic heating				
Straw boiler				
Not environmentally approved boiler without accumulator tank				
Environmentally approved boiler without accumulator tank				
Environmentally approved boiler with accumulator tank				
Pellets burner (switch from oil burner)				
Pellet stove				
Pellet boiler				
Comfort firing				
Wood stove				
Fireplace insert				
Tiled stove (kakelugn)				
Open fireplace				

- Note:
1. Area outside the local plan or aggregated settlements, ie, rural.
 2. Area within the local plan or aggregated settlements, ie, virtually all urban areas.
 3. Areas close to kindergartens, schools, nursing homes etc., and especially densely populated areas.
 4. Area with district heating or natural gas available.

Light blue=allowed, medium blue=might be allowed, dark blue=not allowed.

Source: Miljösamverkan Skåne.

5.3 Nordic study on technical reduction potentials of SLCP from residential biomass combustion – climate and health effect

A study focusing on technical emission reduction potentials from residential biomass combustion in Denmark, Finland and Sweden was performed in a Nordic cooperation during 2017 (Kindbom *et al.* 2018). In the study, technology and behavior specific emission factors developed from the measurement programme performed in the second phase of this project were used (Kindbom *et al.* 2017, TN2017:570).

Technology scenarios were developed based on national projections of future biomass fuel consumption in different combustion technologies in the three countries (Figure 25). In the scenario called *expected technology* the national activity data projections (technologies and fuel use) were adapted into technology types where emission factors from the Nordic measurement programme were available. The second scenario was a *modern technology* scenario where combustion in older technology stoves and boilers was moved to combustion in modern technologies in 2035. The technical potential was estimated based on realistic assumptions on exchange of older combustion equipment with modern, which resulted in an exchange of 10 PJ of biomass out of a total of 148 PJ being combusted in modern equipment instead of in traditional equipment (shown by the red circles in Figure 25). No maximum feasible technical reduction (MFTR) scenario was developed and no assumptions on alternative amounts of biomass fuel use were investigated.

The technology scenarios were further refined with different levels of assumed degree of “bad combustion behaviour”. The expected behaviour was 10% “bad combustion”. The differences in estimated emissions between the scenarios were estimated by applying technology and behaviour specific emission factors for PM_{2.5}, EC/BC, OC, CH₄ and NMVOC (TN2017:570). The estimated potentials for reduced emissions of SLCPs and PM_{2.5} from residential biomass combustion were also transformed into potential impact on health and climate.

Figure 25: Biomass fuel consumption in the adapted baseline technology categories (PJ) in Denmark, Finland and Sweden (expected scenario). In scenarios “modern technology” the fuel used in older stoves and in traditional boilers in 2035 was moved to modern stoves and modern boilers, respectively (red circles)

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 (indicated by red circles in Figure 25). The results show that the potential to reduce emissions from residential biomass burning by replacing those older technologies with modern equipment can be significant, in the order of 15% for PM_{2.5} and OC, 25% for NMVOC and 7–9% for BC and CH₄ (Figure 26). If, in addition to replacement of older equipment, the combustion behaviour is improved from the assumption that 90% of the population have good combustion behaviour to 100% good combustion, the potential to reduce the emissions rises to 26% for PM_{2.5}, 32% for OC, 35% for NMVOC, 15% for CH₄ and 8% for BC.

The estimated potential reduction of PM_{2.5} emissions would lead to significant reductions in adverse health effects. In the order of 1000 premature deaths would be avoided annually in Europe in 2035 as a result of replacing older boilers and stoves with modern equipment and good combustion behaviour.

A reduced climate impact resulting from reduced emissions of the short lived climate pollutants BC, CH₄, 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 PM_{2.5}. The potential emission reductions estimated in the scenarios correspond to approximately 0.1% of the projected total greenhouse gas emissions from Denmark, Finland and Sweden in 2030.

Figure 26: Estimated total emissions (ktonnes) from residential combustion of biomass from Denmark, Finland and Sweden in 2035 in the expected scenario (expected technology, 10% bad combustion), with modern technology (SC4) and in addition, with good combustion behaviour (SC6)

The scenario results thus suggests 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 in Denmark, Finland and Sweden by reducing emissions of PM_{2.5} and SLCPs. The level of penetration of modern technology in residential biomass combustion and the user behaviour in managing the combustion process both have significant impact on the emission levels in the three Nordic countries. The total amount of wood combusted of course would have a large impact on emissions. This aspect was not investigated and the total amount of biomass was the same in all scenarios. Additional alternative developments, such as a different level or rate of replacement of old with modern equipment, or technological development towards even lower-emitting combustion equipment would also affect the results.

In the conclusions in the report it is noted that there are incentives to introduce policies for early scrapping of old devices and replacement to modern equipment, and that effective information campaigns to educate users in proper combustion behaviour are important, since a successful change in combustion behaviour can have a large effect on emissions.

5.4 Swedish study on impact of increased share of pellets in residential biomass combustion

The aim of the study by Gustafsson and Kindbom (2015) was to assess influences on air pollutant emissions, especially particulate matter ($PM_{2.5}$, BC and OC), but also NO_x , CH_4 and NMVOC emissions by increased substitution of fossil fuels with biomass fuels for combustion in 2050. The study also illustrates how an increased use of biomass for combustion may have different effects on the emissions depending on combustion technology. To simulate the change in emissions if “best available technologies” would be used, scenarios with an increased share of pellets, replacing wood logs, in residential combustion were developed. In the scenarios it was assumed that in 2050 all biomass in residential combustion would be pellets (interpolated between 2020 and 2050).

Figure 27 and Figure 28 show the expected projections for BC and CH_4 and the higher emission scenarios resulting from an increased use of biomass, replacing fossil fuels. In the two lower emission scenarios, an increased share of pellets (“best technologies”) has replaced wood log combustion with increased total biomass use, and with total biomass use as in the projection, respectively.

For both BC and CH_4 the combustion technology is important, as good and efficient combustion conditions (represented by increased share of pellets replacing wood logs) will considerably reduce the emissions from residential biomass combustion.

Figure 27: Emissions scenarios for BC from residential biomass combustion. National projections and scenario with increased biomass replacing fossil fuels, and alternative scenarios with increased share of pellets replacing wood logs

Figure 28: Emissions scenarios for methane (CH₄) from residential biomass combustion. National projections and scenario with increased biomass replacing fossil fuels, and alternative scenarios with increased share of pellets replacing wood logs

5.5 Finnish study on particle emission reductions and costs

Ecodesign Directive

Implementation of the Ecodesign Directive will tighten emission limit values for particles in 1–10 MW biomass boilers, and it is estimated that there is need to install flue gas purification equipment in approximately 300 boilers between 2025–2030. This would result at the most in a 10% reduction of total emissions of small particles. (Savolahti *et al.*, 2015)

Emission Reduction Costs

Costs to decrease particle emissions from small combustion by 2030 were estimated by Savolahti *et al.* (2015) as presented in Table 18.

Table 18: Emission reductions and their costs in 2030

Measure	Annual cost [M€/a]	Unit cost [k€/ton]	
		PM _{2.5}	BC
Ecodesign	14	35	150
Boilers	4	15	75
Boilers with accumulator	8	100	310
Iron stoves	2	30	130
Sauna stoves	22	17	43
Information campaign, country-wide (5–50%)*	0.3	0.6–6	4–37
Information campaign, municipalities >20,000 inhabitants (5–50%)*	0.08	1–10	7–66
ESP to boilers, ban to boilers without accumulators	44	29	150
Installation of accumulator	1	3	9
Installation of ESP	43	45	250

Note: *Decrease in bad combustion time of combustion is estimated as 5–50%.

5.6 Danish study on particle emission reductions and costs

A study carried out for the Danish EPA (Miljøstyrelsen, 2013) looked at measures to reduce emissions from residential wood combustion mostly related to speeding up the replacement rate of older technologies. The study looked at the impact of the measures both related to the number of appliances replaced, the impact on the total number of appliances and the impact on the emissions. Different scenarios were analysed and they showed that the benefits of implementing the measures were greater than the estimated costs.

6. On-road and non-road vehicles and machinery

On road and non-road vehicles and machinery

Emissions of BC from on-road and non-road vehicles and machinery are according to current projections expected to decrease in the future, but still to contribute a significant share of the total Nordic emissions.

Existing and possible future technical measures are similar irrespective of country, but non-technical measures may differ. This chapter summarises both technical and non-technical measures to further reduce emissions of BC from vehicles and machinery. It also gives examples of existing local plans and measures (non-technical). A Swedish scenario study on the impact from additional non-technical measures on future urban BC emissions from road traffic is presented. The measures assessed are aimed at reducing traffic.

To decrease human exposure to PM_{2.5} and BC especially urban transport emissions should be reduced. Several non-technical measures to obtain this could be taken into account, such as sustainable city planning which is estimated to account for a considerable decrease of both of exhaust and wear emissions. Especially for more long-term projections for e.g. 2030 when emissions are expected to decrease overall, the relative impact increases of city planning, congestion charges and car sharing aiming at reduced transport.

6.1 Emissions of BC and PM_{2.5} from on-road and non-road vehicles and machinery

Road traffic and non-road mobile vehicles and machinery contributed ~24% to the Nordic BC emissions in 2015 (Chapter 1.1). The successive implementation of technical EUR-standards for cars (road transport), but also regulations for trucks and non-road mobile machinery (NRMM, Chapter 2.3.2) will lead to lower emissions of BC from vehicles and other machinery in the future. The Nordic national projections (Chapter 1.1) indicate that the relative contribution to Nordic BC emissions from on road and non-road vehicles and machinery will be in the order of 13% by 2030.

For PM_{2.5} the numbers are ~16% in 2015 and expected 17% relative contribution in 2030.

6.2 Measures to reduce BC and PM_{2.5} emissions from transport

Measures to reduce BC and PM_{2.5} from on-road and non-road transport include both technical and non-technical (e.g. behavioural) measures. Technical measures are for example standards for the reduction of particles from diesel vehicles (both on road and non-road vehicles and machinery), improved vehicle technologies (e.g. diesel particle filters, including retrofitting of particle filters, fuel-type innovations) and elimination of high-emitting vehicles and machinery (renewal of fleet). Not only technical measures, but also non-technical, such as infrastructure planning and behavioural changes can contribute to lower total emissions. Examples could be shifting to low-emission modes of travel (e.g. walking/cycling) and journey avoidance and route optimization (WHO, 2015).

Instruments to promote these different types of measures (Arctic Council Task Force on Short-Lived Climate Forcers 2011, UNEP 2011, UNEP/WHO 2011, WHO 2015) are for example revision of taxation rates (differentiation based on environmental classification) and economic incentives to stimulate a faster introduction of low emission vehicles and machinery. To promote modal shifts sustainable urban mobility plans could include measures such as low emission zones (green zones), local traffic planning, congestion pricing, parking controls, speed limits, car sharing schemes and in general, promotion of alternative ways of movement (cycling, walking, public transport etc).

