REVIEW, IMPROVEMENT AND HARMONISATION OF THE NORDIC PARTICULATE MATTER AIR EMISSION INVENTORIES

NERI Technical Report no. 809 2010

NATIONAL ENVIRONMENTAL RESEARCH INSTITUTE
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Abstract: In this study the Nordic particulate matter (PM) emission inventories are compared and for the most important sources – residential wood burning and road transport – a quality analysis is carried out based on PM measurements conducted and models used in the Nordic countries. All the institutions in charge of the work on emission inventories in the Nordic countries have participated in this project together with researchers performing PM measurements in the residential and transport sectors in the Nordic countries in order to increase the quality of the PM national inventories. The ratio between the reported emissions of PM_{10} and $PM_{2.5}$ was calculated for each country. Norway has the largest share of $PM_{2.5}$ compared to PM_{10} (88 %), whereas Finland has the lowest (66 %). Denmark and Sweden are right in the middle with 73 and 76 %, respectively. The completeness of the inventories was assessed with particular emphasis on the categories where emissions were reported by one or more countries, while the other categories reported notation keys. It is found that the PM emission inventories generally are complete and that the sources reported as not estimated only are expected to have minor contributions to the total PM emissions. The variability of emission factors for residential wood combustion is discussed and it is illustrated that the emission factors can vary by several orders of magnitude.

Keywords: Particulate matter, emissions, emission inventory, Nordic, TSP, PM_{10}, $PM_{2.5}$, road transportation, residential, wood combustion, emission factors

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Preface

In this study the Nordic particulate matter (PM) emission inventories are compared and for the most important sources – residential wood burning and road transport – a quality analyses are carried out based on PM measurements conducted and models used in the Nordic countries.

All the institutions in charge of the work on emission inventories in the Nordic countries have participated in this project together with researchers performing PM measurements in the residential and transport sectors in the Nordic countries in order to increase the quality of the PM national inventories.

The authors wish to thank the Nordic Council of Ministers (NCM) for financing the study. The project has enabled experts from the Nordic countries Denmark, Finland, Iceland, Norway and Sweden to come together and discuss and compare national data regarding PM emissions.

The work has been carried out in the period 2006 to 2009. In this period the official Nordic PM emission inventories have been revised, which means the figures given in this report may be different from the present official PM emissions inventories for the Nordic countries. The current status for the official inventories is given in Chapter 5.

Summary

This project has conducted a study of the particulate matter (PM) inventories in the Nordic countries. The focus has been on the two major sources road transport and residential combustion.

For road transport both exhaust emissions and non-exhaust emissions such as tyre and brake wear and road abrasion have been included. For residential combustion the work has focussed on wood burning in stoves and small scale boilers, since this is the predominant source of PM emission from the residential sector.

The main goal of this project was to asses the quality and completeness of the PM emission inventories in the Nordic countries. The basis for the evaluation was the countries submissions to the Convention on Long-Range Transboundary Air Pollution (CLRTAP) under the United Nations Economic Commission for Europe (UNECE) in 2007, where the latest reported year was 2005.

The emission inventories for PM in the Nordic countries have somewhat different key sources compared to other parts of Europe; this is caused by different climatic conditions and other structural differences.

An overview of the PM emissions for the Nordic countries are provided in Chapter 2 showing the overall emissions of PM from the Nordic countries distributed on source sectors. A key source analysis is made for the overall Nordic inventory for both PM_{10} and $PM_{2.5}$. For both PM_{10} and $PM_{2.5}$ residential plants, exhaust emissions from road transport and non-exhaust emissions from road transport are in the top five. The other two categories finishing the top five for PM_{10} are agriculture and manufacturing industries and construction. For $PM_{2.5}$ the two other sources included in the top five are manufacturing industries and construction and non-road machinery. Residential plants account for 39 % of the PM_{10} emission and 50 % of the $PM_{2.5}$ emission. However, there are considerable differences between the four countries, where PM inventories are available. For example, in Sweden the PM emission from residential plants comprise a very low share of total emissions compared to Denmark, Finland and Norway. Detailed accounts of the key sources for each of the four countries are included in Chapter 2.

The ratio between the reported emissions of PM_{10} and $PM_{2.5}$ was calculated for each country. Norway has the largest share of $PM_{2.5}$ compared to PM_{10} (88 %), whereas Finland has the lowest (66 %). Denmark and Sweden are right in the middle with 73 and 76 %, respectively.

The completeness of the inventories was assessed with particular emphasis on the categories where emissions were reported by one or more countries, while the other categories reported notation keys. It is found that the PM emission inventories generally are complete and that the sources reported as not estimated only are expected to have minor contributions to the total PM emissions. The completeness of the 2007 submission was compared with the status of completeness in the 2010 sub-

mission in Chapter 5. The recalculations for the year 2005 between the 2007 submission and the 2010 submission are also presented and discussed.

The methodologies used by the countries to estimate PM emissions from residential wood combustion and road transport are described for the Nordic countries, and the differences between them are discussed. For road transport different models are used in the Nordic countries. The differences include different classifications of vehicles, different age classes, different driving condition and different driving modes. Due to the different models there are also differences in emission factors. This is described in-depth in Chapter 3.2.

For residential wood combustion the differences concern the emission factors used and also the level of disaggregation in the emission calculations. The emission factors used in Sweden are lower compared to the other three countries. This can probably be attributed to a different sampling method in the measurements upon which the Swedish emission factors are based. The importance of sampling method, operating conditions and other variables is discussed in Chapter 4.

In Chapter 4 the variability of emission factors for residential wood combustion is discussed and it is illustrated that the emission factors can vary by several orders of magnitude. The importance of the sampling method used to perform the measurements is clearly of great significance. It is shown that measurements performed in a dilution tunnel can result in emission factors that are 2.5-10 times higher compared to in-stack measurements in the hot flue gas.

Several studies have also shown great variations in emission factors depending on variables such as wood species, water content of the wood, log size, batch size and the general operating conditions such as the air flow etc. It is also clear that the emissions vary between different types of appliances. Stoves and boilers have different emission characteristics depending on age and whether the boiler is with or without an accumulation tank. Pellet stoves and boilers have very low emission factors compared to traditional stoves and boilers fired with wood logs. The different emission factor studies carried out for pellet stoves and boilers also show very similar low results for PM emissions.

Chapter 5 provides an overview of the current status of PM emission inventories in the Nordic countries. The basis for this is the countries 2010 submission to the UNECE Convention on Long-Range Transboundary Air Pollution. Additionally the recalculations of emission between the 2007 and the 2010 submission are quantified and the improvements in completeness are presented. The recalculations performed between the 2007 and 2010 submissions are minor.

Sammenfatning

Dette projekt har undersøgt emissionsopgørelserne af partikler i de nordiske lande. Fokus har været på to vigtige kategorier nemlig vejtransport og husholdninger.

For vejtransport er der inkluderet både partikelemissioner fra udstødningen, men også partikler fra slid af dæk og bremser samt vejslid. For husholdninger er der fokuseret på forbrænding af træ i brændeovne og små brændekedler, da træfyring i husholdninger er den altovervejende kilde til partikelforurening fra husholdninger.

Hovedformålet med projektet var at vurdere kvaliteten og kompletheden af emissionsopgørelsen af partikler i de nordiske lande. Udgangspunktet for evalueringen har været landenes rapporteringer til konventionen om langtransporteret grænseoverskridende luftforurening under UNECE (United Nations Economic Commission for Europe) i 2007, hvor det seneste rapporterede år var 2005.

Emissionsopgørelserne for partikler for de nordiske lande har delvist en anden fordeling af vigtige kategorier i forhold til andre dele af Europa. Dette skyldes forskelle i klimatiske betingelser og andre strukturelle forskelle.

I kapitel 2 gives der et overblik over emissionsopgørelserne af PM i de nordiske lande, herunder vises de totale emissioner fordelt på sektorer. En rangering af de vigtigste kategorier til PM-emission er udført for den samlede nordiske emission af både PM_{10} og $PM_{2.5}$. For både PM_{10} og $PM_{2.5}$ er husholdninger, udstødningsemissioner fra vejtrafikken og vej, dæk og bremseslid i top 5 over de største kilder. De andre kategorier i top er for PM_{10} landbrug og fremstillingsvirksomhed, mens det for $PM_{2.5}$ er fremstillingsvirksomhed og ikke-vejgående maskiner. Husholdninger bidrager med 39 % til den totale nordiske emission af PM_{10} og med 50 % til emissionen af $PM_{2.5}$. Der er dog betydelige forskelle landene imellem for så vidt angår de vigtigste kilder. I Sverige udgør emissioner fra husholdninger en meget lille andel af den samlede emission sammenlignet med Danmark, Finland og Norge. En detaljeret opgørelse og diskussion af de vigtigste kategorier i hvert af de fire lande er inkluderet i kapitel 2.

Forholdet mellem de rapporterede emissioner af PM_{10} og $PM_{2.5}$ er beregnet for hvert land. Norge har den største andel af $PM_{2.5}$ sammenlignet med PM_{10}-emissionen (88 %), mens Finland har den laveste andel (66 %). Danmark og Sverige ligger ca. midt imellem med henholdsvis 73 % og 76 %.

Kompletheden af de nordiske landes emissionsopgørelser for partikler blev vurderet med særlig fokus på kategorier, hvor et eller flere lande rapporterer emissioner, mens et eller flere lande anvender notation keys. Efter analysen kan det konkluderes, at emissionsopgørelserne generelt er komplette og de kategorier, der rapporteres som ikke-estimeret (Not Estimated, NE) er af mindre betydning for de samlede partikelemissioner. Kompletheden af 2007-rapporteringen er i kapitel 5 sammenlignet med kompletheden i 2010-afleveringen. Genberegninger foretaget for året 2005 mellem 2007-rapporteringen og 2010-rapporteringen er præsenteret og diskuteret i kapitel 5.

Metoderne, der er anvendt i landene, til beregning af emissioner fra træfyring i husholdninger og vejtransport, er beskrevet for de nordiske lande, og forskellene mellem metoderne er diskuteret. For vejtransport anvendes der forskellige modeller i de nordiske lande. Forskellene mellem metoderne omfatter bl.a. forskellig klassifikation af køretøjskategorier, forskellige aldersgrupperinger samt forskellige kørselsforhold. Fordi landenes modeller refererer forskellige nationale og internationale målinger, er der også forskel i de anvendte emissionsfaktorer, dette er nærmere beskrevet i kapitel 3.2.

For træfyring i husholdninger, er det brug af forskellige emissionsfaktorer der er den vigtigste metodeforskel, men der er også stor forskel på detaljeringsgraden i emissionsopgørelsen. Emissionsfaktorerne, der anvendes i Sverige, er lavere end emissionsfaktorerne, der anvendes i de øvrige nordiske lande. Dette skyldes formentlig målemetoden, der er anvendt ved de svenske målinger, der ligger til grund for de svenske emissionsfaktorer. Betydningen af målemetode, samt driftsbetingelser og andre variable er diskuteret i kapitel 4.

Udsvingene i emissionsfaktorerne for træfyring i husholdninger er diskuteret i kapitel 4 og det er fra flere undersøgelser klart, at emissionsfaktorerne kan variere med flere størrelsesordener. Målemetodens betydning for måleresultaterne er tydeligvis stor. Det er påvist, at målinger udført i en fortyndingstunnel giver emissionsfaktorer, der er 2,5-10 gange højere end emissionsfaktorer der baseret på målinger udført direkte i skorstenen i den varme røggas.

Adskillige undersøgelser dokumenterer, at emissionsfaktorerne varierer meget afhængigt af variable som f.eks. typen af træ, vandindholdet i træet, mængden af træ indfyret, størrelsen af træstykkerne, og de generelle forbrændingsbetingelser som f.eks. tilførslen af luft. Det er også tydeligt, at emissionsfaktorerne er afhængige af forbrændingsteknologien. Ovne og kedler har forskellige emissionskarakteristika afhængigt af alder og hvorvidt kedlen er med eller uden akkumuleringstank. Træpillefyrede ovne og kedler har meget lave emissionsfaktorer sammenlignet med traditionelle ovne og kedler, der fyres med brænde. De forskellige undersøgelser af emissionsfaktorer for ovne og kedler fyret med træpiller viser også meget sammenfaldende og lave emissioner af partikler.

Kapitel 5 indeholder en opdateret status på emissionsopgørelserne for partikler i de nordiske lande. Grundlaget er landenes rapportering i 2010 til UNECE-konventionen om langtransporteret grænseoverskridende luftforurening. I kapitlet vises også omfanget af genberegninger for 2005 i forhold til 2007-rapporteringen, og ændringerne i forhold til komplethed diskuteres. Der er kun i lille omfang foretaget genberegninger mellem 2007- og 2010-afleveringerne.

1 Introduction

1.1 Objectives

The objective of the project has been to assess the quality and completeness of the PM emission inventories in the Nordic Countries.

The results of the project provides a better basis for improvements of the emissions data, which are going to be the basis for further development of the LRTAP Gothenburg protocol, the NEC directive and the EU air quality directives about particulate and near-ground ozone (CAFE). Furthermore, the result of the project may improve the data used in the RAINS model and as a consequence the PM emissions estimated by the model would better reflect the circumstances in the Nordic countries and be in line with the national PM inventories.

1.2 Background

PM emissions in the Nordic countries may differ from the rest of Europe due to different composition, structure and scale of emission sources as well as the climate conditions. The international work often concentrates on emission sources that are not relevant in the Nordic countries or the structure of which differ remarkably from the Nordic ones. There is thus a need to develop methods that better reflect the actual PM emissions in the Nordic countries.

The project has involved all the Nordic countries and consequently strengthened their cooperation. The Nordic countries also benefit through better inventory data to form the basis for assessment of compliance as well as the scientific basis for future negotiations about protocols on emission reductions.

The project is anchored to the national emission inventory work in the countries and is also connected to fulfilling the reporting requirements of the CLRTAP as well as the work on integrated emission registers (EPER and PRTRs). The participants are members in the UNECE TFEIP, EIONET NRC network and UNECE and UNFCCC Review Teams.

The results of a closer Nordic cooperation may strengthen the Nordic influence in the international inventory community, and also help to focus on issues that are important in the Nordic countries, e.g. in the development of the Gothenburg Protocol and the NEC Directive.

Residential wood burning and road transport are known to be important sources to PM emissions in the Nordic countries. Emissions from road transport are in all Nordic countries calculated by models. These models are described and PM emission factors on an aggregated level are compared. Results from measurements of PM from road transport and residential wood use are reviewed and summarised.

The project fits into the goal for the NCM Sea and Air Group (Hav- og Luftgruppen) (Now Klima- og Luftgruppen, Climate and Air Group) concerning long-range transboundary air pollutants with respect to quality assurance and improvements of the emissions data, which are going to be the basis for further development of the LRTAP Gothenburg protocol and the NEC directive. Further, the project contributes to create a better foundation for the EU air quality directives concerning particulate matter and near-ground level ozone (CAFE).

The project has benefited from the NCM project on reviewing, improving and harmonizing air pollutant emission inventories in the Nordic Countries (Saarinen et al., 2006).

The method of inventory comparison and review developed in this project is used. Also, the results from the NCM project 'Particulate matter emissions and abatement options in residential wood burning in the Nordic countries' have been a valuable input to the project.

1.3 Methods

The Nordic emission inventories are compared for the most important sources. For these sources comparison analyses are carried out based on officially reported emissions inventories and PM measurements in the Nordic countries. The differences in the emissions and the used background data are discussed.

A key source analysis has been performed in order to analyse the importance of various sources to the total emissions in a systematic way. Key sources are estimated by calculating the contribution from all individual sources to the national total estimate.

Results from past and ongoing research projects for PM emissions from wood burning in the residential sector in the Nordic countries are summarized and a transformation of emission measurements data into emission factors are made in some cases. The results of different studies are analysed and the impact of different sampling methods and operating conditions are discussed.

1.4 Structure of the report

An analysis of the PM emission inventories in the Nordic countries points out the key sources and the work focuses on these sources. The work includes comparison of the Nordic PM emission inventories with regards to e.g. emission factors, fuels consumption data and the wood combustion technologies used in the Nordic countries.

Chapter 2 gives an overview of the present PM emission inventories in the Nordic countries and an assessment of completeness and differences.

Chapter 3 contains comparisons of the Nordic emission inventories for the residential use of wood as well as for road transport (including a brief description and comparison of models). Residential combustion and road transport together contribute between approximately 30-80 % of the presently reported PM emissions in the Nordic countries.

In Chapter 4 a review of measurements of emissions in the Nordic countries and Europe is given for laboratory and in-field measurements in stoves and small scale boilers.

Chapter 5 describes the development in the PM emission inventories for the Nordic countries between the 2007 submission and the 2010 submission. Recalculations/improvements made in each country are presented and the level of completeness is discussed.

Chapter 6 contains the main conclusions and suggestions for future work.

2 Overview of the PM emission inventories in the Nordic countries

2.1 Emissions of particulate matter in the Nordic countries

The estimated total emissions of particulate matter in the Nordic countries for the year 2005, as reported to UNECE-CLRTAP in submission 2007, are presented in Table 2.1. PM_{10} and $PM_{2.5}$ are particles with an aerodynamic diameter of less than 10 µm and less than 2.5 µm, respectively. $PM_{2.5}$ is a subset of PM_{10}.

Table 2.1 Emissions of particulate matter in the Nordic countries in 2005 (Gg).

	PM_{10} Gg Nordic-2005	$PM_{2.5}$ Gg Nordic-2005
1A1a Public Electricity and Heat Prod	6.8	4.6
1A1b Petroleum refining	1.5	1.4
1A2 Manuf Industries and Construction	12.9	10.1
1A3b Road Transport, exhaust	11.1	10.5
1A3b vi+vii Road transport, non-exhaust	20.8	7.8
1A3d ii National Navigation	2.0	1.9
Other mobile sources	8.7	8.3
1A4b i Residential plants	75.0	73.4
1A4c i Stationary, Agr/Forest/Fish	1.3	0.7
1B1 Fugitive Emissions from Solid Fuels	4.2	2.7
2A2 Lime Production	0.7	0.2
2A7 Other incl. Mining & Construction	8.0	3.2
2B Chemical industry	1.1	0.9
2C Metal production	9.0	6.9
2D1 Pulp and Paper	6.7	5.4
3D Other Product Use	2.0	2.0
4 Agriculture	16.9	4.0
Other sources	3.6	2.9
Total	192	147

The sources with the largest contributions to the emissions of particulate matter are combustion in residential plants and emissions from road transport (Figure 2.1). Emissions from road transport are estimated as exhaust and non-exhaust emissions. Exhaust emissions originate from the combustion of fuels in the vehicles, while the non-exhaust emissions arise from tyre and brake wear as well as from road abrasion. Together the combustion in residential plants and the aggregated exhaust and non-exhaust emissions from road transport contribute with more than 50 % of the total Nordic emissions of particles (56 % and 62 % respectively for PM_{10} and $PM_{2.5}$).