An example of local plans and measures is the city of Gothenburg Environmental Program, where the action plan comprises 212 tangible actions divided in seven action strategies (Göteborgs Stads Miljöprogram, 2013). Several of the actions are aimed at, or would influence, the urban emissions of particles and BC. The actions can roughly be grouped as being mainly aimed at 1) reduced and/or better coordinated transportation of goods within the city, 2) development of a strategy for pricing and availability of parking places that would reduce the use of cars, 3) actions for increasing the travel by bicycle, 4) strategies and actions to promote pedestrian traffic, 5) increased capacity of public transport, 6) supporting the development of car pools, and 7) how congestion taxes can be differentiated and/or used to promote sustainable travel. Apart from these, also reduced speed limits, how environmental qualities and goals can be taken into account and ensured in newly planned areas, and reduced use of studded tyres are, as examples, included in the action plan.

6.3 Swedish study on measures to reduce black carbon from road traffic

In order to reduce emissions of, and human exposure to BC, measures to decrease transport emissions in urban areas would be relevant. An analysis of the effect of measures such as sustainable city planning, congestion tax, green zones, car pools/rentals, revised speed limits, coordinated transport of goods in urban areas etc. has been performed for Sweden in Wisell *et al.* (2015).

According to current national projections, BC emissions from road traffic are expected to decrease substantially to 2020 and even further to 2030 due to modernisation of the vehicle fleet. In Figure 29 projected exhaust emissions are shown as an interval (max and min) while there are no uncertainty estimates regarding wear emissions. Emissions from tyre and brake wear in the future will contribute a large share of BC-emissions from road transport. Wisell *et al.* (2015) however underlines that the calculations for wear-emissions of BC are very uncertain as current knowledge gaps are substantial. In the report, Wisell *et al.* (2015) points out that by a forced rejuvenation of the vehicle fleet, exhaust emissions can be reduced earlier than according to the projections.

Figure 29: National Swedish emissions of BC from road traffic 2000–2030. Exhaust emissions with uncertainty interval, and wear emissions (without uncertainty interval)

The analysis of additional measures in Wisell *et al.* (2015) shows that emissions could be reduced further. The measures analysed are primarily aimed at decreased human exposure by reduced traffic in urban areas. Seven measures are analysed: sustainable city planning, congestion tax, car pools/car rental, changed speed limits, increased e-trading, coordinated goods transport, and optimised transport routes and loading of goods vehicles (Table 19 and Figure 30).

Table 19: Emissions and estimated reductions of BC in Swedish urban areas for different measures aimed at reducing traffic

Tonnes BC/year	Exhaust emissions		Wear emissions	
	2020	2030	2020	2030
Base scenario	144.1	35.0	47.0	52.7
A – Sustainable city planning	-11.2	-7.9	-3.7	-10.6
B – Congestion charge	-2.9	-2.3	-0.9	-2.8
C – Car sharing	-2.8	-2.3	+1.1	-2.7
D – Changed speed limits	-0.4	-0.4	-0.3	-1.0
E – e-trading	-0.6	-0.4	-0.4	-1.1
F – Consolidated goods deliveries	-1.6	-0.9	-0.4	-1.4
G – Route optimisation	-0.5	-0.3	-0.1	-0.4
Remaining emissions	124.1	20.6	42.3	32.8

Source: Wisell et al. (2015).

Figure 30: Emissions and estimated reductions of BC in Swedish urban areas from seven measures aimed at reducing traffic in 2020 and 2030. Exhaust emissions on the left and wear emissions on the right

Source: Wisell et al. (2015).

In Swedish urban areas in 2020 BC emissions from vehicle exhaust is estimated to be 144 tons, which could be reduced by an estimated total of 20 tons by implementing the seven measures (Table 19, Figure 30). Together they contribute to decreased traffic (and decreased emissions), of which sustainable city planning is expected to contribute around half of the decrease. For 2030 the corresponding analysis show that expected exhaust emissions of BC in urban areas would be 47 tons, with a possible decrease of an additional 5 tons if the seven measures are introduced.

Estimates were also made for the effect from these seven measures on wear emissions in urban areas. Since the aim is to reduce the overall traffic, also the wear emissions are reduced, in 2020 by 5 tons (from 47 to 42) and in 2030 by 20 tons (from 53 to 33 tons).

Wisell *et al.* (2015) conclude that by implementing the additional measures above, aimed at reduced traffic in urban areas, the reduction in projected BC emissions in 2020 would be rather small, relatively speaking. In 2030 however, when projected emissions are even lower, the additional measures would have a larger relative impact.

7. Agriculture

Agriculture

Agriculture contributes, and will contribute a very large share of total emissions of methane also in the future. Abatement measures are available to reduce emissions of CH₄ from ruminant enteric fermentation, from manure management (including biogas production), and also the possibility to reduce the number of animals (and thus also the CH₄ emissions) following measures to promote behavioural changes towards less meat consumption. Several of the measures discussed in this chapter are already present to a smaller or larger degree in the Nordic countries, but the applications could be extended. The situation differs between the Nordic countries, and the potential for relevant additional (or extended measures) may vary.

Available measures to decrease emissions from ruminant enteric fermentation comprise increasing production efficiency and animal life-time, breeding and forage optimization. The efficiency of these measures is estimated in the order of about 10–20% methane emission reductions as an example for forage modification.

Slightly higher emission reductions can be reached for manure management by applying acidification or covering slurry tanks – methane emission removal efficiency of these measures could be up to 25–40%.

The most efficient way to reduce methane emissions from livestock is anaerobic digestion with production of biogas from manure substrate. This measure has methane emission reduction efficiency of up to 80%. With a possibility to upgrade biogas to vehicle fuel, it provides triple benefits – reduces methane emissions from the agricultural sector, replaces fossil fuels in transport systems with biofuels, and decreases the need for mineral fertilizer use due to better nitrogen availability in the digested slurry.

Technical solutions for biogas plants in the Nordic countries vary from farm-scale plants to pipeline systems where biogas from small installations is collected in one upgrading plant. Recent cost estimates show variations within the wide range of EUR 40–680/ton CO₂ equivalent reduced. Estimated costs depend on the assumptions made in the calculations, and are mainly affected by installation scale and design, substrate type, and additional technology solutions such as upgrading plants, but of course also depends on if the value of the recovered gas is included.

Lower meat consumption is assumed to result in reduced farming activities and subsequent emission reductions. This type of behavioural change is promoted by e.g. information campaigns, introduction of meat-free days in public institutions and similar administrative and organisational instruments that do not require significant costs. Behavioural change is, however, a long process, so in order to achieve quicker emission reductions this reduced meat consumption should be combined with emission reduction efforts on the production side.

7.1 Methane emissions from agriculture

The main agricultural sources of methane in the Nordic countries are cattle (ruminant enteric fermentation) and manure management (Kindbom *et al.* 2015, TN2015:523). There are several technical options to reduce methane emissions both from enteric fermentation and from manure management. An additional win-win option is to use the manure for biogas production, which reduces methane emissions while producing biogas that can be used as fuel. Another option would be to promote behavioural changes towards reduced meat consumption, which would reduce the animal numbers in agriculture and thus lead to lower methane emissions.

7.2 Abatement of methane emissions from ruminant enteric fermentation

Possible measures for abatement of methane emissions from ruminant enteric fermentation are presented below (Hellstedt *et al.*, 2014, Höglund-Isaksson *et al.*, 2016, Jordbruksverket 2012, EIP-AGRI 2017):

- Reduction of the number of ruminants (this includes increasing the productive life time of ruminants).
- Increase production efficiency (efficient farm management) – produce more output, e.g. milk or meat per digested amount of forage or used amount of energy.
- Forage optimization – adjusting the forage mix or use supplements effective to reduce the production of methane gas (e.g. fat, hydrogen-binding substances, probiotics). An addition of 50g fat per kilogram dry matter forage can result in 20% reduction of methane emissions (Grainger & Beauchemin 2011). Usage of forage supplements is, however, restricted in Europe, and many of them are not allowed to be routinely used. Bryngelsson (2013) estimates methane emission reduction efficiency of forage modification at 10%. It might be higher in theory, but possibilities to add fat or other substances into forage of grazing animals are considered as rather limited. Detailed description of different types of forage optimization measures can be found in EIP-AGRI 2017.
- Genetics – breeding animals with lower methane gas emissions or use genetic manipulation to reduce the formation of methane gas during the food processing.
- Vaccination of ruminants.

Increasing the productive life of the ruminants and overall production efficiency, as well as certain forage additives, are much more commonly used measures than genetic modifications or vaccination. Productivity increase is often included in the national emission projections whereas other options should be considered as extra measures.

In an example from the Swedish Wapnö Farm, Halmstad, described in Hellstedt *et al.* (2014), high efficiency milk and meat production is reached by strategic breeding and optimal forage composition, thus combining two measures to reducing methane emissions, though emission reduction is not a specific purpose at the farm but rather a positive side-effect. Assuming 10% emission reduction from adjusted diet, total annual methane emission reduction from the approximately 1,350 dairy cows and 2,000 calves and heifers is estimated at 29 tonnes from the farm.

7.3 Abatement of methane emissions from manure management

The most interesting measure to reduce methane emissions from manure management is anaerobic digestion of manure, followed by production of biogas. This measure already exists to varying degrees in the Nordic countries. Apart from reducing methane emissions from stalls, this measure has two additional climate benefits: a decreased need for mineral fertilizers due to more easily available nitrogen in the digested slurry, and substitution of fossil fuels by the produced biogas. When using biogas as vehicle fuel, the biogas should be upgraded, i.e. carbon dioxide and contaminants should be removed. This is done at upgrading plants, usually located close to biogas plants.

Combining anaerobic digestion with special pre-processing techniques (such as mechanical separation of slurry into solid and liquid fractions) improves manure degradation, increases the grade of digested substrate and results in even lower methane emissions (Jordbruksverket 2012).

Other, already existing measures to reduce methane emissions from manure management apart from anaerobic digestion include acidification of manure (if manure is acidified, it cannot be further anaerobically digested) and covering slurry tanks with a plastic sheet, a ceiling, peat or straw (Jordbruksverket 2012, Berglund *et al.* 2010, WHO 2015). Additional possibilities to reduce methane emissions from manure are for example:

- Covering and/or shuffling solid manure heaps. Regular shuffling creates oxygen supply resulting in methane emission reductions. Covering manure heaps hinders oxygen supply but reduces temperature, which seems to compensate for oxygen shortage.
- Low temperature in the slurry tanks.
- More precise timing of manure application to crop lands.

Below three measures to reduce methane emissions from manure management are described in more detail:

- Anaerobic digestion of manure with biogas production.
- Acidification of manure.
- Covering of slurry tanks.

The information is from a variety of national and international studies. The studies include potentials for biogas production from manure, its costs and benefits. Existing instruments stimulating biogas production in Sweden are also described.