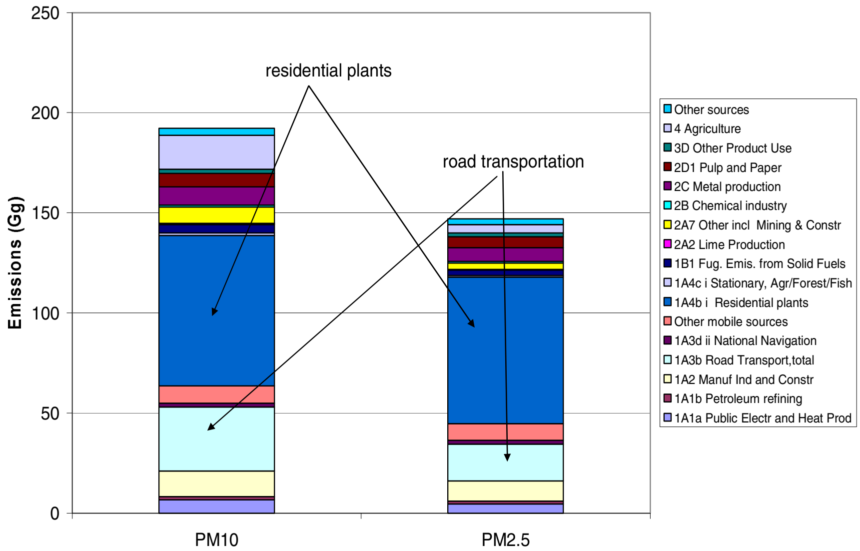

Figure 2.1   Nordic emissions of PM_{10} and $PM_{2.5}$ in 2005 (Gg).

A systematic way of analysing the importance of various sources to the total emissions is by performing a key source analysis. Key sources are estimated by calculating the contribution from all individual sources to the national total estimate. The contributions are sorted in a descending order and the sources which cumulatively add up to 95 % of the total emissions, are defined as key sources (IPCC, 2000).

In Table 2.2 the results from a key source analysis performed on the sum of the reported emissions for 2005 from the Nordic countries is presented. The most important source for both size fractions of PM emissions is combustion in residential plants (small-scale combustion) which contributes to 39 % of PM_{10} and 50 % of the $PM_{2.5}$ emissions in the Nordic countries. The second largest source is road transport, where the non-exhaust emissions contribute to 11 % of the PM_{10} emissions, while the exhaust-emissions contribute 7 % of the total for $PM_{2.5}$. The contribution from road transport as a sum of exhaust and non-exhaust emissions of particles is 17 % for PM_{10} and 12 % for $PM_{2.5}$.

Since both residential combustion and road traffic contribute substantially and are the most important key sources in the combined Nordic emission inventory, a thorough comparison of the methodologies and emission factors used for estimating PM emissions from these sources are made in this project.

Table 2.2 Key Sources, aggregated Nordic emissions in 2005 (Gg). frac=fraction of Nordic total, cum=cumulative fraction of Nordic total.

PM_{10}	Nordic PM_{10} Gg	Nordic PM_{10} frac	Nordic PM_{10} cum
1 A 4 b i Residential plants	75.02	0.39	0.39
1 A 3 b Road Transport, non-exhaust	20.78	0.11	0.50
4 Agriculture	16.94	0.09	0.59
1 A 2 Manufacturing Industries and Construction	12.87	0.07	0.65
1 A 3 b Road Transp. exhaust	11.08	0.06	0.71
2 C Metal production	9.05	0.05	0.76
1A4b ii, 1A4c ii & 1A4c iii Off road machinery	8.19	0.04	0.80
2 A 7 Other including Non Fuel Mining & Construction	8.03	0.04	0.84
1 A 1 a Public Electricity and Heat Production	6.75	0.04	0.88
2 D 1 Pulp and Paper	6.71	0.03	0.91
1 B 1 a Coal Mining and Handling	3.96	0.02	0.93
1 A 3 d ii Navigation+1A4c iii Fishing	2.47	0.01	0.95
$PM_{2.5}$	Nordic $PM_{2.5}$ Gg	Nordic $PM_{2.5}$ frac	Nordic $PM_{2.5}$ cum
1 A 4 b i Residential plants	73.37	0.50	0.50
1 A 3 b Road Transp., exhaust	10.48	0.07	0.57
1 A 2 Manufacturing Industries and Construction	10.14	0.07	0.64
1A4b ii, 1A4c ii & 1A4c iii Off road machinery	7.86	0.05	0.69
1 A 3 b Road Transport, non-exhaust	7.79	0.05	0.75
2 C Metal production	6.89	0.05	0.79
2 D 1 Pulp and Paper	5.36	0.04	0.83
1A1a Public Electricity and Heat Prod.	4.60	0.03	0.86
4 Agriculture	4.03	0.03	0.89
2 A 7 Other including Non Fuel Mining & Construction	3.22	0.02	0.91
1 B 1 a Coal Mining and Handling	2.67	0.02	0.93
1A3d ii Navigation+1A4c iii Fishing	2.43	0.02	0.94
3 Solvent and product use	2.04	0.01	0.96

2.2 National emissions of particulate matter in the Nordic countries

The estimated national total emissions of particulate matter in the individual Nordic countries for the year 2005, as reported to UNECE-CLRTAP in submission 2007, are presented in Table 2.3, where also a comparison of estimated emissions per capita are given. Iceland has not yet performed an emission inventory of particulate matter.

Table 2.3 National total emissions of PM_{10} and $PM_{2.5}$ (Gg) in 2005 in the individual Nordic countries.

	Denmark	Finland	Norway	Sweden*
	PM_{10}	PM_{10}	PM_{10}	PM_{10}
National Total (Gg)	38.14	51.29	56.27	46.52
Emissions/capita (kg pr person)	7	10	12	5
	$PM_{2.5}$	$PM_{2.5}$	$PM_{2.5}$	$PM_{2.5}$
National Total (Gg)	27.79	34.08	49.62	35.47
Emissions/capita (kg pr person)	5	6	11	4

*Data for Sweden corrected compared to submission 2007.

Emissions of particulate matter arise from a multitude of sources within a country and the national total emissions as well as the size fractions of particulate matter may be highly influenced by what activities occur in the country and to what extent. In Figures 2.2 and 2.3 the reported national emissions are presented by source. The figures show that a few sources are comparatively important in all of the Nordic countries, while some sources may be important in only one country.

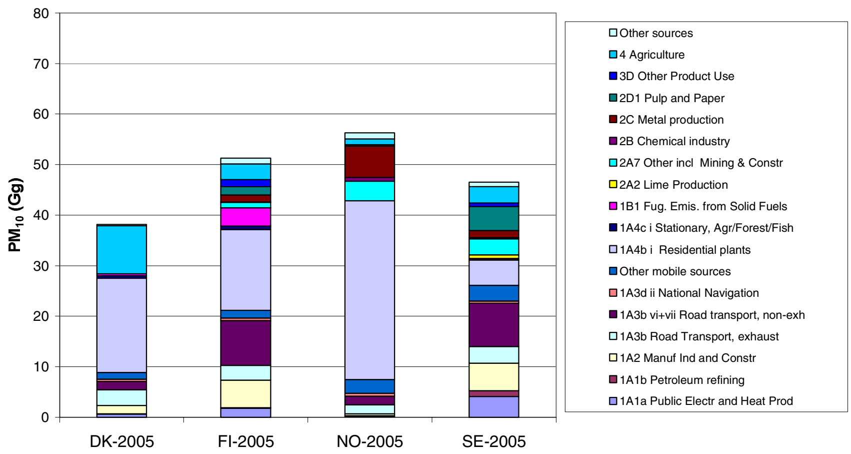

Figure 2.2 National emissions of PM_{10} in 2005 (Gg). DK=Denmark, FI=Finland, NO=Norway, SE=Sweden.

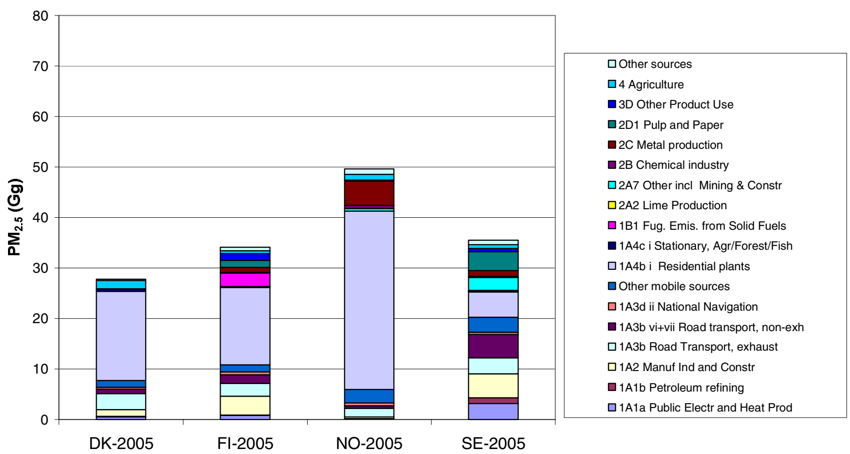

Figure 2.3 National emissions of $PM_{2.5}$ in 2005 (Gg).

Figures 2.4 and 2.5 below show emissions by sources and countries for PM_{10} and $PM_{2.5}$.

Residential plants are important sources for particulate matter emissions in all the Nordic countries. Combustion in residential plants is the largest single source of $PM_{2.5}$ in all countries except Sweden. The methodologies and emission factors used for estimating particulate matter emissions from residential combustion in the Nordic countries are compared, described and discussed in Chapter 3.1.

Road transport, both non-exhaust emissions (tyre and brake wear and road abrasion) and exhaust emissions from combustion of fuels are large source of particulate matter emissions. The non-exhaust emissions contribute to a large share of the national total emissions primarily of the larger particles, PM_{10}, while the emissions from combustion of fuels are relatively more important for $PM_{2.5}$. The methodologies and emission factors used for estimating particulate matter emissions from road transport in the Nordic countries, both the exhaust and the non-exhaust emissions, are compared, described and discussed in Chapter 3.2.

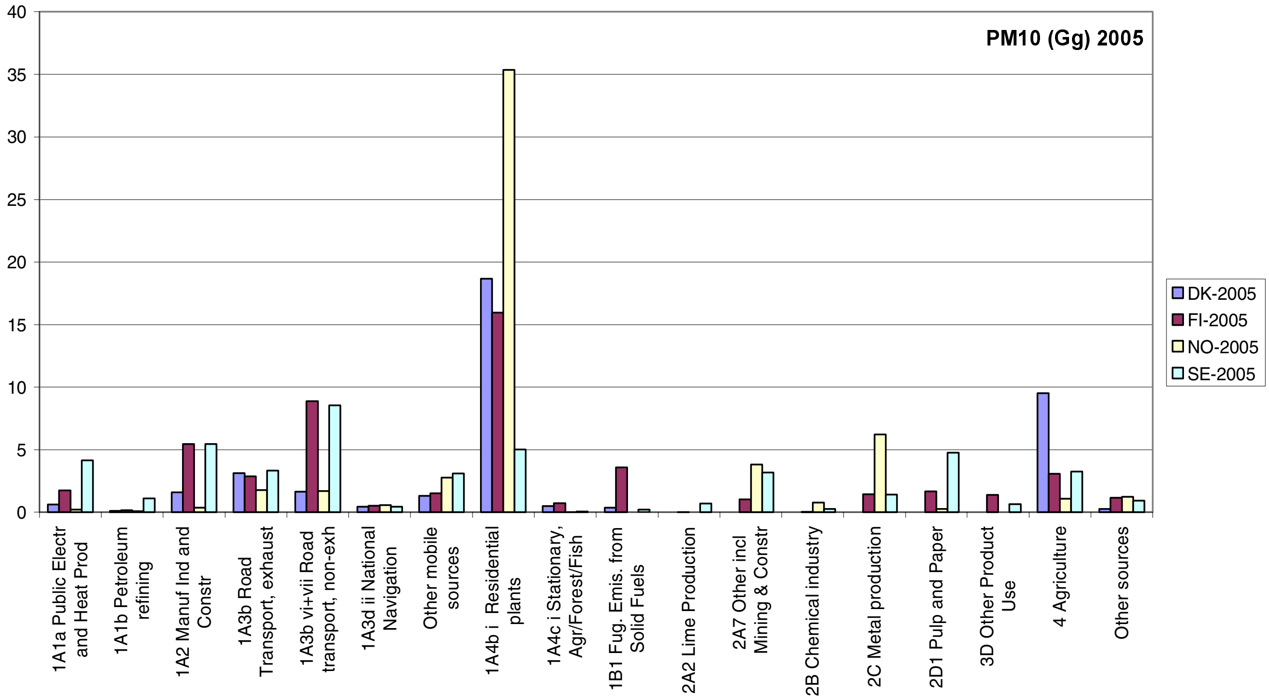

Figure 2.4 Emissions of PM_{10} in the Nordic Countries in 2005 (Gg).

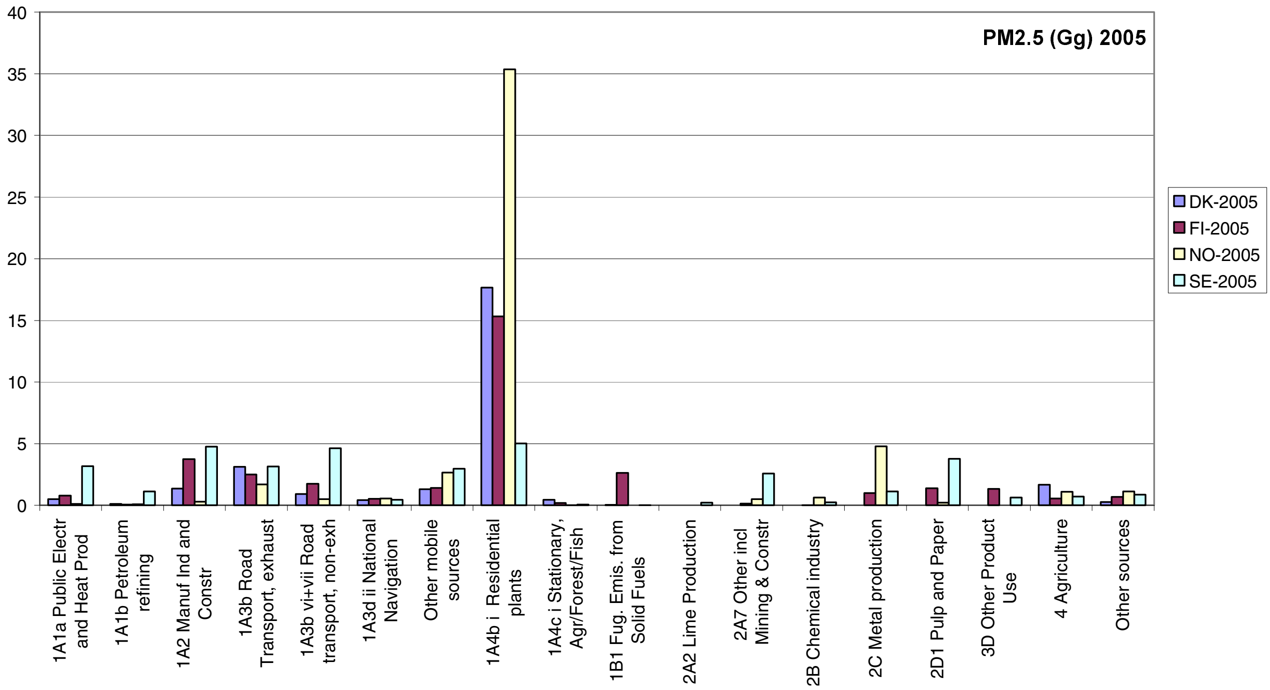

Figure 2.5 Emissions of $PM_{2.5}$ in the Nordic Countries in 2005 (Gg).

2.3 Key sources in the national inventories

Apart from residential plants and road transport, which are important sources of particle emissions in all the Nordic countries there are also some more country specific sources contributing substantially to the national total emissions. In the following, country specific key-source analyses are presented and commented for the individual Nordic countries.

2.3.1 Denmark

In Denmark (Figure 2.6 and Table 2.4) agriculture, off road machinery and combustion in manufacturing industries and construction, in addition to residential plants and road traffic, are key sources for both size fractions of particulate matter emissions. Agriculture is, after residential plants, the second largest source for PM_{10} (25 %), and the third largest for $PM_{2.5}$ (6 %). Combustion in manufacturing industries and construction contributes 4-5 % to the emissions of particles while off-road machinery contributes 3 and 4 % respectively to the PM_{10} and $PM_{2.5}$ emissions.

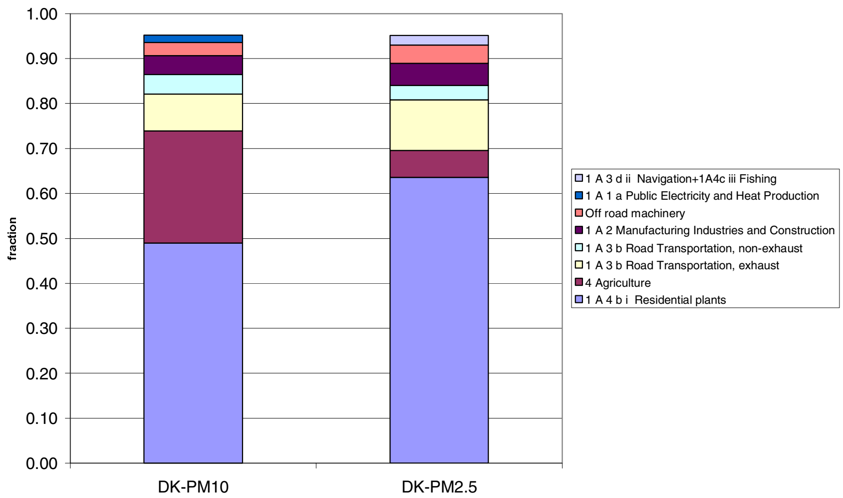

Figure 2.6 Key sources in Denmark (contribution to national total emissions by fraction).

Table 2.4 Key sources Denmark, emission year 2005 (Gg) (frac=fraction of national total, cum=cumulative fraction of national total).

PM_{10} 38.14 Gg	PM_{10} Gg	PM_{10} frac	PM_{10} cum
1 A 4 b i Residential plants	18.68	0.49	0.49
4 Agriculture	9.51	0.25	0.74
1A3b Road Transport, exhaust	3.12	0.08	0.82
1A3b Road Transport, non-exhaust	1.65	0.04	0.86
1A2 Manuf. Ind. and Construct	1.60	0.04	0.91
Off road machinery	1.13	0.03	0.94
1A1a Public Electr and Heat Prod	0.63	0.02	0.95
$PM_{2.5}$ 27.79 Gg	$PM_{2.5}$ Gg	$PM_{2.5}$ frac	$PM_{2.5}$ cum
1 A 4 b i Residential plants	17.67	0.64	0.64
1A3b Road Transport, exhaust	3.12	0.11	0.75
4 Agriculture	1.67	0.06	0.81
1A2 Manuf. Ind. and Construct.	1.35	0.05	0.86
Off road machinery	1.13	0.04	0.90
1A3b Road Transport, non-exhaust	0.90	0.03	0.93
1A3d ii Navigation+1A4c iii Fishing	0.60	0.02	0.95

2.3.2 Finland

In Finland, apart from residential combustion and road transport, combustion in manufacturing industries and construction, as well as fugitive emissions from solid fuels, mainly from peat production and hand-ling (which is included in the code 1B1a, coal mining and handling) are quite important key sources of about 10 % each (Figure 2.7 and Table 2.5). The agricultural sector contributes more to of PM_{10} emissions than to $PM_{2.5}$ emissions. There are also several other key sources in Finland, contributing 3-4 % or less to the national total emissions of the respective PM size fractions. These include e.g. the sources "other sources, including non fuel mining and construction", pulp and paper and metal production processes, off-road machinery, particles from product use as well as emissions from stationary combustion in energy production.

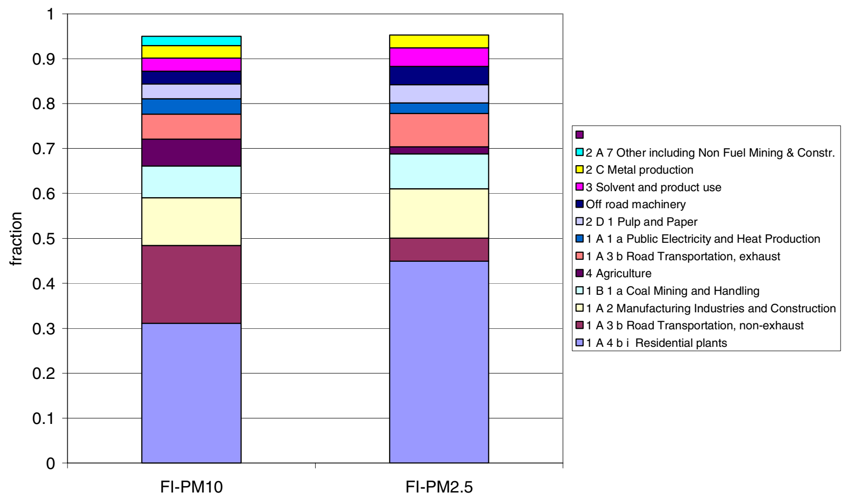

Figure 2.7 Key sources in Finland (contribution to national total emissions by fraction).

Table 2.5 Key sources in Finland, emission year 2005 (Gg) (frac=fraction of national total, cum=cumulative fraction of national total).

PM_{10} 51.29 Gg	PM_{10} Gg	PM_{10} frac	PM_{10} cum
1 A 4 b i Residential plants	15.95	0.31	0.31
1A3b Road Transport, non-exhaust	8.88	0.17	0.48
1A2 Manuf. Ind. and Construct	5.46	0.11	0.59
1 B 1 a Coal Mining and Handling	3.60	0.07	0.66
4 Agriculture	3.08	0.06	0.72
1 A 3 b Road Transport, exhaust	2.86	0.06	0.78
1A1a Public Electr and Heat Prod	1.74	0.03	0.81
2 D 1 Pulp and Paper	1.67	0.03	0.84
Off road machinery	1.48	0.03	0.87
3 Solvent and product use	1.48	0.03	0.90
2 C Metal production	1.44	0.03	0.93
2 A 7 Other including Non Fuel Mining & Constr.	1.03	0.02	0.95
$PM_{2.5}$ 34.08 Gg	$PM_{2.5}$ Gg	$PM_{2.5}$ frac	$PM_{2.5}$ cum
1 A 4 b i Residential plants	15.32	0.45	0.45
1A2 Manuf. Ind. and Construct	3.74	0.11	0.56
1 B 1 a Coal Mining and Handling	2.63	0.08	0.64
1 A 3 b Road Transport, exhaust	2.51	0.07	0.71
1A3b Road Transport, non-exhaust	1.75	0.05	0.76
3 Solvent and product use	1.40	0.04	0.80
2 D 1 Pulp and Paper	1.40	0.04	0.84
Off road machinery	1.37	0.04	0.88
2 C Metal production	0.99	0.03	0.91
1A1a Public Electr and Heat Prod	0.80	0.02	0.94
4 Agriculture	0.56	0.02	0.95

2.3.3 Norway

In Norway (Figure 2.8 and Table 2.6) the dominant key source is residential plants, contributing well above 60 % of the national emissions of PM_{10} and $PM_{2.5}$. Metal production and off road machinery are also relatively large key sources for both PM size fractions (approximately 10 % and 5 % respectively). For the larger particles, PM_{10}, "other sources, including non fuel mining and construction" contribute 7 % to the national total emissions, but this is not a key source for $PM_{2.5}$. Other key sources include road transport, agriculture, chemical industry and shipping (national navigation and fishing).

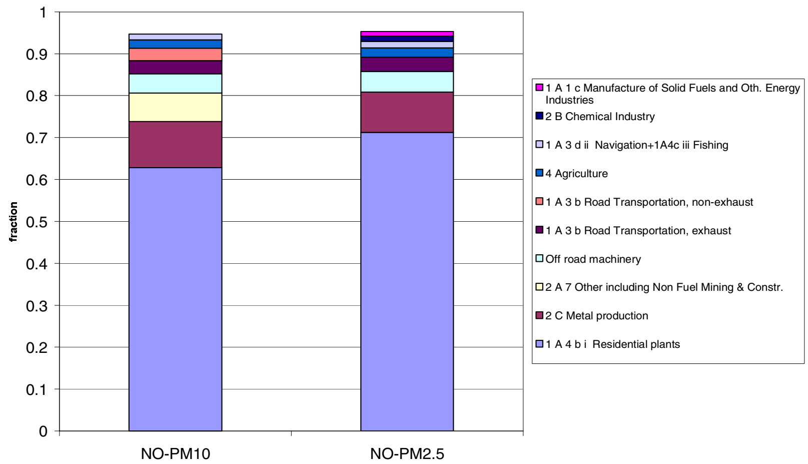

Figure 2.8 Key sources in Norway (contribution to national total emissions by fraction).

Table 2.6 Key Sources in Norway, emission year 2005 (Gg) (frac=fraction of national total, cum=cumulative fraction of national total).

PM_{10} 56.27 Gg	PM_{10} Gg	PM_{10} frac	PM_{10} cum
1 A 4 b i Residential plants	35.36	0.63	0.63
2 C Metal Production	6.21	0.11	0.74
2 A 7 Other including Non Fuel Mining & Constr.	3.82	0.07	0.81
Off road machinery	2.55	0.05	0.85
1A3b Road Transport, exhaust	1.78	0.03	0.88
1A3b Road Transport, non-exhaust	1.70	0.03	0.91
4 Agriculture	1.10	0.02	0.93
1 A 3 d ii Navigation+1A4c iii Fishing	0.78	0.01	0.95
$PM_{2.5}$ 49.62 Gg	$PM_{2.5}$ Gg	$PM_{2.5}$ frac	$PM_{2.5}$ cum
1 A 4 b i Residential plants	35.35	0.71	0.71
2 C Metal production	4.77	0.10	0.81
Off road machinery	2.45	0.05	0.86
1A3b Road Transport, exhaust	1.70	0.03	0.89
4 Agriculture	1.10	0.02	0.91
1 A 3 d ii Navigation+1A4c iii Fishing	0.76	0.02	0.93
2 B Chemical Industry	0.65	0.01	0.94
1 A 1 c Manufacture of Solid Fuels and Oth. Energy Industries	0.53	0.01	0.95

2.3.4 Sweden

In Sweden (Figure 2.9 and Table 2.7) combustion in manufacturing industries and construction, in public electricity and heat production and processes in the pulp and paper industry are relatively large key sources all in the order of approximately 10 %, apart from residential plants and emissions from road transport. Other key sources contributing between 5-8 % each in the Swedish inventory are "other sources, including non fuel mining and construction", off road machinery and agriculture. A few additional key sources, contributing 1-2 % to the total national emissions of the respective PM size fractions, are metal production, petroleum refining and lime production.

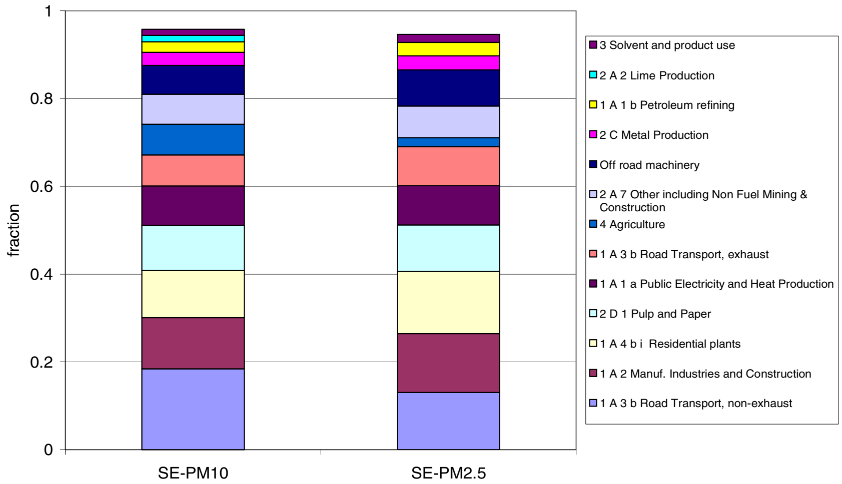

Figure 2.9 Key sources in Sweden (contribution to national total emissions by fraction).

Table 2.7 Key Sources in Sweden, emission year 2005 (Gg) (frac=fraction of national total, cum=cumulative fraction of national total).

PM_{10} 46.52 Gg	PM_{10} Gg	PM_{10} frac	PM_{10} cum
1 A 3 b Road Transport, non-exhaust	8.55	0.18	0.18
1 A 2 Manufacturing Industries and Construction	5.44	0.12	0.30
1 A 4 b i Residential plants	5.03	0.11	0.41
2 D 1 Pulp and Paper	4.77	0.10	0.51
1 A 1 a Public Electricity and Heat Production	4.15	0.09	0.60
1 A 3 b Road Transport., exhaust	3.31	0.07	0.67
4 Agriculture	3.25	0.07	0.74
2 A 7 Other including Non Fuel Mining & Construction	3.18	0.07	0.81
Off road machinery	3.03	0.07	0.87
2 C Metal production	1.41	0.03	0.91
1 A 1 b Petroleum refining	1.11	0.02	0.93
2 A 2 Lime Production	0.69	0.01	0.94
3 Solvent and product use	0.64	0.01	0.96
$PM_{2.5}$ 35.47 Gg	$PM_{2.5}$ Gg	$PM_{2.5}$ frac	$PM_{2.5}$ cum
1 A 4 b i Residential plants	5.03	0.14	0.14
1 A 2 Manufacturing Industries and Construction	4.75	0.13	0.28
1 A 3 b Road Transport, non-exhaust	4.62	0.13	0.41
2 D 1 Pulp and Paper	3.77	0.11	0.51
1 A 1 a Public Electricity and Heat Production	3.18	0.09	0.60
1 A 3 b Road Transport., exhaust	3.15	0.09	0.69
Off road machinery	2.91	0.08	0.77
2 A 7 Other including Non Fuel Mining & Construction	2.57	0.07	0.85
2 C Metal production	1.12	0.03	0.88
1 A 1 b Petroleum refining	1.10	0.03	0.91
4 Agriculture	0.71	0.02	0.93
3 Solvent and product use	0.64	0.02	0.95

In Denmark and Norway, since the small-scale combustion in residential plants is a dominating source, the numbers of key sources (adding up to 95 % of the national total emissions) are smaller than in Finland and Sweden. In Finland and especially in Sweden the contributions of the different sources to the national emissions of PM_{10} and $PM_{2.5}$ are more even.

A few sources are of more importance in one of the Nordic countries than in the others. This is of course due to the different activities and processes occurring in the countries. For example in Denmark agriculture is one of the largest key sources, while agriculture is relatively less important in the other countries, although still a key source. The pulp and paper industry is a key source in both Finland and Sweden due to the industrial structure and large activity of this industry in the two countries. Metal production is the second largest source in Norway and a minor source in Finland and Sweden and of no significance in Denmark.

2.4 Comparison of reported size fractions of particulate matter emissions

The national total emissions of particulate matter emissions from the Nordic countries have been described above, as total emissions of PM_{10} and $PM_{2.5}$, as well as an analysis of the key sources in the respective countries. A further comparison to make is that of the particulate emissions distribution on size fractions (Table 2.8). The Nordic average fraction of $PM_{2.5}$ of PM_{10} is 76 %. The $PM_{2.5}$ fraction is higher in Norway and lower in Finland. Differences in the national estimates may be a result of real differences in the types of sources, in the application of abatement techniques and consequently of the size fractions emitted, but may also, due to insufficient knowledge, be a result of different assumptions on fraction factors used for estimates in the inventories.

Table 2.8 Size fractions of $PM_{2.5}$ of PM_{10} from the Nordic countries national total reported emissions.

	Nordic	DK	FI	NO	SE
Fraction $PM_{2.5}$ of PM_{10}	0.76	0.73	0.66	0.88	0.76

In Table 2.9 and Figure 2.10 a comparison of the $PM_{2.5}$ fraction of PM_{10} in the reported emissions from combustion in residential plants and from exhaust- and non-exhaust emissions from road traffic are presented.

Table 2.9 Fractions of $PM_{2.5}$ of PM_{10} for residential plants and road transport.

	DK	FI	NO	SE
1A4b i Residential plants	0.95	0.96	1.00	1.00
1A3b Road transport, exhaust	1.00	0.88	0.96	0.95
1A3b vi+vii Road transport, non-exhaust	0.54	0.20	0.30	0.54

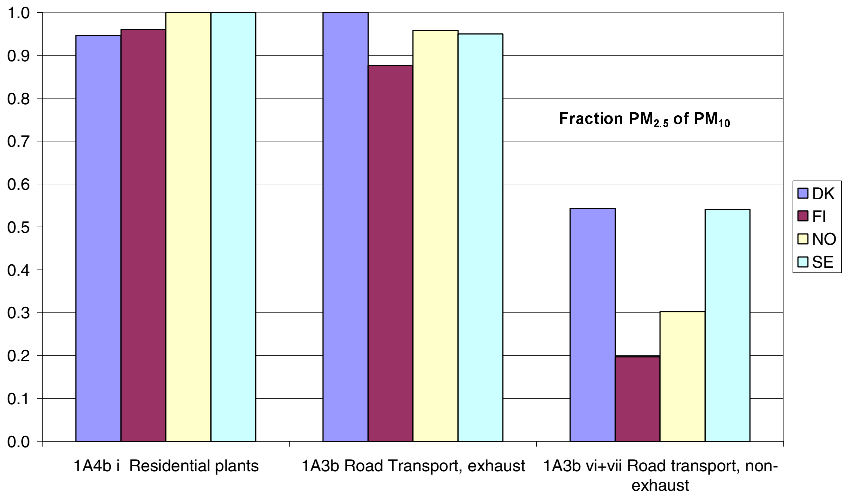

Figure 2.10 Fractions of $PM_{2.5}$ of PM_{10} for residential plants and road transport.

For combustion in residential plants, including all fuels, the fraction of $PM_{2.5}$ in emitted PM_{10} is rather comparable between the countries. The emitted PM_{10} is to at least 95 % expected to consist of particles of the size of $PM_{2.5}$ or smaller according to the reported emissions from the countries. Norway and Sweden report 100 %, meaning all PM_{10} is actually $PM_{2.5}$. For the exhaust emissions from road transport, including all fuels and vehicle types, the shares of $PM_{2.5}$ in PM_{10} are also high and are estimated to at least 88 % - but up to 100 %. In the non-exhaust emissions from road transport, including tyre and brake wear and road abrasion, the share of $PM_{2.5}$ is lower from all countries and varying more, ranging from 20 % to 54 %. The differences in assumptions on size fractions from these sources are further discussed in Chapters 3.1 and 3.2.

2.5 Assessment of completeness

An assessment of completeness in the reporting of national PM emissions for the year 2005 was made based on the submission to UNECE in 2007. Completeness can be understood in the sense that all sources expected to emit particulate matter are covered and estimated. The NFR reporting tables consist of provisions for reporting emissions for 80 individual sources. Not all of these sources exist in the Nordic countries, and some are not expected to emit any particulate matter. Some of the reporting codes in the reporting table are not well specified and may comprise several individual "sub-sources" in a country. Examples are the reporting codes called "other", where reported emissions may not be comparable between countries, and countries may cover somewhat different sources.

An overview of completeness in the NFR reporting tables is given in Table 2.10. The total number of individual sources in the reporting table is 80. Of these, 15-20 % - depending on country - does not occur as a source of emissions of particles. If existing sources not expected to emit any particulate matter (reported as NA, not applicable) are included, 36-40 % of the sources in the reporting tables are not expected to contain any values on particulate matter emissions. In the reporting system it is also allowed to account for emissions, which may not be possible to allocate according to the reporting codes by inserting the notation key IE (included elsewhere), which means that emissions from that source are accounted for, reported and included in another reporting code. From Table 2.10 it can thus be concluded that more than 50 % of the sources are accounted for (a value or IE) and for approximately 35-40 % of the sources a value on PM emissions is not expected (NO, NA), leaving in the order of 10 % of the sources with an incomplete reporting. Sources where emissions could be expected but for different reasons have not been estimated, should be reported by the notation key not estimated (NE).

From Table 2.10 it is obvious that the practice of applying notation keys differs between the Nordic countries. Finland does not have any sources reported as NE, while Norway does not use NO, but reports many sources as NE. In Finland a study was conducted a few years ago to assess sources of particle emissions under the research programme "Integrated assessment modelling of particulate matter in Finland". In the Finnish inventory it is thus assumed that all sources of significance are covered at present. In Norway on the other hand, there is a relatively large number of NEs despite an also large number of reported individual values. The allocation of notation keys has not yet been thoroughly assessed for particles in Norway and there are probably a number of sources presently reported by NE that are not relevant as sources of particle emissions.