7.3.1 *Anaerobic digestion of manure followed by biogas production*

Anaerobic digestion of manure, followed by biogas production is reported to have the potential to reduce methane emissions by up to 80% (Jordbruksverket, 2012). Manure storage conditions and digestion parameters, however, have a critical effect on resulting methane emissions and according to Rodhe (2013) no general standard emission reduction efficiency from anaerobic digestion of manure can be given.

The Swedish Board of Agriculture conducted a study in 2012 with the purpose to assess reduction potentials and costs of measures to further reduce methane emissions from manure management. For the year 2050, it is assumed that 75% of all cattle and pig manure (0.81 million ton) is anaerobically digested (Jordbruksverket, 2012). It is further assumed that anaerobic digestion reduces methane emissions by 80% if no leakages in the system occur. The emission reduction potential in Sweden under the given assumptions is estimated at 0.1 million ton CO₂-equivalents (or ~4000 ton methane) per year in 2050. This corresponds to ~1620 GWh biogas (Jordbruksverket 2012).

In a study by Berglund *et al.* (2010) cost estimates for anaerobic digestion and biogas production are presented. The costs are estimated to be within the interval EUR 0.4–2.7 (SEK 4–24) per m³ slurry, or EUR ~40–220 (SEK 330–2,000) per ton CO₂-equivalent reduced. The calculations assume that the methane emission reduction is 40%, that no investment support is provided, that biogas is sold for upgrade for SEK 2.3/m³, and that 20% of the biogas is used on-site for own energy needs. It is highlighted that profitability of a biogas facility depends on many factors such as investment costs, energy prices, and access to substrate. If investment support is accounted, the costs turn into profit of EUR 0.2–1.2 (SEK 2–11) per m³ slurry, or EUR ~20–100 (SEK 170–920) per ton CO₂-equivalent.

As a comparison, examples on calculated cost-effectiveness from existing plants (Hellstedt *et al.* 2014, presented in more detail in Annex 4) gives a higher cost range, from around EUR 200–680/ton CO₂ equivalent reduced (or EUR 5,000–17,000/ton reduced methane). In these calculations, however, the value of the recovered gas is not included. If the value of recovered gas would be included, the costs would decrease.

The Baltic Manure study (Baltic Manure 2013a, 2013b) is based on the Baltic Manure vision that 25% of all manure will go to biogas plants by 2025. Potentials for manure biogas production in 2025 based on country-specific prerequisites (including geographical differences) are explored, and cost estimates for biogas installations are provided in the report. The main results of the Baltic Manure vision scenarios for Sweden, Denmark and Finland regarding biogas potentials and associated costs are presented in Annex 5.

A general recommendation from the Baltic Manures study is that for better energy yield at slurry digestion, there is a need for energy co-substrates such as solid manure or suitable waste by-products (grasses, straw). This is beneficial for decreasing total methane emissions from the agricultural sector, since technologies for anaerobic digestion of solely solid manure are not well-developed. The Baltic Manure study also highlights in their general recommendations that gas-tight post-digestion tank at biogas plants is strongly recommended in order to recover gas emitted after the digestion stage. This measure can improve the biogas production with at least 15–20%, and at the same time lower the methane emitted.

Instruments stimulating biogas production from manure (Sweden)

Aspects of EU Common Agricultural Policy, CAP, directly or indirectly affecting methane emissions are implemented in the EU member states' national legislation via Rural Development programs. The Swedish Government decided on a Rural Development Program (2014–2020) in June 2014, and the proposal was approved by the European Commission in 2015. The program includes a set of instruments favourable for methane emission reductions, both of economic and information character. Support for investments and for entrepreneurs, capacity building, cooperation and innovation and other activities in line with CAP are included.

One of the economic instruments that have been applied in Sweden for several years is support for investments in biogas production and refining. The new CAP gives EU members the possibility to continue provide this kind of support (Article 17 and Article 28 in EU Regulation 1305/2013), which in Sweden is already implemented within the new Rural Development Program 2014–2020. Up to 40% of the investment costs may be reimbursed by the state given that applying facilities meet certain requirements regarding minimum amount of manure substrate used for biogas production (Jordbruksverket 2017).

Another effective and relatively new economic instrument in Sweden is the so called "manure gas support". The instrument includes payments based on actual biogas production from farm-yard manure and has been initially suggested as a part of a cross-sectoral biogas strategy developed in 2010. In 2014–2015, the suggestion obtained a formal legal support via a national Ordinance (SFS 2014:1528, further amended by SFS 2015:573). The national regulation is based on requirements stated in Chapter 1 Article 43 of EU Regulation 651/2014 that limits the size of biogas installations eligible for operating aid, to maximum value of 500 kW, or 50,000 tons per year, in case vehicle fuel (upgraded biogas) is produced. At present (October 2017), production support for Swedish small scale installations for biogas production is EUR ~0.04/kWh energy content of produced biogas⁴¹ (Jordbruksverket 2017). If the support sum becomes higher than the cost difference between manure-based gas production and fossil-based gas production, it may be decreased.

⁴¹ 1 Nm³ raw gas = 5.982 kWh according to SJVFS 2015:10.

To be eligible for manure gas support, facilities need to fulfil a range of requirements, among others the following (SFS 2014: 1528, SJVFS 2015:10, Jordbruksverket 2017):

- The facility must have a permit for handling animal by-products.
- The facility must have equipment for gas flaring, to be used in case of overproduction or production stoppage.
- The facility must have an established procedure to, at least once a year, search for gas leakages and document those, as well as the measures taken.
- The facility cannot have other state financial aid (e.g. investment support) if the total sum per year is higher than EUR 150 million.
- The facility must be able to measure and report produced/sold gas, generated electricity or produced vehicle fuel in either volume or energy units.

Manure gas operation aid is currently driven in a project form, which means that only facilities included in the project by the Swedish Board of Agriculture can apply for support. Three application periods cover 2015–2017, 2018–2020 and 2021–2023 (SJVFS 2015:10).

A *cross-sectoral regulative instrument in Sweden* is the Swedish Law on sustainability criteria for liquid biofuels (Lag 2010:598). It is relevant for agriculture, solid waste management and waste water treatment. The law is implementing the Renewable Energy Directive (2009/28/EC) and defines a set of criteria, one of the most important of which is that greenhouse gas emissions from vehicle fuel production and use are at least 50% less than those from fossil-based fuels (60% from January 1st 2018) (Lag 2010:598). Vehicle fuel produced from upgraded biogas is covered by these criteria, which means that the law stimulates biogas production, including production from feedstocks such as farm-yard manure, food residues and other organic waste.

7.3.2 Manure acidification

Acidification of manure via supply of acid could reduce methane emissions by 25% – 30% (Jordbruksverket 2012, Berglund *et al.* 2010). Associated costs are estimated in the range from EUR 1–5 per m³ manure treated, or EUR ~72/ton CO₂-equivalent reduced (Berglund *et al.* 2010) to EUR ~670–840/ton CO₂-equivalent (Jordbruksverket 2012).

In a study by Jordbruksverket (2012) it is assumed that for the year 2050, 25% of all cattle and swine manure is acidified (the rest is anaerobically digested). Emission reduction potential of manure acidification in Sweden under the given assumptions is estimated at 0.01 million ton CO₂-equivalents per year in 2050. Associated costs are EUR ~4–5 (SEK 35–45) per m³ manure (Baky *et al.* 2010 cited in Jordbruksverket 2012), or EUR ~670–840 (SEK 6,000–7,600) per ton CO₂-equivalent⁴².

⁴² Assuming factor 10 for recalculation of liquid slurry into dry matter and density of 1 t/ m³.

In Berglund *et al.* (2010) estimated acidification costs are EUR ~1.4 (SEK 12.45), per m³ manure, or EUR ~72 (SEK 650) per ton CO₂-equivalent. The assumed methane emission reduction efficiency of acidification is 32% based on a Danish Study from 2009 (Danish EPA 2009 cited in Berglund *et al.* 2010).

Within the Baltic Manure project, some cost estimates have been done for acidification of slurry, a measure currently stimulated mainly by requirements for ammonia reduction. Costs for a typical farm in Denmark (3,800 pig places) are estimated at EUR 1.04/m³ per year (Baltic Manure 2013b).

7.3.3 Covering slurry tanks

Covering slurry tanks is estimated to have the potential to reduce methane emissions up to around 40%, depending on type of cover and type of slurry. Costs have been reported to be in the order of EUR 0.3–10 per m³ manure covered, or from EUR ~19 (Berglund *et al.* 2010) to EUR 220–370/ton CO₂-equivalent reduced (Jordbruksverket, 2012).

In their study Jordbruksverket (2012) use the results from Rodhe & Nordberg 2011 who have estimated that covering slurry tanks with a plastic sheet reduces methane emissions by 2.9 kg CO₂-equivalents per slaughter pig place and year, or 1.2 kg CO₂-equivalents per ton pig slurry. The measures can be applied also to cattle slurry tanks where a ceiling is expected to have the same effect on emissions. According to Jordbruksverket (2012), covering all slurry tanks in Sweden would result in emission reduction of 0.01 million ton CO₂-equivalents per year in 2050. Costs for covering a tank containing 3,000 m³ slurry with a ceiling or a plastic sheet are EUR ~19–30 thousand (SEK 170–270 thousand), or EUR 6–10/m³ (SEK 57–90/m³). Costs for covering all slurry tanks in Sweden in 2050 are estimated at EUR 45–72 million (SEK 400–650 million), or EUR 220–370 (SEK 2,000–3,300) per ton CO₂-equivalent⁴³ (Jordbruksverket 2012).

Berglund *et al.* 2010 estimates costs for covering slurry with straw at EUR ~0.3 (SEK 2.81), per m³ manure, or EUR ~19 (SEK 170) per ton CO₂-equivalent. Assumed methane emission reduction efficiency is 40%. The thickness of the cover may affect its methane emission reduction efficiency. Other studies (Rodhe *et al.*, 2012, referring to VanderZaag, 2009) indicate emission reductions of 24% with a 15 cm thick straw cover and 28% with a 30 cm thick straw cover, compared to uncovered slurry.

The effect on methane emissions from covering slurry tanks in Sweden was studied in Rodhe *et al.* 2012. Results for different types of covers are summarized in Table 20.

⁴³ Assuming ceiling lifetime of 20 years and no interest rate.

Table 20: Methane emissions from slurry tanks with different types of cover, annual average

	No cover	Straw cover	Plastic sheet
Cattle slurry			
g CH ₄ /kg organic matter	6.4	5.9	4.3
% emission from slurry	2.7%	2.5%	1.8%
Reduction efficiency		8%	33%
Pig slurry			
g CH ₄ /kg organic matter	7.0	7.7	3.7
% emission from slurry	2.6%	2.8%	1.4%
Reduction efficiency		-10%	47%
IPCC template values			
% emission from slurry	17%	10%	10%

Source: Rodhe et al. (2012).