Table 2.10 Completeness in the reporting tables from the Nordic countries, emission year 2005 in submission 2007.

	DK PM_{10}	DK $PM_{2.5}$	FI PM_{10}	FI $PM_{2.5}$	NO PM_{10}	NO $PM_{2.5}$	SE PM_{10}	SE $PM_{2.5}$
Total number	80	80	80	80	80	80	80	80
Individual values	33	33	48	48	44	43	41	41
Number of IE	8	8	2	2	0	0	1	1
Number of NE	10	10	0	0	25	25	6	6
Number of NA	12	12	18	18	11	12	19	19
Number of NO	17	17	12	12	0	0	13	13
% Individual values	41	41	60	60	55	54	51	51
% IE	10	10	3	3	0	0	1	1
% NE	13	13	0	0	31	31	8	8
% NA	15	15	23	23	14	15	24	24
% NO	21	21	15	15	0	0	16	16

IE=Included Elsewhere, Emissions are estimated and included in another reporting code.

NE=Not Estimated, Emissions could occur but have not been estimated.

NA=Not Applicable, Emissions of PM from this source are not expected.

NO=Not Occurring, the source does not occur.

The sources in the Nordic inventories where no values on particulate matter emissions are estimated in any of the countries and which are only reported by notation keys, are listed with the respective notation key chosen in Table 2.11. The "not estimated" (NE) is highlighted in the table since an NE implies that an emission value could be expected. This is, however, most probably not the case for Norway at present, as discussed above.

Table 2.11 Sources reported by only notation keys in all Nordic countries.

	Denmark	Finland	Norway	Sweden
1 A 3 b v R.T., Gasoline evaporation	NA	NA	NA	NA
1 B 1 b Solid fuel transformation	NO	NA	NE	NA
1 B 2 a i Exploration Production, Transport	NA	NA	NA	NO
1 B 2 a v Distribution of oil products	NA	NA	NA	NA
1 B 2 b Natural gas	NA	NA	NA	NO
2 B 1 Ammonia Production	NO	NO	NA	NO
2 B 3 Adipic Acid Production	NO	NA	NA	NO
2 G Other	NO	NO	NE	NO
4 B 2 Buffalo	NO	NO	NE	NO
4 B 3 Sheep	NE	NA	NE	NA
4 B 4 Goats	NE	NA	NE	NA
4 B 5 Camels and Llamas	NO	NO	NE	NO
4 B 7 Mules and Asses	NO	NO	NE	NO
4 C Rice cultivation	NO	NO	NA	NO
5 B Forest and grassland conversion	NO	NA	NE	NA
6 B Waste-water handling	NA	NA	NE	NA
7 Other	NA	NO	NE	NO

To further assess the completeness and identify possible missing sources, a comparison was made of the sources in the reporting tables where some countries have reported values, while others have reported by notation keys. In Table 2.12 the sources with differences in reporting between the Nordic countries are listed. The main question is if the reporting reflects real differences in occurrence of particulate matter sources in the countries or if there are sources missing.

Table 2.12 Sources with data (Gg) or notation keys, differences in countries, possible missing sources?*.

	DK-2005 PM_{10}	DK-2005 $PM_{2.5}$	FI-2005 PM_{10}	FI-2005 $PM_{2.5}$	NO-2005 PM_{10}	NO-2005 $PM_{2.5}$	SE-2005 PM_{10}	SE-2005 $PM_{2.5}$
1 A 1 c Manuf. of Solid Fuels and Other Energy Industries	0.00	0.00	NA	NA	0.54	0.53	0.00	0.00
1 A 3 e i Pipeline compressors	IE	IE	NA	NA	0.00	0.00	NE	NE
1 A 3 e ii Other mobile sources and machinery	NO	NO	0.78	0.72	1.41	1.34	0.41	0.39
1 A 5 a Other, Stationary (incl. Military)	NO	NO	0.03	0.02	0.00	0.00	NO	NO
1 B 1 a Coal Mining and Handling	0.36	0.04	3.60	2.63	NE	NE	NO	NO
1 B 2 a iv Refining/Storage	NA	NA	NA	NA	0.10	0.10	0.04	0.04
1 B 2 a vi Other	NO	NO	NO	NO	NE	NE	0.00	0.00
1 B 2 c Venting and flaring	0.00	0.00	NA	NA	0.09	0.06	0.05	0.05
2 A 3 Limestone and Dolom. Use	IE	IE	NA	NA	NA	NA	IE	IE
2 A 4 Soda Ash Prod. and use	IE	IE	NA	NA	NE	NE	NA	NA
2 A 5 Asphalt Roofing	NE	NE	0.00	0.00	NE	NE	0.00	0.00
2 A 6 Road Paving w. Asphalt	NE	NE	0.07	0.07	NE	NE	NE	NE
2 B 2 Nitric Acid Production	0.00	0.00	NA	NA	0.42	0.31	NA	NA
2 B 4 Carbide Production	NO	NO	NO	NO	0.33	0.33	0.27	0.24
2 B 5 Other	NE	NE	0.04	0.02	0.01	0.01	NE	NE
2 C Metal production	NE	NE	1.44	0.99	6.21	4.77	1.41	1.12
2 D 1 Pulp and Paper	NE	NE	1.67	1.40	0.27	0.20	4.77	3.77
2 D 2 Food and Drink	NE	NE	0.26	0.18	NA	NA	NA	NA
3 A Paint application	NA	NA	0.00	0.00	NA	NA	NA	NA
3 B Degr. and dry-cleaning	NA	NA	0.01	0.00	NA	NA	NA	NA
3 C Chemical Products, Manufacture and processing	NA	NA	0.08	0.05	0.00	NA	NA	NA
3 D Other, including products	NA	NA	1.39	1.34	NE	NE	0.64	0.64
4 B 1 a Dairy	0.30	0.19	0.10	0.06	NE	NE	NA	NA
4 B 1 b Non-Dairy	0.16	0.10	0.11	0.07	NE	NE	NA	NA
4 B 6 Horses	0.01	0.01	0.01	0.01	NE	NE	NA	NA
4 B 8 Swine	3.73	0.61	0.33	0.05	NE	NE	NA	NA
4 B 9 Poultry	5.31	0.76	2.01	0.26	NE	NE	NA	NA
4 B 13 Other	NE	NE	0.05	0.01	NE	NE	NA	NA
4 D 1 Direct Soil Emission	NE	NE	0.48	0.10	NE	NE	NE	NE
4 F Field burn. agric. wastes	NO	NO	NO	NO	1.09	1.09	NO	NO
4 G Other	NO	NO	NO	NO	0.00	0.00	3.04	0.66
6 A Solid waste disp. on land	NA	NA	IE	IE	NE	NE	NE	NE
6 C Waste incineration	NO	NO	0.02	0.01	0.00	0.00	NE	NE
6 D Other waste	0.00	0.00	NA	NA	0.31	0.31	0.21	0.21

* A value shown in the table as 0.00 is an actual value but less than 0.005 Gg.

From Table 2.12 it can be concluded that:

- Several of the sources are small in the countries where values are reported.
- Several reported emissions are process specific and the processes may or may not occur in a country or be of very different importance and magnitude, e.g. metal production and pulp and paper production.
- Depending on how specific sources are defined and handled in a country's inventory there may be differences in a chosen allocation in the reporting system, which may explain if values are reported or not in a specific code, e.g. for Other mobile sources 1A3 e ii, where Denmark reports NO, not occurring while the other countries enter values. There are several places in the reporting system to report various

types of mobile sources and there is no reason to suspect that emissions from any mobile sources are missing in the Danish inventory.

- Finland reports quite substantial particle emissions in the code Coal mining and handling, 1B1a, where Denmark also reports emissions. In Norway it is reported as NE and in Sweden as NA. In Finland the production and handling of peat is the major contributor to the reported emissions in this sector. In Denmark the reported emissions cover storage and handling of coal in connection with coal fired power plants. In Sweden estimated particle emissions from handling of solid fuels is instead reported under 1B1c, Fugitive emissions from solid fuels, other.
- Particle emissions from limestone and dolomite use, 2A3, are reported as included elsewhere, IE, in Denmark and Sweden. The emissions are taken into account in the processes and industries where limestone and dolomite are used. In Finland and Norway particle emissions are reported as NA, but it has been concluded that data on emissions are taken from the facilities reporting directly, and presumably also include particle emissions from limestone and dolomite use in addition to other process emissions.
- Particle emissions from nitric acid production, 2B2, are only reported from Norway and Denmark. Data reported in 2B2 may also include emissions from the production of fertilizers. In Sweden the environmental reports relating to nitric acid production do not include any information on particle emissions and this may be a missing source, the same may be the case for Finland.
- Finland reports particle emissions of some significance from food and drink production, 2D2, which Norway and Sweden consider to be not applicable, and which Denmark has not estimated. In Finland the data originate from the facility reporting. This may be a missing source of particle emissions for the other countries.
- Particle emissions from product use, 3D, are reported by Finland and Sweden. In Finland accidental fires from cars and houses as well as from fireworks, and recently also from tobacco smoking, are taken into account. In Sweden particle emissions from tobacco smoking and from the use of fireworks are included. Denmark reports the category as NA, which is incorrect and is a missing source in the inventory albeit a very minor source. Norway reports this category as NE.
- For agriculture (codes starting with 4), all emissions from animal husbandry and from handling of crops in Sweden are reported in 4G, while corresponding emissions in Denmark and Finland are allocated to several different source codes starting with 4. In Norway these emissions, which are uncertain but could be of significance, are not estimated.
- Norway reports emissions from car and house fires and combustion of tobacco under 6D. Emissions from tobacco will reported under 3D in the 2011 submission.
- From some existing processes emissions of particles are not reported from all the countries. This may be due to incomplete annual reporting from the individual industries, or be a result of different limit values in the requirements for reporting to the authorities in the respective country.
- From the analysis above, it can be concluded that there are probably very few if any significant emission sources of particles missing from the Nordic inventories.

References

IPCC, 2000: Good Practice Guidance and Uncertainty Management in the National Greenhouse Gas Inventories.

Swedish official submission of CLRTAP Air Emission Inventory. Available at: http://www.naturvardsverket.se/sv/Tillstandet-i-miljon/Utslappsdata/Luftfororeningar/Gransoverskridande-fororeningar/

Data from official National Submissions of Emission Inventories to CLRTAP. Available at: http://webdab.emep.int/

3 Comparison of the emission inventories

3.1 Residential use of wood

3.1.1 Introduction

A preliminary study of the Nordic air pollutant inventories showed that the residential sector is a significant source of PM (se Chapter 2, Figure 2.1). A detailed analysis is therefore performed for residential combustion and the information of inventory preparation for the emission sources are collected and compared between the countries.

The emission estimation methods in the countries are compared. In all countries the emissions were calculated from fuel consumption data and national or default emission factors from international guidebooks and databases. Descriptions of the national inventory methodologies and references to emission factors and other data used in the emission inventory work are given in the national Informative Inventory Reports submitted to the CLRTAP Secretariat in 2007.

To enable understanding of the national emission patterns and sources, information of the national fuel consumptions, emission factors and the different appliances for combustion in the residential sector is presented below. A comparison to the EMEP/Corinair Emission Inventory Guidebook methodology is also presented. Emission factors for combustion of wood are analysed more thoroughly as consumption of this fuel is dominating the PM emission from residential combustion in the Nordic countries.

3.1.2 Residential combustion

Fuel consumption

Fuel consumption data for the fuels used in the Residential sector are shown in Figure 3.1 for four of the Nordic countries. The fuel consumption shown in the figure only represents the fuel combusted in local small scale combustion units and not fuels used for district heating or electricity production. Thus, the figures do not express the total energy use in the Nordic households but only what have been combusted locally. For instance, Denmark has a large number of local natural gas combustion units, which explain the large amount of natural gas used in this country compared to the other countries. In Iceland the main part of the residential heat and electricity is supplied by geothermal and hydro power plants and only about 2 % by fuel combustion in local units. As a result almost no emissions come from the residential sector occur and the focus is therefore on Denmark, Finland, Norway and Sweden.

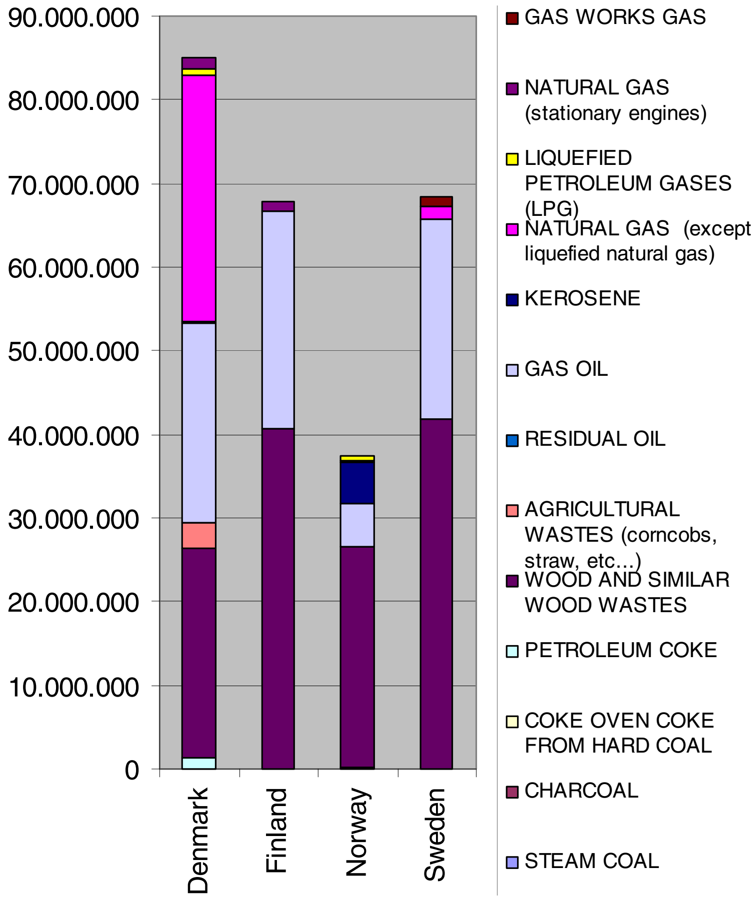

Figure 3.1 Fuel consumption data (GJ) 2005 in the residential sector in the Nordic countries. Some fuels are only used to a very little extent, e.g. steam coal; therefore it is not directly visible in the figure.

PM Emissions

The emission factors for PM applied by the Nordic countries for the most important fuels are compared to the emission factors suggested in the EMEP/EEA Guidebook (2006).

The emission factors for PM for combustion of wood are significantly higher than emission factors for the other fuels. The emission factors used by the Nordic countries are based on international guidelines or measurements carried out in other countries as well as the Nordic countries.

Emissions from small scale wood combustion are affected mostly by the composition and moisture content of the fuel as well as the combustion manners and burning conditions and maintenance of the equipment. In addition, also the boiler technique affects the emissions. All the Nordic emission factors for combustion of gas oil, natural gas, kerosene and LPG are well in line with the default factors, though in most cases in the lower end of the range.

Nordic emission factors for PM are presented in Table 3.1. The Nordic PM emission factors are significantly higher for wood fuels than for the other fuels. The Swedish emission factor (150 g per GJ) for combustion of wood is low compared to the other Nordic countries and the Norwegian emission factor (1342 g per GJ) is very high compared to the other Nordic countries. Swedish measurements showed that the previous national emission factor was too high and therefore the emission factor was revised downwards in 2005.

Table 3.1 $PM_{2.5}$ emission factors for residential combustion in the Nordic countries.

Fuel name	Emission factors, g pr GJ					
	Denmark[1]	Finland[2]	Sweden	Norway[2]	Iceland	EMEP/Corinair[3]
Coal, charcoal	7	25	25	30	NE	397.5
Petroleum coke	30	-	25		NE	3.7
Wood and similar wood waste	670	262	150	1342	NE	695
Straw	211	-	-	-	NE	695
Residual oil	7	0.2	12.5	-	NE	3.7
Gas oil	7	48	3	3	NE	3.7
Kerosene	5	-	2	3	NE	3.7
Natural gas, work gas	0	-	0.5	-	NE	0.5
Liquefied petroleum gases (LPG)	0	-	0.2	3	NE	0.5

[1] From the Danish IIR, 2007 (Illerup et al, 2007a).

[2]Finnish IIR (Finnish Environment Institute http://www.ymparisto.fi/default.asp?node=13256&lan=en

[3]From the Norwegian emission inventory 2007 Documentation of methodologies for estimating emissions of greenhouse gases and long-range transboundary air pollutants (Document 2007/38).

[4] EMEP/Corinair (2006).

3.1.3 Activity data for wood use

The detailed methodology requires allocation of the fuel consumed according to the installation types. As these data are not available in the regular Nordic statistics reports, the categorisation developed in the Nordic project 'Particulate matter emissions and abatement options in residential wood burning in the Nordic countries (Sternhufvud et al., 2004) are applied in the emission inventories. Table 3.2 shows the categories suggested in the project and the estimated fuel consumption data for year 2005.

Table 3.2 Annual energy consumption Fuel use (TJ per year) in the residential sector in different appliances in the Nordic countries for year 2005.

	Denmark	Finland	Norway	Sweden
Stoves				
Old iron stoves, wood logs	10140	1131	16267	8888
Modern iron stoves, wood logs	2086	incl. old	8847	
Pellet stoves			297	
Conventional masonry heaters and stoves		8328		
Kitchen range/stoves		5517		
Masonry ovens		6133		
Sauna stoves		8932		
Open fireplaces		636	1209	1551
Other stoves	297			
Boilers				
Old manually fed boilers with accumulator tank	2131	5297		23010
Old manually fed boilers without accumulator tank	1408	2609		
Modern manually fed boilers with accumulator tank	2138	incl. old		
Modern manually fed boilers without accumulator tank	1427	incl. old		
Pellet boilers	6690	99		6465
Automatically fed boilers other than pellet		1937		1892
Other boilers				
Total sum	26317	40619	26620	41060

In Denmark no official statistics data for use of stoves and boilers are available - only the total wood use, which are reported by the Danish Energy Agency. The figures describing the population of stoves, boilers etc. are based on results from the Danish Technological Institute's survey on fuel consumption patterns for old and new wood-burning stoves and boilers in 2005 and the survey made by the Force Technology and the Danish Technological Institute on firewood consumption in Denmark in 2006 (Illerup et al., 2007b). For the years after 2005 the distribution on the different technologies is estimated from assumed replacement rates for old stoves and boilers, meaning that a certain fraction of old stoves and boilers are assumed to be replaced by newer less polluting technologies (Illerup et al. 2007b).

For Finland the activity data is based on 5-yearly surveys on wood use carried out by Finnish Forest Research Institute. The inventory does not include combustion technologies. However, improvement of the method to a combustion and abatement technique based inventory is underway.

In Sweden one- and two-dwelling statistics are used, together with holiday cottages statistics and multi-dwelling statistics, to calculate emissions from stationary combustion in households, NFR 1A4b. A sample survey is conducted annually to collect data on the use of electricity and heat for a total of 7,000 one- and two-dwellings. From 2000, all dwellings used as permanent dwelling are included in the sample. Every third year, a postal survey collects data from agricultural properties. The sample in this sector is 3,000 objects. Holiday cottages are defined as residences with no permanent residents. Energy consumption in holiday cottages has been surveyed only two times in the last thirty years, 1976 and 2001. In 2002, Statistics Sweden carried out a stratified sample survey to house owners, covering 1,500 of the estimated 750,000 holiday cottages in Sweden 2001. Results show that electricity and biomass combustion are the two main sources of heating in holiday cottages. Activity data in the inventory is taken from yearly reports prepared by Statistics Sweden (Statistics Sweden EN20SM, 1990-2007) based on these surveys. Data is on national level by fuel type.

In Norway, for the years after 2005, the figures of wood use in households are based on responses to questions relating to wood-burning in Statistics Norway's Travel and Holiday Survey. Almost 6,000 people have been interviewed by telephone every year since 2005. The figures in the survey refer to quantities of wood burnt in stoves of different age and technology. The survey quarterly gathers data that cover the preceding twelve months. The figure used in the emission calculations is the average of five quarterly surveys. Before 2005 the use of wood in households is based on figures on the amount of wood burned from the annual survey on consumer expenditure. Information on wood consumption, technology and age of stoves in holiday homes is also included in the new survey.

3.1.4 Comparison with methodological guidance in the EMEP/Corinair Emission Inventory Guidebook

The EMEP/Corinair Emission Inventory Guidebook recommends using the "simpler" method only as worst case emission factors, and recommends using a more detailed estimation methodology with preferably national emission factors when available.

The default emissions factors given in Table 3.3 refer to the simpler methodology described in the Guidebook. The simpler methodology does not take into account differences in the emission factors due to variety of technologies used in the residential sector and it is therefore recommended only to apply this methodology if the contribution of the source in the national totals is small or no data are available for application of a more detailed methodology.

The Nordic emissions factors for PM for combustion of wood are dependent on the combustion conditions including the type of installation applied.

The Guidebook default emission factors for the simple and the detailed methodologies for residential wood combustion are presented in Table 3.3. For PM the emission factors are lower for advanced technologies than for conventional. Especially automatically feeded boilers and stoves have low emission factors.

Table 3.3 Default emission factors for the simple and detailed methodologies for residential wood burning (EMEP/Corinair Emission Inventory Guidebook, 2006).

Installation		TSP (g pr GJ)	PM_{10} (g pr GJ)	$PM_{2.5}$ (g pr GJ)
Simple methodology		730	695.3	694.8
Detailed methodology				
Conventional	Fireplaces	900	860	850
	Stoves	850	810	810
	Boilers	500	475	475
Advanced				
	Stoves	250	240	240
	Pellet stoves	80	76	76
	Manual boilers	80	76	76
	Automatic boilers	70	66	66

3.1.5 Emission factors

For all the Nordic countries combustion of wood in the domestic sector is an important source of PM emissions (Figure 2.4 and 2.5). Emission factors used in inventories and emission models in the Nordic countries are based on guidelines, published literature or measurements (either national or international). European default emission factors may not always be appropriate for the Nordic conditions.

Current emission inventories on PM are quite uncertain, due to the large uncertainties in both activity and emission factor data, and are sometimes missing completely. Another reason for the uncertain emission inventories is the difficulties of estimating standard emission factors from measurements since the emissions from stoves and domestic boilers very much depend on the combustion conditions and technologies. It would be reasonable to assume that the emission factors would be more or less equal in the Nordic countries for the same technologies. Thus, it is important to compare the emission factors used, in order to be able to make a harmonisation. Such a harmonisation would be useful in e.g. comparative studies of total emissions or regulations measures. Please see Chapter 4 for a discussion of the variability in emission factors caused by operating condition, sampling methodology and other variables.

Table 3.4 shows the $PM_{2.5}$ emission factors for wood stoves and boilers used in the official emission inventory reports for the year 2005 for Denmark, Finland, Norway and Sweden.

The particle size distribution for residential plants as reported by the countries in 2007, is shown in Table 3.5.

Table 3.5 Particle size distribution for residential plants.

	TSP	PM_{10}	$PM_{2.5}$
Denmark	100 %	94.8 %	89.6 %
Finland	100 %	95.8 %	92.0%
Norway	100 %	99.9 %	99.9 %
Sweden	100 %	100 %	100 %

While Sweden and Norway calculates all or almost all total suspended particulate matter (TSP) emissions as $PM_{2.5}$, both Finland and Denmark assumes a particle size distribution of similar proportions. German measurements found a $TSP/PM_{10}/PM_{2.5}$ ration of 100/96.6/89.7 (Struschka et al., 2003), which is reasonably close to the particle size fractions used by Denmark and Finland.

Table 3.4 $PM_{2.5}$ emission factors for wood stoves and boilers used in official inventory reports for the year 2005 (g pr GJ).

	Emission factors (g pr GJ)			
	Denmark	Finland	Norway	Sweden
Stoves				
Old iron stoves, wood logs	990	700	1.945	100
Modern iron stoves, wood logs	576	700	303	
Pellet stoves			31	30
Conventional masonry heaters and stoves		140		
Kitchen range/stoves		140		
Masonry ovens		140		
Sauna stoves		140		
Open fireplaces		800	844	150
Other stoves	990	140		100
Boilers				
Old manually fed boilers with accumulator tank	900	80		150
Old manually fed boilers without accumulator tank	1800	700		
Modern manually fed boilers with accumulator tank	135	80		
Modern manually fed boilers without accumulator tank	270	700		
Pellet boilers	32	30		30
Automatically fed boilers other than pellet		50		100
Other boilers		140		

From Table 3.2 it is seen that very different technologies are applied in the Nordic countries. Since the emission factors are very technology dependent (Table 3.4) it is important to have reliable figures for the population of wood burning appliances.

3.1.6 References for the Nordic emission factors

Denmark

The Danish emission factors are based on emission factors calculated by the Danish National Environmental Research Institute, Aarhus University, and emissions measurements by the Danish Technological Institute of CO and NMVOC from wood-burning boilers.

The $PM_{2.5}$ emission factor for old stoves is based on Norwegian measurements on various types of stoves and assumptions on typical wood loads (Illerup & Nielsen, 2004). The emission factor for modern stoves is assumed to equal the emission limit given for the Swan certified stoves. This is about the same value as Norwegian stove producers have stated for new Norwegian stoves. Field emission measurements on wood stoves in a Danish residential area supported the level of the estimated emission factors (Glasius et al., 2006, 2007).

The PM emission factors for old boilers are based on CO emission measurements since no PM emissions measurements have been carried out. The measurements showed that the CO emission is 5-10 times higher for old boilers than for new boilers (Illerup et al., 2007b).

The official emission factors are updated annually, resulting in a decrease in the official aggregated emission factor from 672 g per GJ in 2005 to 533 g per GJ in 2008.

Finland

PM emissions from some types of small boilers and stoves have been measured in the early 1980s by Hahkala et al. (1986). The emissions were highly variable and there were technical measuring problems, especially with condensable PM. The TSP emission factors were estimated to be in the range of 100 mg per MJ to 1 300 mg per MJ. In the emission inventory for 2000, an emission factor for TSP of 400 mg per MJ is used and estimated on the basis of a literature survey. Of this 96% is estimated to be $PM_{2.5}$.

A new 3-year project "Fine particle emissions from wood combustion", was initiated in 2002 in the technological programme "FINE Particles - Technology, Environment and Health 2002-2005" funded by Tekes (the National Technology Agency in Finland). Several types of small combustion devices were measured in the project. See Chapter 4 for a presentation of measurement results from Finnish studies.

A new technology based calculation system for air pollutant emissions from small-scale combustion is underway.

Norway

Norwegian measurements have shown that emissions of particles strongly depend on the wood load (kg wood per hour) (Haakonsen & Kvingedal, 2001). The study shows that the PM emission increases dramatically when the consumption rate of wood decreases. It also shows that the emissions are significantly lower for stoves tested in laboratory and for catalytic stoves. Studies show that a typical load is 1.0 to 1.25 kg wood per hour resulting in a TSP emissions of 40 kg per tonnes dry wood for conventional stoves (older than 1998) or 1 952 g per GJ assuming a heating value of 16,8 GJ per tonnes of wood (18 per cent water content). For Oslo 33 kg per tonnes is used due to less burning of wood during the night. Haakonsen & Kvingedal (2001) recommend using an emission factor for new stoves of 303 g per GJ (or 6,2 kg per tonnes dry wood), and using an emission factor for open fireplaces of 844 g per GJ (or 17,3 kg per tonnes dry wood). Since the emission factor strongly depends on the wood consumption, Haakonsen & Kvingedal (2001) recommend that further studies should be carried out in order to determine the typical wood consumption rate for residential stoves. It is stressed that the emissions factor is quite uncertain. The average PM_{10} emission factor for wood burnt in households in 2005 is 1 342 g per GJ based on information on the amount of wood burnt in stoves of different ages and technologies.

Sweden

The emission factors for official reporting shown in Table 3.2 are those that are used to calculate emissions to the UNECE/EMEP reporting. These factors are based on results from measurements (e.g. Johansson et al., 2003b) in combination with expert judgement on the frequency of older and newer equipment, different kinds of stoves etc. They were chosen to represent a “national average” since the energy statistics used for the international reporting, at present, do not distinguish between different kinds of wooden fuels or technologies. For the future it would be an improvement if more refined and detailed energy statistics could be used. Presently more information is available at Statistics Sweden than is used as activity data for the official reporting, but it has so far not been evaluated and used for these purposes.

The comparison of the aggregated $PM_{2.5}$ emission factors for wood combustion used in the official reports in the Nordic countries shows a range from 150 to 1877 g per GJ (Figure 3.1) indicating a large variability of an order of magnitude. The differences in the emission factors are due to differences in the used technologies but also to differences in the technology dependent emission factors – very different emission factor levels are seen for the same technology.

The aggregated emission factors for Denmark and Finland are 670 g per GJ and 262 g per GJ, respectively. However, this is mostly due to use of different technologies in the two countries; the technology dependent emissions factors are almost on the same level.

The Swedish emission factors are significantly lower than the emission factors used in the other Nordic countries. For old iron stoves the Swedish emission factor is about twenty times lower than the Norwegian emission factor. The Swedish emission factors are based on Swedish in-field measurements, and the reason for the low values may be due to the used measuring technique. In Chapters 4 and 5 a review of the Nordic measurements and the current status of the Nordic PM emission measurements are given.

3.2 Road transport

3.2.1 Introduction

The emission sources included in the road transport sector are presented in Table 3.6. The sector is divided into seven sub-sources from which emissions should be considered.

Table 3.6 Emission sources to be reported under NRF category 1A3B Road Transport.

NFR 1A3b	ROAD TRANSPORT
1A3bi	Passenger cars
1A3bii	Light duty vehicles
1A3biii	Heavy duty vehicles
1A3biv	Mopeds & Motorcycles
1A2bv	Gasoline evaporation
1A3bvi	Automobile tyre and brake wear
1A3bvii	Automobile road abrasion

The vehicle categories for reporting are split, because road vehicle power trains make use of a range of fuels, engine technologies and after treatment devices. On the one hand, this vehicle split attempts to introduce the level of detail necessary for vehicle technology distinction and on the other hand to preserve the spatial resolution for the three major driving classes (urban, rural and highway). The total emissions from road transport include emissions from the thermally stabilised engine operation (hot), the warming-up phase (cold start) and emissions due to evaporation. The calculation models in the countries can make corrections for instance for road gradient and vehicle load and take into account country specific variables. Also emissions from automobile tyre and brake wear and road abrasion are included as sources to be reported

Detailed information of the national calculation models for road transport is available from the following sources:

- Denmark: Annual Danish Emission Inventory Report to UNECE: Inventories from the base year of the protocols to year 2005 (Illerup et al. 2007).
- Finland: LIPASTO calculation model www.lipasto.vtt.fi
- Iceland: No emission estimates for particulates are reported.
- Norway: Aasestad et al 2007 The Norwegian Emission Inventory. Reports 2007/38
- Sweden: EMV calculation model (Hammarström & Karlsson, 1998).

PM_{10} emissions

Both non-exhaust emissions (tyre and brake wear and road abrasion) and exhaust emissions from combustion of fuel contribute significantly to PM emissions. Emission of PM_{10} from road transport contributed to approximately 25 % of the total PM_{10} emissions in Sweden, 23 % in Finland, 13 % in Denmark and only 6 % in Norway. The low percentage for Norway is due to the large PM_{10} emissions from combustion in the residential sector. Exhaust emissions are at quite the same level in all the countries, while non-exhaust emissions vary. The non-exhaust emissions contribute with more than 70 % of the PM_{10} emissions from road transport in Finland and Sweden. Almost 50 % of the PM_{10} emissions in Norway originate from non-exhaust, while the share is almost 35 % in Denmark. The reported PM_{10} emissions from road transport for 2005 are presented in Figure 3.2 and 3.3.

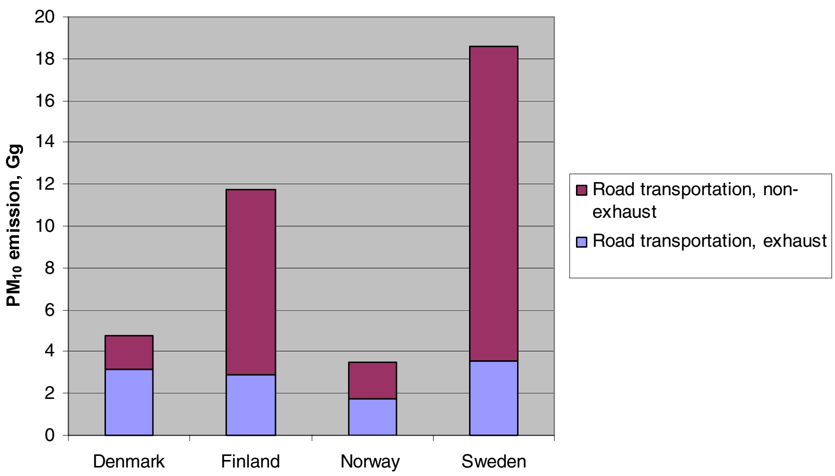

Figure 3.2 Nordic PM_{10} emissions from road transport 2005.

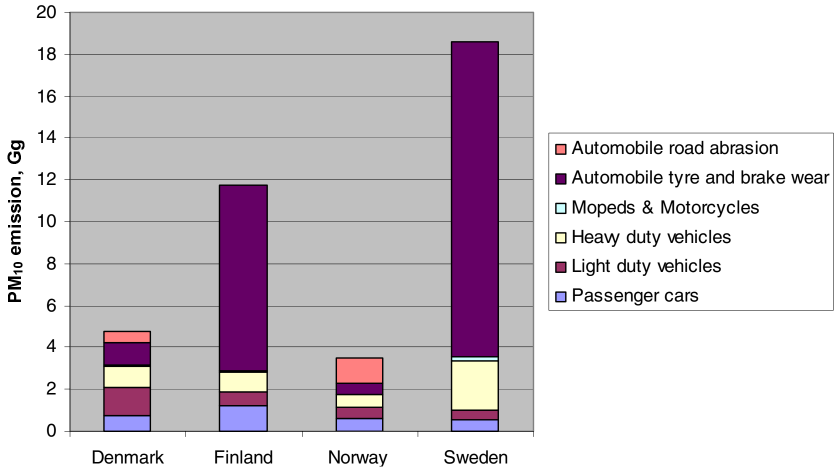

Figure 3.3 Nordic PM_{10} emissions from road transport 2005 (For Finland and Sweden automobile tyre and brake wear and road abrasion are not separated but reported as a sum).

Table 3.7 Nordic PM_{10} emissions from road transport by sub-sectors. 2005. Gg.

	Denmark	Finland	Norway	Sweden
Total	4,8	11,7	3,5	18,6
Passenger cars	0,7	1,2	0,6	0,5
Light duty vehicles	1,3	0,7	0,6	0,4
Heavy duty vehicles	1,0	0,9	0,6	2,4
Mopeds & Motorcycles	0,1	0,0	0,0	0,1
Automobile tyre and brake wear	1,1	8,9	0,5	15,1
Automobile road abrasion	0,5	IE	1,2	IE

$PM_{2.5}$ emissions

Both non-exhaust emissions (tyre and brake wear and road abrasion) and exhaust emissions from combustion of fuel also contribute to a large source of $PM_{2.5}$ emissions. Emission of $PM_{2.5}$ from road transport contributed to approximately 22 % of the total $PM_{2.5}$ emissions in Sweden, 13 % in Finland, 14 % in Denmark and only 4 % in Norway. The low percentage for Norway is as for PM_{10} due to the large $PM_{2.5}$ emissions from combustion in residential sectors. The non-exhaust emissions contribute to almost 60 % of the $PM_{2.5}$ emissions from road transport in Sweden. In Finland 41 % of the $PM_{2.5}$ emissions from road transport origin from non-exhaust and in Norway and Denmark around 22 % originates from non-exhaust. The reported $PM_{2.5}$ emissions from road transport for 2005 are presented in Figure 3.4 and 3.5.

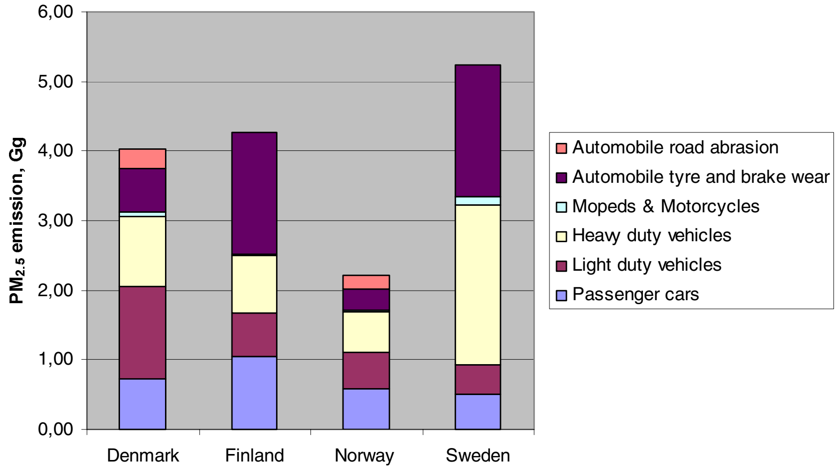

Figure 3.4 Nordic $PM_{2.5}$ emissions from road transport 2005. Gg.