7.4 Abatement of methane emissions by reduced meat consumption

Reduced meat consumption would result in decreased livestock farming with subsequent decrease in methane emissions. Instruments and measures affecting meat consumption may include (Dahlin & Lundström 2011):

- Lower VAT for *climate-friendly* products.
- Economic support for stores and restaurants that have a wide assortment of vegetarian options.
- Toll on imported meat produced in a *climate-unfriendly* way.
- Excise tax on meat.
- Information for the general public regarding climate effects of meat production and health effects of reduced meat consumption.
- Administrative decisions on meat-free days in educational institutions.
- Ban on products exceeding a certain carbon footprint limit.
- Labelling meat-containing products in stores and restaurants, e.g. indicating carbon footprint.

Some suggestions that seem good in theory are most likely almost impossible to implement in practice. One such suggestion is introducing an upper limit of meat carbon footprint measured in CO₂-equivalents per kilogram. Exact calculation of carbon footprint for each particular meat product is very complicated since emissions origin from several stages (deforestation, forage plantation, digestion, product transportation), each with large uncertainties (Jordbruksverket 2013). Both carbon footprint limitation and information to customers about carbon footprint of meal portions in stores and restaurants are therefore considered to be unrealistic instruments (Jordbruksverket 2013).

One of the easiest instruments to implement in practice is meat-free days in educational institutions, or more climate-friendly meat alternatives – such as chicken instead of veal. This instrument does not result in extra costs; all that is needed is an administrative decision. The share of municipalities in Sweden that have introduced meat-free days in municipal institutions (such as schools and pre-schools) has increased from 33% to 58% during the past three years (SMMI 2017). Moreover, a number of institutions have taken this initiative without waiting for a decision on a municipality level.

7.4.1 *Scenario studies on reduced meat consumption in Sweden*

Three future scenarios based on different options regarding meat consumption in Sweden are outlined in a study by Larsson (2015). All scenarios assume increased efficiency in the agricultural sector and a fossil-free energy system in Sweden in 2050:

- **Baseline fossil-free:** 25% more meat, 50% more cheese and 30% less milk than consumed in 2012.
- **Less beef and lamb:** production of beef and lamb is reduced by 60% compared to the current level, which is partly compensated by 40% higher consumption of chicken and pork.
- **Vegan diet:** meat, dairy products and fish are substituted with vegetables.

The *Baseline fossil-free* scenario estimates average greenhouse gas emissions in 2050 at ~1.65 ton CO₂-equivalent per person per year. The *Less beef and lamb* scenario would in 2050 cause emissions of ~1 ton CO₂-equivalent per person per year. If meat, dairy and fish were entirely replaced by vegetable food, emissions would be reduced to ~0.3 tonnes CO₂-equivalent per person per year. This means that reducing the consumption of beef and lamb has ~39% emission reduction efficiency regarding greenhouse gases, whereas vegan diet has ~82% emission reduction efficiency. It is, however, unclear exactly how much of this reduction is attributable to methane.

Another study investigating greenhouse gas emission reduction potential from reduced meat consumption in Sweden is by Jordbruksverket (2012). An alternative scenario in this study assumes reduction of beef and pork consumption by 25% compared to baseline development (both scenarios assume increased efficiency but no energy mix changes). The emission reduction in the scenario with 25% less beef and pork consumption is 0.91 Mton CO₂-equivalents. If half of the reduced meat is instead substituted by chicken, the emissions will decrease by 0.81 Mton CO₂-equivalents compared to baseline development.

8. Waste treatment

Waste treatment

Methane is emitted from previously deposited organic waste in landfills, from management of currently produce waste, and from waste water treatment. Emissions of CH₄ from waste are expected to decrease in the future, mainly due to the existing ban of landfilling of organic waste. Emissions from waste treatment will however remain a significant CH₄ emission source.

During the past decades, Nordic countries efficiently implemented several instruments aimed at emission reductions in the waste management sector. Landfill tax and ban on landfilling organic waste have decreased methane emissions – but they still occur, in particular at old landfill sites, at facilities treating food and other organic waste, and at wastewater plants.

Existing and additional measures available to reduce methane emissions from waste management can be divided into three groups:

- Measures for waste prevention, separate collection and recycling.
- Measures aimed at emission reductions from facilities treating organic solid waste and wastewater sludge.
- Measures to capture and reduce emissions from landfills.

Waste prevention and separate collection with subsequent recycling is a typical example of a measure combining efficient infrastructure with information campaigns to promote behavioural changes. Waste prevention efforts usually do not involve high costs and are often regulated by administrative and economic instruments. From all the waste fractions, food waste is of particular interest from methane perspective – good practice to reduce food waste is being developed and shared at the EU level.

At wastewater treatment facilities, the most efficient measure to reduce methane emissions is anaerobic digestion of waste-water sludge, especially in combination with thermal pyrolysis and/or upgrading plants and sealed sludge tanks to reduce leaks. Anaerobic digestion is also efficiently used for household organic waste treatment. Methane measurements and gas leak identification systems are important measures to reduce leakage from organic waste treatment and biogas production facilities.

Methane emissions at landfills originate from landfill gas. To capture and recover landfill gas, the most established efficient measure is gas collection, recovery and upgrade systems. In addition, gas recovery rates can be significantly (up to 90%) increased by applying so called micrometeorological methods based on continuous measurement and evaluation of methane fluxes to optimize landfill performance. One of the relatively new efficient measures for landfill emissions is bio-cover – a multi-layer covering system consisting of inert and compost materials and reducing methane emissions by 79–94%.

8.1 Methane emissions from waste management

In the waste management systems methane is emitted from previously deposited organic waste in landfills, from management of currently produced organic waste, and from waste water treatment. Technical measures to reduce methane emissions in waste treatment are available, but also behavioural changes and non-technical measures are interesting, especially waste prevention and recycling.

8.2 Existing instruments regulating methane emissions from waste

The Nordic countries have similar instruments in place regulating methane emissions in the waste sector. Below is an overview of the three most important instruments – landfill tax, ban on landfilling organic material, and regulations on landfill gas (mostly methane) recovery – as of December 2017.

Table 21: Nordic countries' national instruments in the waste sector

Country	Landfill tax		Ban on landfilling organic waste, implemented
	€/t	Imposed	
Norway		1999, repealed 2015	01.07.2009: TOC** <10%
Sweden	50	2000	1.1.2005 : TOC <3%
Finland	70	1996	1.1.2016: TOC < 10%
Denmark	63	1987	1997, TOC <3%
Iceland	No tax	No tax	No ban

Note: ** TOC=Total Organic Carbon.

Source: CEWEP (2017) and EEA (2017).

Landfill tax is one of the oldest instruments in waste management, currently imposed in all Nordic countries except for Iceland. The first country in the North to implement the landfill tax was Denmark in 1987. Landfill taxes are considered to have contributed significantly to reduce landfilling of all types of waste, even though they do not specifically target the organic fraction. The tax size in the Nordic countries varies from EUR 50/t in Sweden to EUR 70/t in Finland. The tax for depositing biodegradable waste at landfills was removed from 2015 in Norway.

Ban on landfilling organic materials and regulations on methane recovery have been introduced as part of the implementation of the European Landfill Directive (99/31/EC). The Directive requires diversion of biodegradable (or organic) municipal waste from landfills as well as landfill gas collection and use. If the collected gas cannot be used to produce energy, it should be flared (99/31/EC).

8.3 Abatement of methane from organic waste in existing landfills

Landfill depositing of organic waste is prohibited in all the Nordic countries except Iceland. The remaining organic content in existing landfills decomposes over time and methane emissions from this source will slowly decrease. Nevertheless, since landfills currently contribute to substantial methane emissions (Kindbom *et al.* 2015, TN2015:523), measures could be relevant. Landfill gas collection and biogas recovery systems are well-known technical measures that exist in all the Nordic countries (Table 22).

Table 22: Number of landfill sites with biogas recovery systems in 2014

	Number of sites	Biogas production, raw biogas (GWh/year)
Denmark	30	83
Finland	39	312
Norway	85	270
Sweden	55	254

Source: Hellstedt *et al.* (2014).

Less wide-spread methane-reducing technologies relevant for landfills are for example (Hellstedt *et al.* 2014):

- Biocover – a filter of biologically active waste, compost, built-in in “windows” in the final soil cover of the landfill body. The technique shall be used on landfills with rather low but still significant production of landfill gas where other techniques are not applicable.
- Micrometeorological methods – a system for continuous measurements of landfill gas parameters used for evaluation of methane fluxes and optimization of landfill performance by more efficient methane recovery.

In Denmark the use of biocovers to oxidise methane to CO₂ in the top layers of landfills has been implemented to reduce CH₄ emissions. DKK 178 million has been budgeted, which is expected to enable the establishment of biocovers at 100 landfills by 2020. The establishment of biocovers is expected to reduce CH₄ emissions by between 79 and 93%. Measurements are being done before and after the establishment of biocovers to document the precise oxidation factor and hence the methane reduction potential.

Good examples of existing measures in the Nordic countries to reduce emissions of methane from waste sources are presented in Hellstedt *et al.* (2014) and summarised below. Measures and cases, together with their cost-effectiveness and emission reductions, are presented shortly below. Investment costs in the study are annualized using a payback time of 20 years and annual interest of 7%. The value of recovered gas is not included.

Gas collection system and upgrading: Àlfsnes, SORPA, Reykjavik, Iceland. Collected gas is upgraded and mainly used as vehicle fuel. Annual methane emission reduction from

reduced leakage (including flaring of excessive gas) and replacement of diesel is estimated at 2.4 tonnes and 2506 tonnes, respectively. Annualised investment costs are estimated at EUR 306,777, operation and management costs are assumed to constitute 25% of investment costs. Calculated cost-effectiveness is EUR 285/ton reduced methane.

Biocover system: Klinthom losseplads, Denmark. The bio-cover system is a layer of inert inorganic material covered with a layer of compost, on the top of the waste body. The system's reduction efficiency is 88–94% and corresponds to annual methane emission reduction of 76–129 tonnes. Annualised costs (including investment and operational costs) are estimated at EUR 44,205. Calculated cost-effectiveness is EUR 687/ton reduced methane.

Micrometeorological methods for efficient landfill gas recovery, Pääjät-Häme Waste Disposal Ltd., Lahti, Finland. Continuous measurements are used to calculate methane fluxes and optimize landfill performance by more efficient gas capture and recovery. The system has resulted in methane recovery rate increase from 50% to 90% (~1 MW of additional energy). Annual methane emission reduction is estimated at 118 tonnes. Annualised costs are estimated at EUR 18,879. Calculated cost-effectiveness is EUR 120/ton reduced methane.