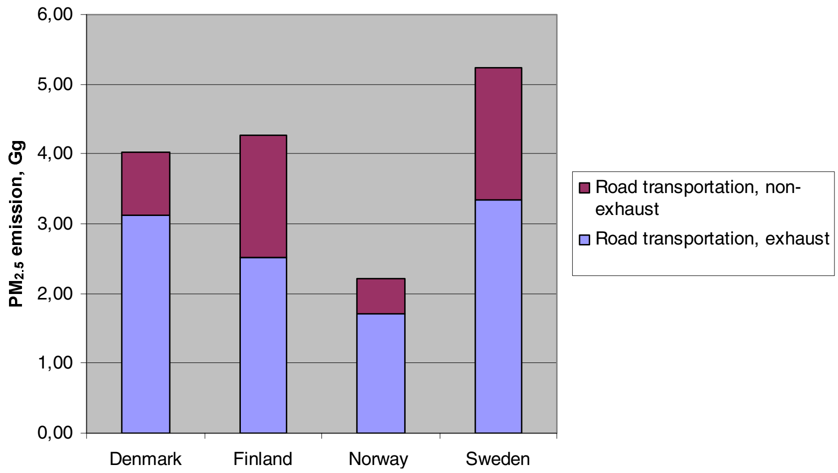

Figure 3.5 Nordic $PM_{2.5}$ emissions from road transport 2005.Gg (For Finland and Sweden automobile tyre and brake wear and road abrasion are not separated but reported as a sum).

Table 3.8 Nordic $PM_{2.5}$ emissions from road transport by sub-sectors. 2005. Gg.

	Denmark	Finland	Norway	Sweden
Total	4.0	4.3	2.2	5.2
Passenger cars	0.7	1.1	0.6	0.5
Light duty vehicles	1.3	0.6	0.5	0.4
Heavy duty vehicles	1.0	0.8	0.6	2.3
Mopeds & Motorcycles	0.1	0.0	0.0	0.1
Automobile tyre and brake wear	0.6	1.8	0.3	1.9
Automobile road abrasion	0.3	IE	0.2	IE

Emissions factors used for estimating PM emissions from road transport in the Nordic countries, both the exhaust and the non-exhaust emissions, will be compared, described and discussed later in this chapter.

3.2.2 Fuel use and kilometres driven

Information on fuel use in the road transport sector in 2005 in the Nordic countries is provided in Figure 3.6 and Table 3.9 below and on kilometres driven in Figure 3.7 and Table 3.10. Fuel use affects particle emissions from exhaust gases and kilometres driven particle emissions from tyre and brake wear as well as from road abrasion.

According to the data, petrol fuelled passenger cars are the main category in all countries. For fuel used this means 45.2 % in Denmark, 45.3 % in Finland, 60.8 % in Iceland, 45.9 % in Norway and 61.8% in Sweden. The second largest category in all countries is diesel fuelled heavy duty vehicles, which contributes to fuel use by 27.1 % in Denmark, 29.0 % in Finland, 18 % in Iceland, 25.8 % in Norway and 22.9 % in Sweden. The third largest category by fuel use is in Denmark, Norway and Sweden diesel fuelled light duty vehicles (15.8 %, 13.4 %, and 6.6 %, respectively), while in Finland and Iceland the third category is diesel fuelled passenger cars (14.5 % and 13.1 % , respectively).

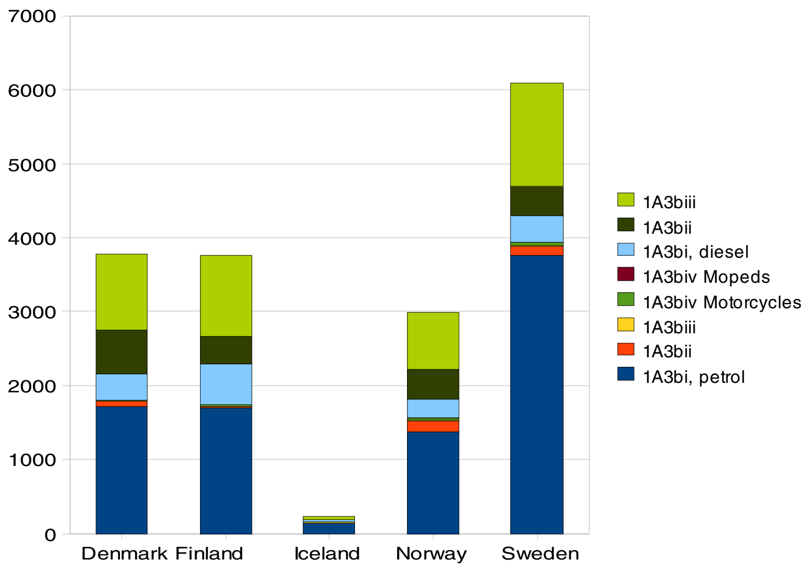

Figure 3.6 Fuel use in the road transport sector (kt) in the Nordic countries in 2005. For explanation on the NFR codes, see Table 3.9.

Table 3.9 Fuel use (kt) in the transport sector in the Nordic countries in 2005.

NFR	Traffic mode	Denmark	Finland	Iceland	Norway	Sweden
1A3bi	Passenger cars, petrol	1711	1704	143,721	1325	3766
1A3bii	Light duty vehicles, petrol	76	19	7.3	139	120
1A3biii	Heavy duty vehicles, petrol	1	0	1.7	21	10
1A3biv	Motorcycles petrol	23	26	-	25	40
1A3biv	Mopeds, petrol	-	-	-	8.7	-
1A3bi	Passenger cars, diesel	349	547	31	301	360
1A3bii	Light duty vehicles, diesel	598	374	9.9	442	405
1A3biii	Heavy duty vehicles, diesel	1025	1093	42.6	784	1395

In the road transport sector, if studied by kilometres driven in each category, the largest category in all countries is again petrol fuelled passenger cars; the shares are for Denmark 58.4 %, Finland 66.8 %, Norway 62.4 % and Sweden 75.4 %. The second largest source in Denmark is diesel fuelled light duty vehicles (16.7 %), in Finland and Sweden diesel fuelled passenger cars account for 16.0 % and 8.4 % of the mileage, respectively, while in Norway the mileage shares for diesel fuelled light duty vehicles and passenger cars are quite even, 11.4 % and 11.3 %, respectively. The third largest source by kilometres driven was diesel fuelled passenger cars in Denmark (13.1 %), diesel driven light duty vehicles in Finland (7.7 %) and in Sweden (6.1 %). For Iceland only total mileage is available.

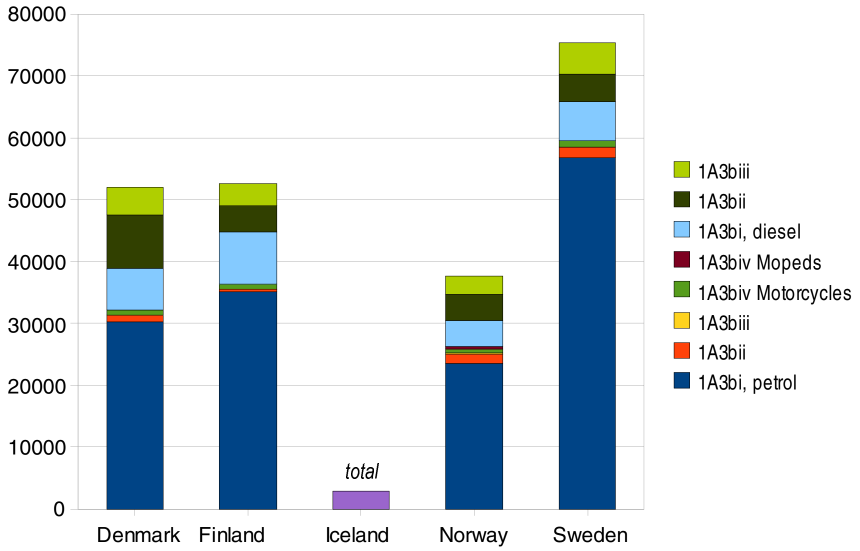

Figure 3.7 Million kilometres driven in the Nordic countries, 2005. For explanation on the NFR codes, see Table 3.10.

Table 3.10 Kilometres (in millions of kilometres) driven in the Nordic countries in 2005.

NFR	Traffic mode	Denmark	Finland	Iceland	Norway	Sweden
1A3bi	Passenger cars, petrol	30 372	35 168		23 306	56 864
1A3bii	Light duty vehicles, petrol	899	260		1419	1618
1A3biii	Heavy duty vehicles, petrol	8	0		140	34
1A3biv	Motorcycles petrol	817	989	2800	642	952
1A3biv	Mopeds, petrol	-	-		463	-
1A3bi	Passenger cars, diesel	6799	8448		5174	6326
1A3bii	Light duty vehicles, diesel	8690	4074		4607	4572
1A3biii	Heavy duty vehicles, diesel	4392	3724		2783	5029

3.2.3 Emission factors

The implied PM_{10} and $PM_{2.5}$ emission factors for exhaust gases and tyre, brake and road abrasion are presented in Tables 3.11 and 3.12. The great variation between the emission factors used in countries may be due to the fact that the emission factors take into account the car fleet, mean distances driven, use of studded tyres, road surface material as well as driving conditions, which may differ between the countries. It is therefore not possible to draw conclusions from the implied emission factors, if the calculations reflect the real situations in the countries correctly. The differences in the Nordic road transport models are presented in Chapter 3.2.5.

For the implied emission factors for exhaust gas particles there are two-fold differences for all categories but the largest variations are related to motorcycles and mopeds for which Finland and Norway have even 10 times lower emission factors than Denmark and Sweden.

The Finnish emission factors for exhaust gases are national and based on measurements. The Danish emission factors come from the European calculation emission calculation model COPERT, version IV, while the Swedish emission factors originate from the European ARTEMIS calculation model. The Norwegian emission factors are based on several sources: COPERT II (EEA, 1997), a German report (Hassel et al., 1994), Norwegian measurements (SFT, 1993), Swedish reports (AB Svensk Bilprovning, listed in SFT, 1993), The Corinair Emission Inventory Guidebook (EEA, 1996) and results from the MEET programme (Sérié & Joumard, 1996).

For tyre and brake wear the differences in the implied emission factors between the countries are smaller, mainly twofold. The Norwegian implied emission factors are lower in all other categories but for motorcycle brake wear.

For road dust, the differences in the emission factors are due to the different sources of emission information behind the emission inventories for the Nordic countries. The Finnish emission factors are expert estimates based on comparisons to information from countries with similar conditions and will be used in the recalculation of the time-series of emissions (1990 onwards). The Danish emission factors originate from the European emission calculation model COPERT. The Swedish emission factors include the re-suspension of previously worn asphalt material, and reflect the use of studded tyres in Sweden. The emission factors used for Norway are prepared to describe the specific Norwegian emission situation. The emission factors used also include emissions due to asphalt wear by studded tyres in Norway.

Table 3.11 Nordic implied PM_{10} emission factors for road transport.

NFR	Transport mode	unit	DK	FI	NO	SE
1 A 3 b i	Passenger cars, petrol	g pr tonne	96.5	45.0	151	76.7
1 A 3 b ii	Light duty vehicles, petrol	g pr tonne	131.9	78.0	115	250.6
1 A 3 b iii	Heavy duty vehicles, petrol	g pr tonne	2258.0	-	100	2699.9
1 A 3 b iv	Motorcycles & Mopeds, petrol	g pr tonne	2498.5	572.0	145 & 140	3918.5
1 A 3 b i	Passenger cars, diesel	g pr tonne	1563.4	2060.0	1315	811.2
1 A 3 b ii	Light duty vehicles, diesel	g pr tonne	2167.3	1876.0	1227	1527.0
1 A 3 b iii	Heavy duty vehicles, diesel	g pr tonne	1063.1	864.0	785	773.0
1 A 3 b iv	Mopeds & Motorcycles, diesel	g pr tonne	-	572	NO	NA
1 A 3 b vi	Tyre, Passenger car	g pr M km	7468	7700	3450	7704
1 A 3 b vi	Tyre, Van	g pr M km	12272	12200	4,5	12168
1 A 3 b vi	Tyre, Heavy vehicle	g pr M km	31961	36600	18563	36618
1 A 3 b vi	Tyre, Motorcycles	g pr M km	3470	2800	1725	2760
1 A 3 b vi	Brake (new passenger car)	g pr M km	7462	8200	6000	8236
1 A 3 b vi	Brake (old passenger car)	g pr M km	7462	8200	6000	-
1 A 3 b vi	Brake (new vans)	g pr M km	13421	12800	7500	12848
1 A 3 b vi	Brake (old vans)	g pr M km	13421	12800	7500	-
1 A 3 b vi	Brake (heavy vehicle)	g pr M km	36682	38100	32250	38142
1 A 3 b vi	Brake (motorcycle)	g pr M km	4668	2100	3000	2148
1A3bvii	Road dust (light vehicle)	g pr M km	7416	139000	33269	92774
1A3bvii	Road dust (heavy vehicle)	g pr M km	38000	49000	33269	-

Table 3.12 Nordic implied $PM_{2.5}$ emission factors for road transport.

NFR	Transport mode	unit	DK	FI	NO	SE
1 A 3 b i	Passenger cars, petrol	g pr tonne	96,5	49,0	151	72,8
1 A 3 b ii	Light duty vehicles, petrol	g pr tonne	131,9	68,0	115	238,1
1 A 3 b iii	Heavy duty vehicles, petrol	g pr tonne	2258,0	-	100	2564,9
1 A 3 b iv	Motorcycles & Mopeds, petrol	g pr tonne	2498,5	501,0	145 &140	3722,6
1 A 3 b i	Passenger cars, diesel	g pr tonne	1563,4	1804,0	1264	770,6
1 A 3 b ii	Light duty vehicles, diesel	g pr tonne	2167,3	1644,0	1175	1450,6
1 A 3 b iii	Heavy duty vehicles, diesel	g pr tonne	1063,1	756,0	738	734,4
1 A 3 b iv	Mopeds & Motorcycles, diesel	g pr tonne	-	501	NO	NA
1 A 3 b vi	Tyre, Passenger car	g pr M km	5227	5400	0	5393
1 A 3 b vi	Tyre, Van	g pr M km	8590	8500	0	8518
1 A 3 b vi	Tyre, Heavy vehicle	g pr M km	22373	25600	0	25633
1 A 3 b vi	Tyre, Motorcycles	g pr M km	2429	1900	0	1932
1 A 3 b vi	Brake (new passenger car)	g pr M km	2970	3300	6 000	3277
1 A 3 b vi	Brake (old passenger car)	g pr M km	2970	3300	6 000	-
1 A 3 b vi	Brake (new vans)	g pr M km	5341	5100	7 500	5113
1 A 3 b vi	Brake (old vans)	g pr M km	5341	5100	7 500	-
1 A 3 b vi	Brake (heavy vehicle)	g pr M km	14598	15200	32 250	15179
1 A 3 b vi	Brake (motorcycle)	g pr M km	1858	900	3 000	855
1A3bvii	Road dust (light vehicle) *	g pr M km	4005	75000	5 544,8	50098
1A3bvii	Road dust (heavy vehicle) *	g pr M km	20520	27000	5 544,8	-

3.2.4 Short description of the Nordic road transport models

Denmark

Danish annual emissions from road traffic are calculated using an internal NERI model with a structure similar to the European COPERT III emission model. The emissions are calculated for operationally hot engines, during cold start and fuel evaporation, and a fuel balance in the model modifies the estimated fuel consumption in order to reach the figures for fuel sold in Denmark. The model incorporates the emission effect of catalyst wear. The emission components considered are SO_2, NO_x, NMVOC, CH_4, CO, CO_2, N_2O, NH_3, TSP, PM_{10}, $PM_{2.5}$, as well as HM's and POP's. For PM the non-exhaust PM contributions from tyre and brake wear as well as road abrasion are also included.

The basic trip speed dependent emission factors in g pr km, and cold start and evaporation data are taken from the latest version of the COPERT model - COPERT IV. However, the CO_2 and SO_2 emission factors are fuel-related and country specific. Input data for vehicle stock and mileage (three road classes: urban, rural and highway) are obtained from the Danish Road Directorate and the National Motorcycle Association, and is grouped according to average fuel consumption and emission behaviour. For each vehicle sub-category, the emissions are estimated by combining vehicle type and annual mileage figures with hot emission factors, cold:hot ratios and evaporation factors.

Hot emissions

For operationally hot engines the calculation is as follows for non-catalyst vehicles:

$$E_{j,k,y} = EF_{j,k,y} \cdot S_k \cdot N_{j,y} \cdot M_{j,y} \quad (6)$$

Here E = fuel use/emission, EF = fuel use/emission factor, S = road type share, N = number of vehicles, M = annual mileage, k = road type, j = layer, y = year.

For catalyst vehicles the calculation becomes:

$$E_{j,k,y} = DF_{j,k,y} \cdot EF_{j,k,y} \cdot S_k \cdot N_{j,y} \cdot M_{j,y} \quad (7)$$

DF is the deterioration factor used to take into account catalyst wear.

Cold start emissions

For cold start the extra emissions from conventional gasoline and all diesel vehicles are calculated as:

$$CE_{j,y} = \beta \cdot N_{j,y} \cdot M_{j,y} \cdot EF_{U,j,y} \cdot (CEr - 1) \quad (8)$$

Where CE is the cold extra emissions, β = cold driven fraction, EF_U = hot emission factor for urban driving, CEr = Cold:Hot ratio.

For catalyst vehicles the cold extra emissions are found from:

$$CE_{j,y} = \beta_{red} \cdot \beta_{EUROI} \cdot N_{j,y} \cdot M_{j,y} \cdot EF_{U,j,y} \cdot (CEr_{EUROI} - 1) \quad (9)$$

where β_{red} = the β reduction factor for post EURO I technologies.

Evaporation emissions

For evaporation the emissions are estimated for hot and warm running losses, hot and warm soak loss and diurnal emissions. The hot and warm running losses are calculated as:

$$R_{j,y} = N_{j,y} \cdot M_{j,y} \cdot ((1-\beta) \cdot HR + \beta \cdot WR) \quad (10)$$

where R is running loss emissions and HR and WR are the hot and warm running loss emission factors, respectively.

Hot and warm soak emissions (for carburettor vehicles only) are found as:

$$S_{j,y}{}^{C} = N_{j,y} \cdot \frac{M_{j,y}}{l_{trip}} \cdot ((1-\beta) \cdot HS + \beta \cdot WS) \quad (11)$$

where S^C is the soak emission, l_{trip} = the average trip length, and HS and WS are the hot and warm soak emission factors, respectively.