8.4 Treatment of currently produced organic waste

Currently, since landfill depositing of organic waste is prohibited, most organic waste produced in the Nordic countries is treated in waste fired combustion systems, via anaerobic digestion or compost handling (Hellstedt *et al.* 2014). Anaerobic digestion is one of the few ways to both recycle nutrients and recover the energy content from the organic waste, as recovered gas can contribute to replacing fossil fuels as an energy source. One ton of bio-waste sent to biological treatment can deliver 100–200 m³ of biogas (EU COM (2008) 811 final).

Composting is best suited for green waste and woody material (e.g. garden waste) whereas anaerobic digestion is especially suitable for treating wet bio-waste, including kitchen waste. The digestate can be further composted (EUCOM (2008) 811 final). One of the ways to facilitate anaerobic digestion and composting, as well as to decrease the moisture content of incinerated waste, is to have separate collection of organic fractions such as kitchen waste.

8.4.1 Anaerobic digestion of organic waste and biogas production

An example on anaerobic digestion of household waste with biogas production is the *Uppsala Biogas Plant*, Sweden (Hellstedt *et al.* 2014). The plant produces biogas and bio fertilizers from household food waste and organic waste from food companies (such as slaughter houses). Uppsala Water undertakes intensive information campaigns aimed at separate sorting of organic waste. Calculated methane emission reduction from replacement of diesel with biogas is 3 tonnes. Reductions of methane emissions compared to other waste treatment options (e.g. composting) is not quantified. Annualised

investment costs are estimated at EUR ~2 million, operation and management costs – at EUR ~1.5–2 million. Calculated cost-effectiveness is EUR 684,720/ton reduced methane. This number would be lower if methane emission reductions other than from diesel substitution are included.

Biogas and upgrading plants consist of an interlinked system of storage tanks, valves, transmission lines etc. where methane leaks may occur. There are a number of methods and techniques for identification of methane leaks and further reducing methane emissions in installations for anaerobic digestion and upgrading. Obvious prerequisites for low methane leaks is an optimised plant design, as well as optimised operation parameters such as pressure, temperature, and time. Proper management is important and includes regular controls and emission measurements with thorough documentation and follow-up of the results (Hjort *et al.* 2015, Hellstedt *et al.* 2014).

For reducing methane emissions from biogas and upgrading plants, there is a national instrument of administrative and informational character in Sweden. The Swedish Waste Management Association in 2007 started an initiative for biogas and upgrading plants where they were encouraged to voluntarily undertake a commitment to regularly work with leak identification and reduction of methane emissions (Avfall Sverige 2011a). The Swedish Waste Management Association, responsible for dissemination of information concerning measurement methods and good practice examples, has published a detailed manual (Avfall Sverige, 2011b) covering methods and instruments for methane measurements and gas leak identification. The first analysis of the effectiveness of the initiative was made in 2012. Measurements indicated that methane losses from certain biogas plants decreased from 6.7% in 2007 to <0.1% in 2010 (Avfall Sverige, 2012). For one of the joint upgrading plants, the losses were 12% in 2008 and 2% in 2011 (Avfall Sverige, 2013). Measurements from the period 2013–2015 have shown a decrease in the average loss of methane from upgrading plants from 2.7% in the period 2007–2009 to 0.9% during 2013–2015 (Avfall Sverige, 2016).

Potential instruments encouraging biogas production from organic waste (food waste, manure, slaughter house waste, food industry waste) in Sweden are analysed in Avfall Sverige (2014). The analysis includes suggestions on the structure, economic analysis and assessments of greenhouse gas reductions for each considered instrument. Among the instruments considered in the study and not yet introduced in Sweden are the following:

- Mandatory collection of food waste.
- Climate certificates system for vehicle fuels, similar to the system used in electricity production (Energimyndigheten 2017).
- Investment support for “environmental lorries”.
- Increased CO₂ tax.
- Support for recycled nutrients.

The study concludes that the first two instruments have the greatest potential to be introduced and to result in increased biogas production and decreased methane emissions.

8.5 Wastewater treatment

Methane emissions from wastewater treatment plants originate mainly from sludge handling. *Anaerobic digestion of sludge and upgrading plants* is the most efficient way to collect the produced methane from waste water treatment, and this type of measure, including biogas production, exist in the Nordic countries (Table 23).

Table 23: Waste water treatment plants and biogas production in the Nordic countries (except Iceland) in 2014

	Number of sites	Biogas production, raw gas (GWh/year)
Denmark	65	220
Finland	15	135
Norway	25	164*
Sweden	135	660

Note: *2008.

Source: Hellstedt et al. (2014).

To increase the amount of waste suitable for anaerobic digestion, *thermal hydrolysis* is a good measure. In this process, sludge is exposed to high temperature and pressure resulting in an increased degree of degradation, which increases biogas production. Thermal hydrolyses is suitable for all kinds of substrate for biogas production, including sludge from waste water treatment plants, organic waste and manure (Hellstedt *et al.* 2014).

An example of *thermal hydrolysis of sludge* is, Fredericia Spildevand A/S, Denmark (Hellstedt *et al.*, 2014). Thermal hydrolyses of sludge from secondary treatment, which was disposed to landfills prior to 2001, has increased the biogas production by more than 100% (by ~1630 thousands m³ per year). Total investment costs are estimated at EUR 2.2 million.

An example of a methane reduction measure from wastewater treatment in Hellstedt *et al.* (2014) is of *sealed tanks for digested sludge* at Rya wastewater treatment plant (WWTP), Gothenburg, Sweden. Placing a sealed steel tank inside the existing concrete silo in 2013 has resulted in methane emission reduction of 81 tonnes. Annualised investment costs are estimated at EUR 497,896. Calculated cost-effectiveness is EUR 6,146/ton reduced methane.

8.6 Waste prevention and recycling

Among measures for *organic waste prevention and recycling* in order to reduce methane emissions the following are highlighted in WHO (2015) and Höglund-Isaksson *et al.* (2016):

- Food waste prevention and reduction in the whole food production and consumption chain.
- Paper recycling.
- Recycling of wood industry residues for board production.

Below the issues of reduction and separate collection of food waste is discussed.

8.6.1 Reduction of food waste

A rather new concept is avoidable food waste – unnecessary waste that could have been consumed as food if handled in a different way. This part of food waste is particularly important to reduce. Effective measures to reduce (avoidable) food waste are described in for example Naturvårdsverket 2014, Naturvårdsverket 2015, Livsmedelsverket, 2015, and Gramm-Hanssen *et al* 2016. The measures are presented for different stages of the food chain, from primary production (agriculture, fishing), processing in industry, wholesale and retail, institutional and commercial kitchens, and in private households. Some of the measures are of technical nature, but most concern behavioural changes such as better planning and handling of the food products, as well as information, advice and knowledge-sharing.

In the UN Sustainable Development Goal (SDG) number 12, “Ensure sustainable consumption and production patterns”, there is one specific target, SDG 12.3 on food waste: “By 2030, halve the per capita global food waste at the retail and consumer levels and reduce food losses along production and supply chains, including post-harvest losses (compared to 2015)” (UN 2017).

The EU Commission has taken this SDG target as a starting point for work on reducing food losses within the framework of its Circular Economy Strategy (EC 2017a). Good practices in food waste prevention and reduction are collected on the web (EC 2017b) to facilitate exchange of good practices. A wide range of initiatives to prevent and reduce food waste that are underway at national, regional and local level in the EU, are presented under the following headings:

- Research and innovation.
- Awareness, information and education.
- Policy, awards, self-imposed certification.
- Food redistribution.
- Food waste measurement.

In a study from Naturvårdsverket (2015) the reduction of greenhouse gases (GHG) associated with a 20% waste food reduction (based on 2012 level) is estimated. Two scenarios reflecting two possible ways to reach 20% food waste reduction were considered:

- Scenario 1: At all stages, food waste is reduced by 20%.
- Scenario 2: At all stages, *avoidable* food waste is reduced by 34%.

The results are presented in Table 24.

Table 24: Reduced emissions of greenhouse gases following 20% reduction of food waste, tonnes CO₂-eq

Stage	Scenario 1	Scenario 2
Industries	62,810	105,857
Food stores	25,200	38,649
Restaurants	56,232	58,758
Large kitchens	22,968	20,129
Households	412,081	344,833
Total	579,291	568,226

Source: Naturvårdsverket (2015).

The total greenhouse gas emissions are estimated at 2,896,454 tonnes CO₂-eq, so the emission reduction associated with waste reduction is ~20% for both scenarios (Naturvårdsverket, 2015). The impact on methane emissions alone was not specifically analysed.

8.6.2 *Separate collection of food waste*

When food waste cannot be prevented, it should at least be collected separately. In Sweden there is an environmental milestone-target saying that that 50% of food waste should be separately collected and treated biologically by 2018, of which 40% with energy recovery (i.e. biogas production) (Miljömål 2017). In the annual follow up of the target, the assessment is that the target will not be reached. For 2014 it is estimated that 38% of the food waste was collected separately, an increase from 31% in 2013. It also says that the share digested with energy recovery was 27%, as compared to the target of 40%. One obstacle to reaching the target is said to be poor profitability of many biogas plants (Miljömål 2017).

The Swedish Waste Association (Avfall Sverige, 2014) estimated that if the share of separately collected waste is increased from 50% to 70% (maximum possible), it can result in 0.02–0.07 million ton CO₂-eq emission reduction (methane not specified). The study implies that reaching the share of 70% is possible if there is an instrument requiring separate collection of food waste. Increased costs are assumed to be included in the waste handling charges.

8.6.3 *Information material*

Since most of the measures suggested for food waste reduction concern behavioral changes, information and dissemination of knowledge are important elements to promote change. As an example, information material on prevention of food waste (as well as other consumer waste types) for schools and teachers has been developed in Nordic cooperation (Poulsen *et al.* 2015).

9. Oil and gas production

9.1 Methane from oil and gas production and transmission

Among the Nordic countries this source is important primarily in Norway (Kindbom *et al.* 2015, TN2015:523). The largest sources of methane in the oil and gas system are from venting and fugitive emissions (leaks). These emissions are difficult to measure and quantify, and available data on emissions are considered to be uncertain. Already today, however, several techniques to abate emissions of methane are implemented in Norway.

Technical and operational abatement measures considered as best practices, with potentially high methane emission-reducing effect are listed in Carbon Limits (2012), Banks (2013) and Hellstedt *et al.* (2014). Best practices include:

- Flaring instead of venting (would decrease methane emissions, but increases BC emissions).
- Extended recovery and utilization, rather than venting, of associated gas (recycling the gas back to the low pressure part of the processes or to the fuel gas system).
- Improved control of unintended fugitive emissions from the production of oil and natural gas (e.g. direct inspection and maintenance, leakage detection and repair).
- Reduced gas leakage from long-distance transmission pipelines and from storage and loading of hydrocarbon products (e.g. reduction of pressure upstream, vapour recovery units).
- The petroleum Act states that flaring on the Norwegian continental shelf is prohibited unless for safety reasons.
- The CO₂ Tax Act introduced in 1991 provided further incentives for the operators on the Norwegian continental shelf to reduce flaring (e.g. flare gas recovery) and thereby methane emissions.

10. Discussion and conclusions

A number of measures are, to varying degrees, already in place in the Nordic countries to abate emissions of SLCPs. National emission projections show that emissions of BC, PM_{2.5} and CH₄ are expected to decrease in the future. In order to reduce emissions beyond those expected according to the national projections, additional reduction measures are needed. Current national projections, taking existing legislation and measures into account, show that residential biomass combustion and transport will be important sources of BC also in the future, and that agriculture and waste management will be important sources of CH₄-emissions.

Within the EU recent regulations will contribute to reduced emissions, for example the amended Ecodesign directive and the NRMM (Non-Road Mobile Machinery) regulation are expected to lead to reduced emissions of BC and PM_{2.5}. For methane, EUs Common Agricultural Policy (CAP), and the Circular Economy package (amending the Waste Framework Directive and the Directive on Landfill of Waste), will contribute to reduced emissions of methane. The efficiency of these regulations are however difficult to predict. Furthermore, all the Nordic countries also have national climate policy or action plans, or climate legislation in place which, out of the SLCPs, at least takes methane into account. In Norway an action plan specifically targeting SLCPs is available.

10.1 Model analysis of efficient SLCP abatement measures

In the project, a GAINS model analysis, based on the ECLIPSE project results for the Nordic countries was carried out (Chapter 3), and additional measures for the individual Nordic countries were assessed. The analysis indicate that in order to reach the modelled emission reduction potential for black carbon, measures within the residential wood combustion sector should be prioritized. Among the efficient measures are replacement of boilers and heating stoves with new appliances, installation of ESP (electrostatic precipitator) and high-efficiency dedusters, and switch from wood logs to pellets. 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, and for Iceland the introduction of EUR 6/VI on 100% of road diesel transport.

The 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 BC emission reduction potential in the Nordic countries. Further BC emission reductions can, according to the GAINS model analysis, be achieved by speeding up vehicle fleet renewal so that most of the diesel vehicles are EUR 6/VI. For methane, the large part of the emission reduc-

tion potential lies within the waste management and wastewater treatment sector (anaerobic treatment with gas recovery and upgrade), and in oil and gas industries and gas distribution networks (primarily in Norway and Denmark). Full realization of the 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 CO₂ equivalents).

10.2 Literature review of efficient measures

As is evident from the model analysis there is not one specific measure that will solve all problems, but rather a combination of a number of different measures aimed at various emission sources. Beside general technical measures such as increased energy efficiency, improved insulation of buildings also non-technical measures such as behavioural changes could contribute to reduced emissions. Behavioural changes are for example improved user practices in residential wood combustion (BC), reduced driving in road transport (BC), and reduced meat consumption (CH₄).

In addition it should be noted that although the Nordic countries share many similarities, there are differences in national conditions, in the contribution of the different SLCP sources to national emissions, as well as in the current status and future needs of implementation of different actions and measures.

When looking at each of the important emission sources separately, the following conclusions can be drawn:

10.2.1 Measures identified for Residential combustion

Residential biomass combustion contributes, and will in the future contribute a large share of Nordic BC and PM_{2.5} emissions according to current projections. There are differences between the Nordic countries both in the contribution from residential combustion to national emissions, and in which instruments and measures to abate emissions are already applied. Differences in future needs may also depend on differences in existing technical combustion equipment and practices. As a result of this, the question of relevant and efficient “additional measures” may be different depending on country.

A common and important non-technical measure is information campaigns for correct use and maintenance of wood burning equipment. Correct use and maintenance can have a significant impact on the emission levels. Technical measures such as replacing older equipment with low-emitting technologies can also significantly reduce emissions from residential biomass combustion.

Emission limit regulations and eco-labelling are likely to have a future impact on emission reductions as manufacturers develop equipment according to upcoming regulations. Subsidies on replacing older equipment have resulted especially in Denmark in rather cost-efficient emission reductions. Aside from such economic instruments, Norway’s perhaps most important measure is to introduce emission limits for new

stoves which probably will be updated when the Ecodesign directive is adopted. In Finland, a large share of residential biomass burning equipment are masonry heaters, which are not readily replaced and hence information campaigns to ensure correct practices are identified as the most efficient way in order to decrease emissions.

10.2.2 Measures identified for Road transport

On-road and non-road vehicles and machinery emissions of BC are according to current projections expected to decrease in the future, but still to contribute a significant part of the total Nordic emissions. Technical measures are similar irrespective of country, and in principle consists of renewal and modernisation of the vehicle fleet (EUR 6/VI), as well as use of diesel particle filters (DPF).

Non-technical measures may differ depending on country. In order to decrease human exposure to PM_{2.5} and BC, especially urban transport emissions should be reduced. Several non-technical measures to obtain this could be taken into account, such as sustainable city planning, congestion charges, car sharing etc.

10.2.3 Measures identified for Agriculture

Agriculture contributes, and will contribute a very large share of total emissions of methane also in the future. Abatement measures are available to reduce emissions of CH₄ from ruminant enteric fermentation, from manure management (including biogas production), and also the possibility to reduce the number of animals (and thus also the CH₄ emissions) following measures to promote behavioural changes towards less meat consumption. Several of the measures discussed are already present to a smaller or larger degree in the Nordic countries, but the applications could be extended. The situation differs between the Nordic countries, and the potential for relevant additional (or extended measures) may vary.

Available measures to decrease emissions from ruminant enteric fermentation comprise increasing production efficiency and animal life-time, breeding and forage optimization. The efficiency of these measures is estimated in the order of about 10–20% methane emission reductions as an example for forage modification. Slightly higher emission reductions can be reached for manure management by applying acidification or covering slurry tanks – methane emission removal efficiency of these measures could be up to 25–40%.

The most efficient way to reduce methane emissions from livestock is anaerobic digestion of manure with production of biogas. This measure has methane emission reduction efficiency of up to 80%. With a possibility to upgrade biogas to vehicle fuel, it provides triple benefits – reduces methane emissions from the agricultural sector, replaces fossil fuels in transport systems with biofuels, and decreases the need for mineral fertilizer use due to better nitrogen availability in the digested slurry.

Lower meat consumption is assumed to result in reduced farming activities and subsequent emission reductions. Behavioural change is, however, a long process, so in order to achieve quicker emission reductions reduced meat consumption should be combined with emission reduction efforts on the production side.

10.2.4 Measures identified for Waste treatment

Methane is emitted from previously deposited organic waste in landfills, from management of currently produce waste, and from waste water treatment. Emissions of CH₄ from waste are expected to decrease in the future, mainly due to the existing ban of landfilling of organic waste. Emissions from waste treatment will however remain a significant CH₄ emission source.

During the past decades, Nordic countries efficiently implemented several instruments aimed at emission reductions in the waste management sector. Landfill tax and ban on landfilling organic waste have decreased methane emissions – but they still occur at old landfill sites, at facilities treating food and other organic waste, and at wastewater plants.

Existing and additional measures available to reduce methane emissions from waste management can be divided into three groups:

- Measures for waste prevention, separate collection and recycling.
- Measures aimed at emission reductions from facilities treating organic solid waste and wastewater sludge.
- Measures to capture and reduce emissions from landfills.

Waste prevention and separate collection with subsequent recycling is a typical example of a measure combining efficient infrastructure with information campaigns to promote behavioural changes. Waste prevention efforts usually do not involve high costs and are often regulated by administrative and economic instruments. From all the waste fractions, food waste is of particular interest from methane perspective – good practice to reduce food waste is being developed and shared at the EU level.

At wastewater treatment facilities, the most efficient measure to reduce methane emissions is anaerobic digestion of waste-water sludge, especially in combination with thermal pyrolysis and/or upgrading plants for production of biogas. Anaerobic digestion is also efficiently used for reducing methane emissions from household organic waste treatment.

Methane emissions at landfills originate from landfill gas. To capture and recover landfill gas, the most established efficient measure is gas collection, recovery and upgrade systems. In addition, gas recovery rates can be significantly (up to 90%) increased by applying so called micrometeorological methods based on continuous measurement and evaluation of methane fluxes to optimize landfill performance. One of the relatively new efficient measures for landfill emissions is bio-cover – a multi-layer covering system consisting of inert and compost materials, reducing methane emissions by 79–94%.

10.2.5 Measures identified for Oil and gas production and transmission

Oil and gas production and transmission is an important source for methane emissions primarily in Norway among the Nordic countries. The largest sources of methane in the oil and gas system are from venting and fugitive emissions (leaks). Already today several techniques to abate emissions of methane are implemented in Norway.

Technical and operational abatement measures considered as best practices, with potentially high methane emission-reducing effect include:

- Flaring instead of venting.
- Extended recovery and utilization, rather than venting, of associated gas.
- Improved control of unintended fugitive emissions from the production of oil and natural gas.
- Reduced gas leakage from long-distance transmission pipelines and from storage and loading of hydrocarbon.

According to the SLCP model analysis in chapter 3 the largest emission reduction potential for CH₄ in Norway and Denmark lie within the oil and gas production systems. For Norway the largest emission reduction potential is "Replacement of grey cast iron distribution networks in gas distribution systems". For Denmark it is "Recovery and use of associated gas in oil and gas industries".

10.3 Recommendations for further work

The Nordic countries share many similarities, but there are also differences in national conditions and in the importance of the different SLCP sources contribution to national emissions. Furthermore, the status of implementation of different actions and measures that influence SLCP emissions varies between the countries. This means that a measure may already exist in one country, but not in another, where it is "additional" and possible to implement for further emission reductions.

In order to identify the most efficient additional measures to reduce SLCP emissions nationally, each individual country needs to do a country specific analysis. The GAINS-model analysis and the literature review presented in this report could serve as a starting point for assessing measures to abate SLCP as a group of pollutants originating from very different emission sources.

The national analysis could in principle follow a line of thought as of below:

- Identify present levels of SLCP emissions from national emission sources (e.g. national emission inventories).
- Identify and map existing relevant policies and measures and analyse and estimate their probable future emission reduction impact.

- Assess future emission levels (and important sources) taking existing measures into account (national WEM – projections) and whether additional emission reductions are required in relation to (national) objectives or targets.
- Clarify if climate impact and/or health benefits are the most important objective for further emission reductions (this may steer measures towards focusing on e.g. BC and/or CH₄).
- Identify efficient additional measures (technical and non-technical) that are available (and feasible) to reach the targets, and assess their emission reduction potential and cost-effectiveness (see Norwegian action plan for SLCP as an example, Table 6). This may also include extending the application of already existing measures.