Average maximum and minimum temperatures per month are used in combination with diurnal emission factors to estimate the diurnal emissions from uncontrolled vehicles $E^d(U)$:

$$E_{j,y}{}^{d}(U) = 365 \cdot N_{j,y} \cdot e^{d}(U) \quad (12)$$

Fuel balance
For gasoline vehicles all mileage numbers are equally scaled in order to obtain gasoline fuel equilibrium. For diesel the fuel balance is made by adjusting the mileage for light and heavy-duty vehicles and buses.

More information is given by Winther (2007) and Illerup et al. (2007).

Finland
Emissions from road transport in Finland are calculated by the LIISA calculation software developed and maintained by the Technical Research Centre of Finland (VTT). A detailed description of the model and the updated results are presented in English on web page http://lipasto.vtt.fi/indexe.htm

The software calculates the total road traffic emissions of municipalities, provinces and the whole country based on vehicle mileage (km/a) of different vehicle types on different road types and emission coefficients determined per kilometre driven (g pr km). SO_2 and CO_2 calculation are based on fuel consumed (t/a) and emission coefficient (g pr kg fuel). The compounds calculated are CO, HC, NO_x, CH_4, N_2O, SO_2, CO_2 and fuel consumption. The results are classified by vehicle type: passenger car, van, bus and lorry and by road type: main street, collector street, residential street, local plan road, main road in built-up area, classified road in built-up area, main road in rural area, classified road in rural area. The system takes into account the impact of road type, vehicle type, engine type, age of vehicle, starts, cold driving and idling. Also advanced fuels are considered (reformulated fuels).

Road mileage is obtained from the road register of the Finnish Road Administration (Finnra). Total street mileage is obtained from Finnra's calculation of street mileage for the whole country. The total street mileage is divided among the cities according to number of inhabitants. The emission factors are based on international databases and national measurements at the VTT.

The main features of the calculation method are described in equation:

$$E_{y,v} = \sum_{l=1}^{9}\sum_{m=1}^{20}\sum_{p=1}^{8}\sum_{r=1}^{6} s_{l,m,p,r,u,v}\left({}^{a}b_{l,m,p,r,u,v,y} + {}^{j}b_{l,m,p,r,u,v,y} + {}^{k}b_{l,m,p,r,u,v,y}\right)$$

where

$E_{y,v}$ is total emission of compound y during year v

s is mileage

${}^{a}b$ is the emission coefficient for hot driving

${}^{j}b$ is the emission coefficient for idle motion

${}^{k}b$ is the emission coefficient for cold starts

and where

l is type of vehicle

m is model year of vehicle

p is road type

r is speed class

u is fuel type

The emissions from motorcycles and mopeds are calculated separately as a product of emission factor (from COPERT III) and mileage.

Iceland

No description is available to explain the calculation of road transport emissions in Iceland.

Norway

Norwegian road traffic emissions are calculated using a model developed by the Norwegian Pollution Control Authority (SFT). The model is fuel-based and the total consumption of various fuels provides the framework for determining the emissions. The emission factors depend on the kind of vehicle (type, weight, technology, age), fuel type and driving mode. The total number of vehicle-kilometres does not enter the calculations directly, but the fractions of the total mileage estimated for each combination of vehicle category and driving mode are used to allocate fuel consumption to the various combinations.

Total emissions Q of a pollutant j from fuel type k, while driving with a warm engine are calculated from the equation below.

$$Q_{jk} = M_k \sum_i \left(p_{ijk} \cdot \frac{l_{jk}}{\overline{l_k}} \cdot \left(\frac{T_{ik}}{T_k} \right) \right)$$

where

Q is total emissions

M is total fuel consumption

p is emission factor (g pr kg)

l is fuel consumption (kg pr km)

T is vehicle-kilometres

k is fuel type

i is combination of vehicle type, fuel type and driving mode

j is pollutant

There are 10 vehicle classes based on vehicle type, weight and fuel, 31 age classes and five driving modes based on the speed limits. In addition, emissions from motorcycles and mopeds are calculated with a simplified method.

Emissions from cold starts are calculated separately as an additional emission contribution per start. Emission factors are given by vehicle category and technology and are mainly taken from Copert (EEA, 1997) and Sérié & Joumard (1996). Detailed driving patterns and regional temperature data are used. The driving patterns are taken from a travel survey (Haukeland et al., 1999).

Emissions from evaporation are calculated separately using the method given in the Corinair Emission Inventory Guidebook (EEA, 1996).

Emissions from tyre and brake wear are calculated by multiplying emission factors with annual mileage, while the emission estimates for road abrasion takes into account the specific wear of studded tyres, mileage per vehicle category, part of year with studded tyre use in the area and share of vehicle category using studded tyres.

The activity data are primarily taken from official registers, public statistics and surveys. The data for total fuel consumption are supplied by the Norwegian Petroleum Industry Association. The number of vehicles in the various categories and age groups are from the Norwegian Directorate of Public Roads. The average annual mileage figures are mainly determined from surveys by Statistics Norway and the Institute of Transport Economics. The Directorate of Public Roads provides data on the annual number of vehicle-kilometres driven on national and country roads.

The emission factors are based on several sources: Copert II (EEA, 1997), a German report (Hassel et al., 1994), Norwegian measurements (SFT, 1993), Swedish reports (AB Svensk Bilprovning, listed in SFT 1993), The Corinair Emission Inventory Guidebook (EEA, 1996) and results from the MEET programme (Sérié & Joumard, 1996).

Norway is currently working on implementing the Handbook Emission Factors for Road Transport (HBEFA) model to calculate national emissions from road transport. This implementation will lead to more detailed activity data, both concerning traffic activity and fleet composition. The emission factors for transport will also differ from the ones currently used in the Norwegian inventory. The HBEFA estimates exhaust and cold start emissions from road transport. Calculations of particle emissions from road abrasion and tyre and brake wear will not be altered.

Sweden

Since emission year 2004, the Swedish road traffic emissions are calculated mainly by using the ARTEMIS Road Model, developed within the EU 5 FP-project ARTEMIS (Assessment and Reliability of Transport Emission Models and Inventory Systems) (Keller et al, 2005). The Swedish National Road Administration (SNRA) has the responsibility for the calculations, but the underlying work is carried out by the Swedish Transport Research Institute (VTI). The calculations of emissions of SO_2 from combustion of gasoline are based on thermal values from Statistics Sweden and the Swedish EPA, whereas the calculations of emissions of

SO_2 from combustion of diesel are based on thermal values from the Swedish Petroleum Institute (SPI). Since the present version of the ARTEMIS model does not involve PM_{10} from gasoline vehicles, the PM_{10} emissions from gasoline are calculated with the national model EMV (a model for calculating exhaust emissions from road traffic), developed and hosted by VTI. The ARTEMIS model provides emissions and emission factors for segments and sub-segments of six main vehicle categories for a large number of traffic situations (276), as well as for average speeds, based on emission measurements according to different sets of real-world driving cycles, representative for typical European driving. The model's calculated emissions are separated into hot emissions, cold-start emissions and evaporative emissions.

ARTEMIS is built around two main modules - a fleet model and a traffic activity scenario model. The fleet model includes information on vehicle type, size, age, mileage, load, engine technology (gasoline, diesel etc.) and emission requirements. The traffic activity scenario model includes information on how vehicle mileage is distributed among vehicle categories and traffic scenarios. Traffic scenarios depend on the following parameters: road configuration, speed limit, sinuosity and gradient and traffic conditions. Sweden has 81 different traffic scenarios, which are used for calculations. Every combination of a traffic scenario and a vehicle segment responds to a unique emission factor.

3.2.5 Differences between the Nordic road transport emission models

The following differences exist between the Nordic calculation models used for estimating the emissions from road traffic:

- The main difference is the basis for calculation of emissions. In the Norwegian and Swedish models the calculation is based on fuel consumption, while in the Finnish model the calculation is based on mileage.
- The Danish model is a bottom-up model using mileage in sub-categories, and model results are adjusted for fuel sales.
- Classification of vehicles: the models used by Norway and Denmark separate vehicles into 12 and 21 classes, respectively. In the Finnish model vehicles are divided into 11 types. In the model used by Sweden 33 different classes are considered. The classifications are presented in Table 3.13.
- The effect of aging of vehicles has been covered differently. The Finnish model uses 20 age classes, the Norwegian model 31. The Danish model uses age classes according to the EU legislation system, and the full fleet matrix in the Danish 2005 inventory cover 79 different combinations of vehicle categories, fuel types and engine size/total weight's. The Swedish model also uses age classes according to the EU legislation system.
- Different driving conditions and fuel evaporation: All countries calculate the emissions from hot driving and during cold starts. The Danish, Norwegian and Swedish models include also the emissions from fuel evaporation. The Finnish model takes into account idling and the emissions from fuel evaporation are calculated separately from the road transport model.
- The effect of driving mode on emissions has been taken into account differently. The Danish model uses three road classes. In the Finnish

model the mileage is divided among eight different road types, four of which are further divided into six speed classes. In the Norwegian model the fuel consumption is allocated to five driving modes, which are based on the speed limits. In the ARTEMIS model used by Sweden, information on e.g. road configuration and speed limits are included in the traffic scenarios. All in all 81 different traffic scenarios exist in Sweden.

Table 3.13 Vehicle categories used for calculation of road traffic emissions in the Nordic countries.

	Finland	Sweden	Norway	Denmark
Passenger cars	Petrol-driven, cat. Petrol-driven, non-cat. Diesel	Petrol-driven, < 1,4 l Petrol-driven, 1,4 – 2,0 l Petrol-driven, > 2,0 l Diesel, < 2,0 l Diesel, > 2,0 l LPG 2-stroke	Petrol-driven Diesel	Petrol-driven, < 1,4 l Petrol-driven, 1,4 – 2,0 l Petrol-driven, > 2,0 l Diesel, < 2,0 l Diesel, > 2,0 l LPG 2-stroke
Light duty vehicles, < 3,5 t	Petrol-driven, cat. Petrol-driven, non-cat. Diesel	Petrol-driven Diesel	Petrol-driven Diesel	Petrol-driven Diesel
Heavy duty vehicles, > 3,5 t	Diesel buses Diesel lorries, no trailer Diesel lorries with trailer	Petrol-driven trucks Diesel trucks, rigid; 8 size categories Diesel trucks, articulated/-truck-trailer; 5 size categories Diesel buses, 2 sizes Diesel coaches, 3 sizes	Petrol-driven buses Diesel buses Petrol-driven, > 3,5 t Diesel, 3,5 – 7,5 t Diesel, 7,5 – 16 t Diesel, >16 t	Petrol-driven trucks Diesel trucks, 3,5 – 7,5 t Diesel trucks, 7,5 – 16 t Diesel trucks, 16 – 32 t Diesel trucks, > 32 t Diesel buses Diesel coaches
Two-wheelers	Mopeds Motorcycles	Mopeds, < 50 cm^3 Motorcycles, 2-stroke Motorcycles, < 250 cm^3 Motorcycles, 250 – 750 cm^3 Motorcycles, > 750 cm^3	Mopeds Motorcycles	Mopeds, < 50 cm^3 Motorcycles, 2-stroke Motorcycles, < 250 cm^3 Motorcycles, 250 – 750 cm^3 Motorcycles, > 750 cm^3

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4 Review of recent measurements in stoves and small scale boilers

Residential plants and in particular wood combustion have become a larger and larger source of emissions. The most relevant pollutants include NMVOC, PAH, dioxin and of course PM.

In addition to being a key category for many pollutants, the emission estimates are also highly uncertain; this is caused by a high degree of uncertainty both regarding the activity data and the emission factors.

Therefore studies are still being carried out to improve the emission factors for residential wood burning. In this chapter the recently published articles and reports on this issue will be presented and discussed.

4.1 Recent studies of PM emissions from residential wood burning

A recent doctoral thesis (Bäfver, 2008) found that the particle emission from residential wood combustion was in the range of 12-120 mg pr MJ except for two measurements, which were deemed as extreme cases. The lowest emissions were, as expected, found for wood pellets, where the emission was at the same level as for wood fired district heating plants.

An interesting issue is the difference in particle measurements dependent on whether the measurements are done in cooled flue gas as opposed to measurements directly in the chimney. According to Bäfver (2008) the particle mass concentration was 2-10 times higher when measuring in the cooled down flue gas compared to direct chimney measurements.

Tissari has documented PM_1 emission measurements from a number of different wood combustion technologies (Tissari, 2008). The emission factors are provided in g pr kg of wood. The pellet burners and boilers have the lowest emission factors, while the highest emission factors are measured for wood stoves and sauna stoves. Generally the emission factors from wood stoves from a number of referenced studies are a factor 3-45 higher than for pellet boilers. The ratio of PM_1 to PM_{10} was measured to be 0.8 and the heating value listed at 18.3 MJ pr kg (Tissari et al., 2008). The highest emission factor in the study by Tissari (2008) is for a sauna stove, where an emission factor of 5 g pr kg was derived. When using the heating value and PM ration listed above a PM_{10} emission factor of approximately 340 g pr GJ. Other studies referenced by Tissari (2008) have emission factors for wood stoves at more than twice this level, i.e. over 700 g pr GJ.

A study by Todorovic et al. (2007) found median emission factors for different technologies for wood combustion from 28-1200 mg pr MJ. The low emission factor was for wood pellets, while the highest emission factor was for a boiler without accumulation tank non-optimal operating conditions. There are, however, significant ranges for the emission factors, e.g. for a BBR approved boiler with accumulation tank the emission factor range is 11-450 mg pr MJ.

Klippel & Nussbaumer (2007) have compiled measurements for three different stoves, an old simple metal stove, a modern stove with quality label and a special stove with two combustion steps. The three stoves were all tested under different operating conditions, ranging from what is described as ideal circumstances over typical circumstances to examples of bad and very bad operating conditions. Table 4.1 shows the emission measurements from Klippel & Nussbaumer (2007) converted to emission factors.

Table 4.1 Emission factors for three different stoves. Derived from Kippel & Nussbaumer (2007).

g pr GJ	Simple stove	Advanced stove	2 stage combustion
Ideal conditions	11-89	29-46	7-14
Typical conditions	157-2144	8-179	18-21
Difficult conditions	86-4647	129-143	29-54

It can be seen that the emission factors vary greatly especially for the old (simple) stove. The advanced stove had a high emission factor of 179 g pr GJ; this was in a case where 4 kg of wood with a water content of 20 % were added to embers. Some of the operating conditions tested included firing with wet wood, smouldering, inserting large amounts of wood with restricted airflow etc. Some of these issues will be further discussed in Chapter 4.2.

A Danish study on old boilers showed emission levels of 588-736 g pr GJ. Newer boilers were in the range of 100-335 g pr GJ and modern approved boilers had emission factor of 64-233 g pr GJ. (Winther, 2008)

A Danish study carried out measurements on wood combustion installations of different age classes. The emission factors varied from 150-481 g pr GJ for wood stoves. The low emission factor was actually for the oldest age class. However, the emission factor is only based on a single installation. A measurement carried out on an old wood boiler showed an emission factor of 813 g pr GJ. Like for the old stove the emission factor for the old boiler was also based on a single measurement. (Glasius et al., 2007).

4.2 The importance of operating conditions and other variables

Many studies show the importance of the operating conditions on the resulting emissions. Klippel & Nussbaumer (2007) has made several measurements under different operating conditions. Measurements have been made with wood with varying water content, of different loads and for different stages of the combustion process. As expected this causes the emission factors to fluctuate significantly.

Tissari et al. (2009) investigated the impact on PM emissions of appliance type, batch size and log size during the three main stages of combustion (firing, combustion and burn-out). The study showed that the PM emission was highest in a sauna stove, while the conventional and modern masonry heaters were lower. The conventional masonry heater was only significantly higher in emissions than the modern masonry heater during the firing phase. As expected the firing phase produced the highest emissions of PM for all three appliance types. The study found that big batch size significantly increased the emissions. For PM_1 the emission increased by 90 % using a twice as large batch size. Regarding log size the study found that small logs resulted in higher emissions of PM_1 than big logs. The average emission factor for small logs was almost five times higher than the emission factor for big logs.

Paulrud et al. (2006) reports emission measurements from 20 different tests carried out for different species of wood, different water content, different batch sizes and different ignition conditions. The emissions of PM varied from 20-180 mg pr MJ.

Other studies have focused on the influence on the wood species in connection with emissions. Schauer et al. (2001) measured emissions from a fireplace combusting pine, oak and eucalyptus. The lowest PM emission was measured from oak (5.1 g pr kg) while eucalyptus and pine had considerably higher emission rates at 8.5 and 9.5 g pr kg, respectively.

Another important factor sometimes overlooked is the age of the combustion appliance. Due to the increased attention to the air pollution originating from wood stoves and boilers, modern appliances have significantly lower emissions compared to older appliances. Glasius et al. (2007) found that wood stoves over three years old had an emission factor that was 40 % higher compared to wood stoves that was three years old or less. Johansson et al. (2004) reported measurements carried out on both old boilers and modern boilers. For the old boilers the resulting emission factors were between 87 and 2200 mg pr MJ and the modern boilers showed emission rates between 18 and 89 mg pr MJ. So it is clear that in order to have a reliable emission inventory it is necessary to have solid information regarding the technology distribution of wood combustion appliances, e.g. number of old boilers vs. new boilers.

4.3 The importance of sampling methodology

There are several different methods available for measuring PM emissions. They can roughly be divided into the following categories (Winther, 2008):

- In-stack gravimetric methods (e.g. VDI2066 bl.2).
- Out-stack gravimetric methods without dilution tunnel (e.g. SS028426).
- Gravimetric methods with dilution tunnel (e.g. Force Technology/NERI, NS3058).
- Electrostatic methods (e.g. BS3841).
- Cascade impactors (e.g. VDI2066 bl. 5).
- Low pressure impactors (e.g. ELPI, DLPI).
- Optical scanners (e.g. LASX, SMPS).

The main difference is whether the emission measurement is carried out in the hot flue gas either in-stack or out-stack or if the measurements are carried out after the semi-volatile compounds have condensed.

Typically, the Swedish laboratory measurements (e.g. Johansson et al., 2004) are based on Swedish Standard (SS028426), which is an out-stack heated filter - meaning that the semi-volatile compounds will not have condensed. In the field measurements an in-stack filter was used to measure PM. (Johansson et al., 2006).

The measurements carried out in Denmark all use out-stack methods with dilution tunnel comparable to Norwegian Standard (Glasius et al., 2005; Glasius et al., 2007; Winther, 2008). Therefore, the measurement method can be the reason why the Swedish measurements show a significantly lower level compared to the Danish measurements.