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Sammanfattning

Åtgärder som minskar utsläppen av SLCP finns i varierande grad redan på plats i de nordiska länderna. Nationella utsläppsprognoser, som tar hänsyn till befintliga åtgärder och lagstiftning, visar att de totala utsläppen av sot (black carbon, BC) och metan (CH_4) förväntas minska till 2030. I framtiden kommer förbränning av biobränslen i bostadssektorn (småskalig biomassaförbränning) och transporter att vara viktiga källor till BC, liksom jordbruk och avfallshantering för CH_4 -utsläpp. Målsättningen i denna del av projektet var att identifiera effektiva åtgärder för att minska utsläppen av SLCP utöver de nuvarande utsläppsprognoserna. Analysen omfattar huvudsakligen BC och CH_4 , men eftersom BC är en del av utsläppta partiklar ($\text{PM}_{2.5}$) och många åtgärder fokuserar på $\text{PM}_{2.5}$ snarare än på BC, så ingår också reduktion av $\text{PM}_{2.5}$ -utsläpp i analysen. I denna rapport diskuteras både tekniska åtgärder, såsom filter eller förbättrad teknik, och icke-tekniska åtgärder, såsom beteendeförändringar som leder till minskade utsläpp.

En modellanalys för att identifiera effektiva tekniska åtgärder för minskade SLCP-utsläpp i de enskilda nordiska länderna, utöver nuvarande prognoser har genomförts. Analysen omfattar de kombinerade SLCP-utsläppen och baserades på resultat för de nordiska länderna från ECLIPSE-projektet. Analysen, som genomfördes i GAINS-modellen, visar att för att nå den modellerade tekniska potentialen för utsläppsminskning för black carbon bör åtgärder inom småskalig biomassaförbränning prioriteras. Bland de effektiva tekniska åtgärder som identifierades i GAINS-analysen är: utbyte av äldre pannor och kaminer till modern utrustning, installation av effektiva partikelfilter och ESP (elektrostatiskt filter), samt att ersätta ved med pellets. Enligt modellresultaten skulle dessa åtgärder sammantaget ge den största potentialen att minska emissioner av BC i Danmark, Finland och Sverige, medan för Norge har "good practice" vid fackling i olje- och gasindustrin den högsta reduktionspotentialen. På Island är införandet av Euro 6 / VI på 100 % av dieselfordon viktigast.

Åtgärderna som riktas mot småskalig biomassaförbränning kan enligt modellberäkningarna minska BC-utsläppen med 3,7 kt år 2030 - vilket är cirka 79 % av den beräknade totala tekniska potentialen för minskning av BC-utsläpp i Norden. Ytterligare utsläppsminskningar kan uppnås genom att öka takten i förnyringen av dieselfordon till Euro 6 / VI.

För metan finns den största utsläppsminskningspotentialen inom sektorerna avfallshantering och avloppsrening (anaerob behandling med gasåtervinning och uppgradering), i olje- och gasindustrin samt i gasdistributionsnät (främst i Norge och Danmark).

Ett fullständigt genomförande av den modellerade strategin för utsläppsminskning av SCLP i Norden år 2030 skulle medföra betydande hälsofördelar för hela Europa

(> 60 000 år sammanlagt i förlängd livslängd) - och en minskad klimatpåverkan (med 14 miljoner ton CO₂-ekvivalenter).

Som framgår av den kombinerade SLCP-analysen behövs olika tekniska åtgärder riktade mot olika utsläppskällor för att minska utsläppen av SLCP och uppnå den tekniska potentialen för minskade utsläpp. För BC är de viktigaste källorna för åtgärder i det nordiska sammanhanget biomassaförbränning och dieselfordon. För CH₄ är jordbrukssektorn och avfallshantering de viktigaste källorna, följt av olje- och gasproduktion, särskilt för Norge. Utöver de tekniska åtgärderna i modellen kan allmänna tekniska åtgärder såsom ökad energieffektivitet och förbättrad isolering av byggnader, men även icke-tekniska åtgärder bidra till att minska utsläppen. Icke-tekniska åtgärder är t.ex. beteendeförändringar såsom förbättrade rutiner vid biomassaförbränning i hushållssektorn (BC), minskade vägtransporter (BC) och minskad köttkonsumtion (CH₄).

En litteraturstudie av möjligheter att minska utsläppen utöver befintliga prognoser utfördes för var och en av de viktiga SLCP-utsläppskällorna. Existerande, planerade eller möjliga åtgärder diskuteras. Åtgärds-kostnader eller kostnadseffektivitet av åtgärder presenteras i den mån det redovisas i litteraturen.

Småskalig biomassaförbränning bidrar, och kommer i framtiden att bidra till en stor andel av de nordiska utsläppen av BC och PM_{2.5} enligt nuvarande prognoser. Det finns skillnader mellan de nordiska länderna, både vad gäller storleksordningen på bidraget från småskalig biomassaförbränning till nationella utsläpp och i vilka lagar, regler och åtgärder för att minska utsläppen som redan tillämpas. Till följd av detta kan det skilja mellan de nordiska länderna i vad som kan anses vara relevanta och effektiva "kompletterande åtgärder". Regleringar för utsläppsgränser och miljömärkning av förbränningsutrustning kommer sannolikt att få en framtida inverkan på utsläppen. Framför allt i Danmark har ekonomiskt stöd vid utbyte av äldre utrustning mot modern tidigare resulterat i relativt kostnadseffektiva utsläppsminskningar. Förutom den typen av ekonomiska instrument är Norges kanske viktigaste åtgärd att införa utsläppsgränser för nya kaminer. I Finland sker en stor del av den småskaliga biomassaförbränningen i "masonry stoves" (murade spisar som är integrerade i byggnaden och därför inte kan bytas ut) och i Finland har därför informationskampanjer för att säkerställa korrekta metoder vid eldning identifierats som det mest effektiva sättet att minska utsläppen. Informationskampanjer för korrekt hantering av vedeldningsutrustning är en viktig icke-teknisk åtgärd då korrekt användning och underhåll kan ha betydande inverkan på utsläppsnivåerna. Informationskampanjer förekommer i alla nordiska länder. Tekniska åtgärder, såsom utbyte av äldre typer av småskalig förbränningsteknologi mot lågemitterande teknik kan också avsevärt minska utsläppen från förbränning av biomassa i bostadssektorn.

Utsläpp av BC från vägtrafik och arbetsmaskiner förväntas enligt nuvarande prognoser minska i framtiden, men de kommer fortfarande bidra till en betydande del av de totala nordiska utsläppen. Tekniska åtgärder är likadana oavsett land och består i princip av förnyelse och modernisering av fordonsflottan (Euro 6 / VI) samt användning av dieselpartikelfilter (DPF).

Jordbruket bidrar, och kommer också i framtiden att bidra med en stor del av de totala utsläppen av CH₄. Åtgärder finns för att minska utsläppen av CH₄ från boskap (idisslare), från gödselhantering (inklusive biogasproduktion). Man har också möjligheten att minska antalet djur (och därmed även CH₄-utsläppen) genom att främja beteendeförändringar mot mindre köttkonsumtion. Flera av de diskuterade åtgärderna existerar redan i mindre eller större utsträckning i Norden, men de skulle kunna utvidgas. Situationen skiljer sig mellan de nordiska länderna, och potentialen för relevanta ytterligare (eller utvidgade åtgärder) kan variera.

Det mest effektiva sättet att minska metanutsläpp från gödselhantering är anaerob nedbrytning följt av produktion av biogas. Denna åtgärd har en metanemissionsreduktionseffektivitet på upp till 80 %. Möjligheten att uppgradera biogasen till fordonsbränsle ger tredubbla fördelar – det minskar metanutsläppen från jordbrukssektorn, det ersätter fossila bränslen i transportsystemet med biobränslen och det minskar behovet av mineralgödsel på grund av bättre kvävetillgänglighet i det anaerobt nedbrutna slammet.

Vid avfallshantering emitteras metan från deponier med tidigare deponerat organiskt avfall, från hantering av nyproducerat organiskt avfall och från avloppsrening. Utsläppen av CH₄ från avfallshantering förväntas minska i framtiden, främst på grund av det existerande förbudet mot deponering av organiskt avfall. Utsläpp från avfallshantering kommer emellertid att fortsätta vara en viktig utsläppskälla för CH₄. I allmänhet är anaerob behandling av organiskt avfall och avloppsslam, med gasåtervinnings- och uppgraderingssystem en effektiv åtgärd för att minska metanutsläpp.

Informationskampanjer och effektiv infrastruktur för att förebygga uppkomsten av avfall och för separat insamling med efterföljande återvinning är exempel på åtgärder för att främja beteendeförändringar. Livsmedelsavfall är av särskilt intresse ur metanperspektivet. Goda exempel och bra metoder för att minska matavfall utvecklas och delas på EU-nivå.

På deponier är gasåtervinning och system för uppgradering av deponigasen etablerade metoder för att minska metanutsläpp. Gasåtervinningsgraden kan ökas signifikant (upp till 90 %) genom tillämpning av mikrometeorologiska metoder som baserade på kontinuerlig mätning och utvärdering av metanflöden. En annan effektiv åtgärd för att minska utsläpp från deponier är att täcka över deponin (biocover) – ett flerskiktssystem som består av inerta och kompostmaterial, vilket kan minska CH₄-utsläppen med 79–94 %.

Olje- och gasproduktion och transport av produkterna är viktiga källor för metanutsläpp, främst i Norge bland de nordiska länderna. Redan idag implementeras flera tekniker för att minska CH₄-utsläppen i Norge. Tekniska och operativa åtgärder som betraktas som bästa praxis, med potentiellt hög metanemissionsreducerande effekt, inkluderar: fackling, utökad återvinning och användning av gas, samt förbättrad kontroll och minskning av oavsiktliga diffusa utsläpp och läckor från produktionsprocesser och från transport och lagring av olje- och gasprodukter.

De nordiska länderna har många likheter, men det finns också skillnader i nationella förhållanden, som till exempel vilka SLCP-källor som bidrar mest till nationella utsläpp och vilka åtgärder för att minska utsläpp som redan är genomförda. För att identifiera de mest effektiva nationella åtgärderna för att minska SLCP-utsläppen ytterligare måste varje enskilt land göra en egen analys. Modellanalysen (GAINS) och litteraturstudien som presenteras i denna rapport kan vara en utgångspunkt för att analysera och bedöma lämpliga ytterligare åtgärder för att minska utsläpp av SLCP.

Annex 1: ECLIPSE-based analysis – methodological details

Our GAINS-analysis is based on the datasets developed within the ECLIPSE study (Stohl *et al.* 2015a, Stohl *et al.* 2015b, and Klimont *et al.* 2017); however, we used a different GAINS module and made certain modifications to the available scenarios developed within ECLIPSE. A summary of the main differences between our analysis and the underlying ECLIPSE study is presented in the table below.

Table 1: Own analysis compared to the underlying ECLIPSE study – summary

Parameter	ECLIPSE	Own analysis
GAINS module	GAINS Global	GAINS Europe
Baseline scenario, GAINS Europe	<i>ECLIPSE_V5a_CLE_base</i>	<i>ECLIPSE_V5a_CLE_base</i>
Scenario with additional measures for SLCP, GAINS Europe	<i>ECLIPSE_V5_SLCP_base</i>	<i>SLCP-MIT*</i>
Geographical coverage	World	Nordic countries
Years considered	2015–2050	2030

GAINS module

GAINS model is available in several modules, including GAINS Europe, GAINS Global, GAINS Asia, GAINS UNFCCC Annex I, and GAINS Russia. ECLIPSE analysis has been conducted with the GAINS Global – this module is only available for a limited number of experts and mostly used as a research tool. ECLIPSE scenarios are also available in the GAINS Europe module – this module was used in our study as it is open for all registered users.

SLCP scenarios in the GAINS Europe

Baseline, or current legislation (CLE), scenario implies efficient enforcement of committed legislation. We use the same scenario as developed within ECLIPSE.

SLCP mitigation scenario assumes maximum possible application of SLCP mitigation measures that both reduce climate forcing and do not have negative effect on air quality. The mitigation scenario developed within ECLIPSE (*ECLIPSE_V5_SLCP_base*) was finalized in 2014, i.e. earlier than when the baseline scenario (*ECLIPSE_V5a_CLE_base*) was last modified. Some updates in the activity data made in

the baseline scenario seem to not have been introduced in the SLCP mitigation-scenario in the GAINS Europe. For own analysis within this study we have created a “hybrid” scenario SLCP-MIT* to assure that the same set of activity data is used in the baseline and in the mitigation scenario with additional measures. The SLCP-MIT* scenario combines activity data from *ECLIPSE_V5a_CLE_base* (including updates after 2014) with SLCP-targeting additional measures from *ECLIPSE_V5_SLCP_base*.

Emission reduction potential in our study is the difference between the baseline scenario and the mitigation scenario. Normally, by emission reduction potential is meant the difference in emissions between the baseline scenario and the MTFR (Maximum Technically Feasible Reduction) scenario. Since for the Nordic countries SLCP-MIT* scenario implies even higher application rates of effective measures targeting SLCP than those implied in the latest publically available MTFR (Amann 2015a, 2015b, IIASA 2017), it can be considered as updated MTFR, and the difference between two scenarios can thus be considered as emission reduction potential for SLCP. For PM_{2.5}, however, the actual reduction potentials are higher since measures targeting PM_{2.5} but not BC are not included in the SLCP-MIT* scenario.

Geographical coverage and years considered

ECLIPSE analysed SLCP effects and measures on the global-scale while our analysis is focused on the five Nordic countries, with a few extensions: health effects from potential emission reductions are estimated for the whole Europe, and climate effects are relevant on the global scale.

ECLIPSE assumes that implementation of SLCP-reducing measures starts in 2015; the results are presented for the period 2015–2050. In our analysis, we focus on the year 2030.

Annex 2: Emissions in the Nordic countries, according to the baseline scenario

Figure 1: Methane, kt

Figure 2: Black carbon, kt

Figure 3: PM_{2.5} kt

Annex 3: Baseline emission control trends in the residential combustion of biomass in the Nordic countries

Application of technologies is given as percentage of the total residential combustion. Colour codes in legends represents combustion in improved, new and pellet stoves, boilers and fireplaces. The remaining percentage is combustion in conventional devices with lower level of abatement and higher emission factors.

Figure 1: Denmark and Finland

Figure 2: Norway and Sweden

Annex 4: Examples on Nordic biogas production from manure

Good examples of existing measures in the Nordic countries to reduce emissions of methane from agricultural sources are presented in Hellstedt *et al.* (2014). Biogas production on different scales is assumed to be the most efficient measure to abate methane emissions. Digestion of manure is in the study assumed to mainly contribute to the reduction of methane emissions by replacing energy from fossil sources with biogas and not by reducing emissions from manure storage and spreading.

Biogas production examples from Hellstedt *et al.* (2014), together with their cost-effectiveness and emission reductions, are presented shortly below. Investment costs in the study are annualized using a payback time of 20 years and annual interest of 7%. The value of recovered gas is not included. A manure conversion factor for stored liquid manure of 10% (recommended by IPCC) is used, although it is considered to overestimate emissions in the Nordic countries.

Large-scale biogas production: Måbjerg BioEnergy, Holstebro, Denmark. This is one of the largest biogas plants in the world digesting liquid and solid manure received from 140 suppliers, together with food industry waste and waste water from local sewage facility and producing biogas for heat and power. Annual methane emission reductions from replacement of fossil fuels, in electricity and in heat production, are 5.4 tonnes and 57.6 tonnes, respectively. Annualised investment costs are estimated at EUR 5,190,000. Calculated cost-effectiveness is EUR 5,217/ton reduced methane.

Small-scale biogas production: Lövsta, Uppsala, Sweden. Manure is digested together with potatoes and waste flour from a mill. The produced electricity and heat is mostly used internally, with a small amount exported. Annual methane emission reduction from replacement of fossil energy sources is estimated at 380 kg. Total investment costs are estimated at EUR 2.95 million. Annual operational costs are expected to be EUR 145–155 thousand, resulting in total annualized costs of EUR 430,000 and cost-effectiveness of EUR 5,085/ton reduced methane.

Biogas production from solid horse manure: Sötåsen/JTI, Töreboda, Sweden. Co-digestion of large share of solid horse manure together with cattle manure is conducted at a plant as full-scale testing. The gas is mainly used for power and heat production. Methane production is strongly dependant on bedding material. Annual methane emission reductions from co-digestion of solid horse manure, assuming saw dust as bedding material, is estimated at 24 kg. Annualised investment costs are estimated at EUR 56,600. Calculated cost-effectiveness is EUR 17,300/ton reduced methane. This may be compared to the cost effectiveness of a similar sized plant for digestion of liquid manure which was calculated to be EUR 43,900/ton CH₄.

Small-scale local biogas production with gas distribution pipelines to collective upgrading plant: Biogas Brålanda, Sweden. The system consists of four different biogas plants located at four different farms, which is a quite unique constellation. After passing through a joint upgrading plant, gas is distributed to a compressor and vehicle fuel filling station where it is used by local buses. Annual methane emission reduction from replacement of fossil energy sources is estimated at 2 tonnes. Annualised investment costs are estimated at EUR 743,500. Calculated cost-effectiveness is EUR 6,250/ton reduced methane.

Annex 5: Baltic Manure study on biogas potentials

The main results of *the Baltic Manure vision* (Baltic Manure, 2013a) scenarios for Denmark, Finland and Sweden regarding biogas potentials and associated costs are summarised below. Note that by a biogas potential in this study a total production in a given year is considered, meaning that a certain part of the potentials will be reached without introduction of extra instruments and measures.

Denmark

Manure-based biogas *potential* for Denmark is estimated in the Baltic Manure study at 5.6–6.9 TWh by 2030. One scenario from the Danish Task Force on biogas is that 90% of all manure in 2030 is used for biogas production. This will require some 900 farm-scale plants and 50–100 cooperative/ industrial biogas plants (depending on their size).

Investment costs in Danish biogas plants vary from EUR 33–66/ton of manure capacity annually. To reach 50% of manure being digested to biogas in 2020, roughly EUR 0.5–1.0 billion in investments is required.

The scenario for 90% of total manure being treated in biogas plants means approximately 30 million tonnes of manure and a total investment costs of approximately EUR 1–2 billion.

The *operation and maintenance costs* for manure-based biogas plants in Denmark are around EUR 7–10.7/ton of manure. As a comparison, the cost of the energy produced (an income for a facility) is EUR 15–21 per GJ.

Finland

In the Baltic Manure study it is estimated that 25% of the *techno-economical potential* in 2025 is 1.25 million ton in Finland, or 0.3 TWh of energy (only farms with over 100 animals are included, manure left on pasture is excluded). To reach this goal, four biogas plants with a size of 1 MW should be built every year during 2014–2025, which means 43 plants in total.

The *investment costs* of biogas plants in Finland are relatively high (Table 1). As an average, investment cost of building a farm-scale biogas plant (feedstock <10,000 t/a) is about EUR 0.5 million. The total investment in biogas plants for digesting the techno-economical manure potential is about EUR 250 million. This in-

vestment does not include possible investments cost of hygienisation or pre-treatment units often required when co-substrates as waste from energy crops are used as feedstock. Biogas upgrading is also not included in these calculations.

Table 1: The average investment cost of biogas plants in Finland

Feedstock	Amount of feedstock t/a	Investment million €
Mainly manure	15,000–30,000	1.3–1.7
Mainly manure	90,000	10*
Waste materials	14,000–16,000	3.6–7**

Note: *Includes biogas upgrading plants.

**Includes hygienisation and pre-treatment of biowaste.

Source: Marttinen et al. (2013) cited in Baltic Manure (2013a).

Sweden

The Baltic Manure study estimates that the total techno-economic manure-based biogas *potential* in Sweden is 2.67–4.11 TWh per year, of which 50–68% (1.34–2.78 TWh) comes from manure and the rest from co-substrates such as organic waste, grass, straw and other by-products from cultivation. This is 6–9 times higher biogas production than in 2010.

Investment costs for Swedish digestion plants are presented in Table 2. The total investment in biogas plants for digesting the techno-economical manure potential is calculated to EUR 730 Million. This investment does not include investment in the capacity to digest the co-substrates (organic waste, grass and straw) or to upgrade the biogas in “co-digestion plants”.

Table 2: Investment of a biogas plant digesting liquid and solid manure in the Swedish manure biogas scenario

	Farm scale manure plants	Large scale manure plants	Co-digestion plants	Units
1) Specific “Basic investment”	920	690	1160	EUR/m ³ digester volume
2) “Pre-treatment” investment	116,000	462,000	462,000	EUR/plant
3) Specific “storage tank” investment**	30	30	30	EUR/m ³ digestate storage tank
Total specific investment	1,250	900	1290	EUR/m ³ digester volume

Note: *Calculations include weight losses for manure due to produced biogas and 10 months storage capacity connected to the digestate, produced from solid manure.

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Measures to reduce emissions of Short-Lived Climate Pollutants (SLCP) in the Nordic countries

In the future residential biomass combustion and transport will be important sources for emissions to air of black carbon (BC), as will agriculture and waste management for emissions of methane (CH₄). Measures to abate emissions of Short-Lived Climate Pollutants (SLCP) are to varying degrees already in place in the Nordic countries. To reduce emissions beyond current emission projections, additional measures are required. Both technical measures, such as improved technologies, and non-technical measures, such as promoting behavioral changes favoring reduced emissions are discussed in this report.

The overall objective of this project is to improve the Nordic emission inventories of Short Lived Climate Pollutants. This report presents results from the third and final phase of the project, an assessment of efficient measures to reduce emissions of Short-Lived Climate Pollutants (SLCP) in the Nordic countries.

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