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

A test on a wood stove carried out by the Danish Technological Institute showed a ration of approximately 4.8 between an in-stack measurement and a measurement in a dilution tunnel (Winther, 2008).

The proposal for a European standard for measuring PM from residential solid fuel burning appliances proposed to measure the particles in a dilution tunnel (Gaegauf & Griffin, 2007). However, in the published standard (CEN/TS 15883:2009) three different methods are presented in annex A. These include both measurements in dilution tunnels (Norwegian standard) and in the stack (German/Austrian standard).

In order to ensure comparability between emission inventories in the future there is a need to establish a common method for deriving emission factors, since differences of a factor of up to 10 obviously makes it impossible to compare results.

The measurements carried out in a dilution tunnel best represent the actual emission of PM when the flue gas is emitted from the chimney, whereas measurements done in the hot flue gas will neglect the contribution to the PM emission from semi volatile compounds that forms PM when the temperature decreases.

4.4 Summation

The emission from residential wood combustion depends - as described above - on a number of different parameters. Ideally, when calculating emissions, the calculations should be disaggregated to the appliance type (boiler, stove, fireplace etc.) and the age of the appliance (old, new, modern etc.). However, as shown in previous sections the emissions vary heavily depending on wood species, water content, batch size, log size and the general combustion conditions. It is therefore difficult to establish an emission inventory that takes all these factors into account.

Table 4.2 below shows emission factors for different wood combustion techniques.

Table 4.2 Example of available emission factors and their variability.

Fuel/appliance	PM mg pr MJ	Reference
Wood boiler	26-450	Johansson et al., 2006
Wood boiler	87-2200 (Old boilers)	Johansson et al., 2004
Wood boiler	18-89 (Modern boilers)	Johansson et al., 2004
Wood boiler	588-736 (TSP, old boilers)[1]	Winther, 2008
Wood boiler	96-335 (TSP, newer boilers)[1]	Winther, 2008
Wood boiler	64-233 (TSP, modern boilers)[1]	Winther, 2008
Wood boiler	963-1481 (Old boiler)[2]	Glasius et al., 2005
Wood boiler	813 (Old boiler)[2,3]	Glasius et al., 2007
Wood stove	22-180	Paulrud et al., 2006
Wood stove	7-173 ($PM_{2.5}$)	Hedberg et al., 2002
Wood stove	37-350	Boman, 2005
Wood stove	120-320 ($PM_{2.5}$)	MacDonald et al., 2000
Wood stove	344-5075 (Old stoves)[2]	Glasius et al., 2005
Wood stove	100, 90 (PM_1)	Ohlström et al., 2005
Wood stove	2500 (PM_{10}, prior to 1998)[2]	Haakonsen & Kvingedal, 2001
Wood stove	388 (PM_{10}, 1998 onwards)[2]	Haakonsen & Kvingedal, 2001
Wood stove	875-1438 (PM_{10}, conventional)[2]	Basrur, 2002
Wood stove	313 (PM_{10}, advanced)[2]	Basrur, 2002
Wood stove	344 (Modern)[2]	Glasius et al., 2007
Wood stove	481 (New)[2]	Glasius et al., 2007
Wood stove	150 (Old)[2,3]	Glasius et al., 2007
Wood stove	11-4667 (Old stove)[4]	Klipper & Nussbaumer, 2007
Wood stove	29-179 (Modern stove)[4]	Klipper & Nussbaumer, 2007
Continued		
Wood stove	7-54 (Modern stove)[4]	Klipper & Nussbaumer, 2007
Wood stove	49 (PM_1)[5]	Tissari, 2008
Wood stove	144-450 ($PM_{2.5}$)[2]	MacDonald et al., 2000
Wood stove	72 (TSP)	Struschka et al., 2003
Sauna stove	148-273 (PM_1)[5]	Tissari, 2008
Modern masonry heater	38 (PM_1)[5]	Tissari, 2008
Conventional masonry heater	33-98 (PM_1)[5]	Tissari, 2008
Pellets burner	12-65	Johansson et al., 2003
Pellets burner	35, 25 (PM_1)	Ohlström et al., 2005
Pellets burner	15 (PM_1)[5]	Tissari, 2008
Pellets boiler	15, 10 (PM_1)	Ohlström et al., 2005
Pellets boiler	16-27 (PM_1)[5]	Tissari, 2008
Pellets stove	11-81	Boman, 2005
Pellets stove	17-46	Boman, 2005
Open fire place	170-780	Purvis & McCrills, 2000
Open fire place	181-563 ($PM_{2.5}$)[2]	MacDonald et al., 2000
Open fire place	319-594(PM_{10})	Schauer et al., 2001
Open fire place	180-760 ($PM_{2.5}$)	Fine et al., 2001
Open fire place	1081 (PM_{10})[2]	Haakonsen & Kvingedal, 2001
Open fire place	1188 (PM_{10}, conventional)[2]	Basrur, 2002
Open fire place	313 (PM_{10}, advanced)[2]	Basrur, 2002
Wood chips boiler	20, 10 (PM_1)	Ohlström et al., 2005
Wood chips boiler	50, 30 (PM_1)	Ohlström et al., 2005

[1] Lower limit is for boilers with accumulation tank.

[2] Converted using LHV of 16 MJ pr kg.

[3] Based on a single installation.

[4] Recalculated from mg pr Nm3 to mg pr MJ.

[5] Converted using LHV of 18.3 MJ pr kg.

As seen from Table 4.2 the emission factors vary greatly. Some of the major differences can be explained by different sampling methods as described in Chapter 4.3. The large differences from the same studies where the same sampling methodology is used can be attributed to the large impact of operating conditions and other variables as described in Chapter 4.2.

For wood boilers the emission factor can be anywhere between 18 and 2200 mg pr MJ. However, old boilers are in the range of 600-2200, while new and modern boilers have emission factors in the range of 18-300 mg pr MJ. When taking into account the different sampling methods the results by Johansson et al. (2004) and Winther (2008) are quite comparable for modern boilers. The ratio between the two is between three and four, which is in good agreement with the ratios presented in Nussbaumer et al. (2008).

For wood stoves the difference in emission factors are even greater ranging from 10 to 5500 mg pr MJ. A noticeable difference can be seen depending on whether the measurements are carried out on old stoves or newer or modern stoves.

For pellet stoves and boilers the emission factors are generally very low and there is good agreement between studies.

For open fireplaces the emission factors vary between 170 and 1200 mg pr MJ. The lowest emission factors are from studies with in-stack measurements.

A common sampling method is necessary to be able to make any meaningful comparisons between emission factor measurements, since it is shown that the results can differ in the most extreme cases by a factor of 10 between sampling methods.

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5 Current status of the PM inventories in the Nordic countries

5.1 Emissions of PM in the Nordic countries as of 2010

The total reported emissions of $PM_{2.5}$ in the Nordic countries are shown in Table 5.1. Iceland did not report PM emissions in their 2010 submission to the Convention on Long-Range Transboundary Air Pollution.

Table 5.1 $PM_{2.5}$ emissions from the Nordic countries, Gg.

	2005	2006	2007	2008
1A1a Public Electricity and Heat Production	4,6	4,9	4,8	4,8
1A1b Petroleum refining	0,4	0,4	0,4	0,4
1A2 Manufacturing Industries and Construction	9,0	8,6	8,2	7,8
1A3b Road Transport, exhaust	9,2	8,7	8,4	7,7
1A3b vi+vii Road transport, non-exhaust	7,8	7,9	10,7	10,7
1A3d ii National Navigation	1,8	1,8	1,7	1,4
Other mobile sources	5,7	5,7	5,5	5,1
1A4b i Residential plants	71,9	71,1	71,4	71,0
1A4c i Stationary, Agriculture/Forestry	1,2	1,0	1,2	1,2
1B Fugitive Emissions	2,9	4,9	3,1	3,3
2A2 Lime Production	0,2	0,2	0,2	0,2
2A7 Other incl. Mining & Construction	0,8	1,0	0,8	0,8
2B Chemical industry	0,9	0,7	0,7	0,7
2C Metal production	8,6	7,1	6,6	6,8
2D1 Pulp and Paper	5,4	4,8	4,6	3,4
3D Other Product Use	2,0	2,0	1,1	0,9
4 Agriculture	3,9	3,7	3,4	3,6
Other sources	2,4	2,4	3,5	3,4
Total	138,7	136,7	136,2	133,1

The dominant source of $PM_{2.5}$ emissions in the Nordic countries is residential plants. PM emissions from residential plants primarily come from burning of wood in fireplaces, stoves and small single household boilers.

The emissions from residential plants account for between 52 % and 54 % of the $PM_{2.5}$ emissions from 2005 to 2008. The other major categories are road transport - both exhaust (6-7 %) and non-exhaust (6-8 %) and manufacturing industries and construction (6-7 %).

The total $PM_{2.5}$ emission has decreased by 5.6 Gg from 2005 to 2008 corresponding to 4 %. The reductions have primarily happened in the exhaust emissions from road transport (17 %) and from industries, e.g. manufacturing industries and construction (13 %), metal production (21 %) and pulp and paper (37 %).This is to some extent countered by increases in the non-exhaust $PM_{2.5}$ emission from road transport (38 %)

5.2 National emissions of PM in the Nordic countries

The PM_{10} and $PM_{2.5}$ emissions reported by the Nordic countries in 2010 are shown in Table 5.2 and Table 5.3.

Table 5.2 PM_{10} emissions from the Nordic countries, Gg.

	2005	2006	2007	2008
Denmark	32,50	33,64	37,29	35,00
Finland	51,29	54,65	47,86	49,03
Norway	56,32	53,27	50,12	48,08
Sweden	41,65	41,09	41,26	39,23

Table 5.3 $PM_{2.5}$ emissions from the Nordic countries, Gg.

	2005	2006	2007	2008
Denmark	25,43	26,48	30,15	28,29
Finland	34,08	34,80	34,27	36,03
Norway	49,69	46,68	42,82	41,55
Sweden	29,47	28,73	28,96	27,23

For PM_{10}, Table 5.2 shows that Denmark is the only Nordic country that has experienced an increase in PM_{10} emissions from 2005 to 2008. Norway has had the largest decrease in PM_{10} emission - both in absolute terms and in percentage terms.

For $PM_{2.5}$ both Denmark and Finland have had an increase in emissions whereas both Norway and Sweden have had declining $PM_{2.5}$ emissions.

Table 5.4 shows the fraction of $PM_{2.5}$ compared to PM_{10} for four of the Nordic countries.

Table 5.4 Fraction of total $PM_{2.5}$ of total PM_{10}. in %.

	2005	2006	2007	2008
Denmark	78,2	78,7	80,8	80,8
Finland	66,5	63,7	71,6	73,5
Norway	88,2	87,6	85,4	86,4
Sweden	70,7	69,9	70,2	69,4

Sweden has the lowest fraction of $PM_{2.5}$ compared to PM_{10} at around 70 %, while Norway has the highest share of around 87 %. The most pronounced trend is for Finland where a large jump occurs from 2006 to 2007. This is due to a significant increase in the non-exhaust $PM_{2.5}$ emission from road transport, while the PM_{10} emission from the same category decreases slightly.

5.2.1 Denmark

In Denmark the largest source by far to the $PM_{2.5}$ emission are residential plants, and in particular wood burning in stoves and small single household boilers. Residential plants account for approximately 63 % in 2005 and 2006, but in 2007 and 2008 the share for residential plants increases to almost 70 %. The increase in share is caused by a sharp increase in emissions from the residential sector, while the other sectors remain relatively constant. Table 5.5 shows the $PM_{2.5}$ emissions from Denmark.

Table 5.5 $PM_{2.5}$ emissions from Denmark, Gg.

	2005	2006	2007	2008
1A1a Public Electricity and Heat Production	0,51	0,60	0,63	0,53
1A1b Petroleum refining	0,10	0,10	0,11	0,11
1A2 Manufacturing Industries and Construction	1,35	1,36	1,28	1,21
1A3b Road Transport, exhaust	2,95	2,85	2,69	2,42
1A3b vi+vii Road transport, non-exhaust	0,90	0,93	0,98	0,96
1A3d ii National Navigation	0,31	0,29	0,26	0,24
Other mobile sources	1,39	1,30	1,24	1,19
1A4b i Residential plants	15,90	17,03	20,97	19,68
1A4c i Stationary, Agriculture/Forestry	0,45	0,44	0,44	0,44
1B Fugitive Emissions	0,04	0,06	0,06	0,05
2A2 Lime Production	IE	IE	IE	IE
2A7 Other incl. Mining & Construction	0,00	0,00	0,00	0,00
2B Chemical industry	0,00	0,00	0,00	0,00
2C Metal production	0,01	0,01	0,02	0,02
2D1 Pulp and Paper	NE	NE	NE	NE
3D Other Product Use	NE	NE	NE	NE
4 Agriculture	1,37	1,33	1,32	1,27
Other sources	0,15	0,16	0,16	0,18
Total	25,43	26,48	30,15	28,29

The large increase in $PM_{2.5}$ emissions from the residential sector is caused by an increase in the wood consumption. The wood consumption has increased by 35 % from 2005 to 2008 with the largest increase being between 2006 and 2007 (21 %).

The other large sources of $PM_{2.5}$ emissions are the transport sectors and other mobile sources. The exhaust emissions from road transport as well as the emissions from other mobile sources have been decreasing while the non-exhaust emission is relatively constant.

Agriculture contributes with about 1.3 Gg (5 % of the national total) and that has remained almost constant since 2005.

5.2.2 Finland

The largest source of $PM_{2.5}$ emission in Finland is residential plants, which account for approximately 45 % of the total emission for the years 2005-2007, and 49 % in 2008. The other large sources are non-exhaust road transport (12.4 % in 2008), fugitive emissions (8.3 % in 2008) and manufacturing industries (7.1 % in 2008).

Table 5.6 shows the $PM_{2.5}$ emissions from Finland.

Table 5.6 $PM_{2.5}$ emissions from Finland, Gg.

	2005	2006	2007	2008
1A1a Public Electricity and Heat Production	0,80	0,91	0,88	0,72
1A1b Petroleum refining	0,07	0,05	0,02	0,02
1A2 Manufacturing Industries and Construction	3,74	3,14	2,87	2,58
1A3b Road Transport, exhaust	2,51	2,31	2,24	2,16
1A3b vi+vii Road transport, non-exhaust	1,75	1,77	4,42	4,47
1A3d ii National Navigation	0,52	0,54	0,56	0,37
Other mobile sources	1,51	1,36	1,06	0,97
1A4b i Residential plants	15,32	15,64	15,46	17,80
1A4c i Stationary, Agriculture/Forestry	0,20	0,03	0,23	0,21
1B Fugitive Emissions	2,63	4,54	2,81	2,98
2A2 Lime Production	0,01	0,01	0,01	0,01
2A7 Other incl. Mining & Construction	0,14	0,26	0,06	0,12
2B Chemical industry	0,02	0,05	0,03	0,02
2C Metal production	0,99	0,72	0,42	0,71
2D1 Pulp and Paper	1,40	1,04	1,05	0,67
3D Other Product Use	1,34	1,39	0,35	0,42
4 Agriculture	0,56	0,55	0,30	0,37
Other sources	0,57	0,47	1,51	1,43
Total	34,08	34,80	34,27	36,03

The emissions fluctuate annually due to variations in fuel consumption related to the annually varying climatic conditions .The time-series has not been recalculated yet (Syke, 2010).

5.2.3 Norway

The largest source of $PM_{2.5}$ in the Norwegian inventory is residential plants accounting for roughly 70 % of the emissions. The emission share has been decreasing from 2005 to 2008. The other major sources are metal production (8.7 % in 2008), other mobile sources (4.5 % in 2008), manufacturing industries and construction (3.5 % in 2008) and exhaust emissions from road transport (3.4 % in 2008).

The $PM_{2.5}$ emissions from Norway are presented in Table 5.7.

Table 5.7 $PM_{2.5}$ emissions from Norway, Gg.

	2005	2006	2007	2008
1A1a Public Electricity and Heat Production	0,10	0,10	0,11	0,10
1A1b Petroleum refining	0,08	0,08	0,08	0,07
1A2 Manufacturing Industries and Construction	1,33	1,34	1,43	1,45
1A3b Road Transport, exhaust	1,69	1,62	1,55	1,43
1A3b vi+vii Road transport, non-exhaust	0,52	0,53	0,55	0,57
1A3d ii National Navigation	0,54	0,56	0,58	0,51
Other mobile sources	1,71	1,89	2,05	1,88
1A4b i Residential plants	35,38	33,74	29,52	28,43
1A4c i Stationary, Agriculture/Forestry	0,01	0,01	0,01	0,01
1B Fugitive Emissions	0,16	0,19	0,13	0,17
2A2 Lime Production	0,00	0,00	0,00	0,00
2A7 Other incl. Mining & Construction	0,50	0,50	0,56	0,52
2B Chemical industry	0,65	0,49	0,47	0,49
2C Metal production	4,83	3,50	3,65	3,62
2D1 Pulp and Paper	0,20	0,18	0,18	0,18
3D Other Product Use	0,00	0,00	0,00	0,00
4 Agriculture	1,10	0,97	1,00	1,12
Other sources	0,91	0,97	0,96	1,01
Total	49,69	46,68	42,82	41,55

Unlike Denmark and Finland, Norway has experienced a decrease of almost 20 % in $PM_{2.5}$ emissions from residential plants. In 2005 33.7 % of the wood was burnt in new clean-burning stoves; in 2008 this proportion had increased to 45.7 %. In addition to emitting less PM, new stoves are also more energy-efficient than old stoves. This has led to a reduction in wood consumption. From 2005 to 2008 the wood consumption in households decreased by 14 %, The new stoves have resulted in households gaining 1.0 TWh of extra energy from the wood burnt in the 2008 and a reduction in the release of PM of 17.5 Gg compared to a situation with only old technology stoves. The large overall decrease in $PM_{2.5}$ emission of 8.1 Gg since 2005 is primarily due to the decrease from residential plants (6.9 Gg) and metal production (1.2 Gg).

5.2.4 Sweden

In Sweden the largest source of $PM_{2.5}$ emission is residential plants (18.5 % in 2008). However, that share is significantly lower compared to the other three Nordic countries. The other major sources are non-exhaust emissions from road transport (17.3 % in 2008), public electricity and heat production (12.8 % in 2008), pulp and paper (9.3 % in 2008), manufacturing industries and construction (9.2 % in 2008) and metal production (9.1 % in 2008).

Table 5.8 presents the Swedish $PM_{2.5}$ emissions.

Table 5.8 $PM_{2.5}$ emissions from Sweden, Gg.

	2005	2006	2007	2008
1A1a Public Electricity and Heat Production	3,17	3,26	3,21	3,48
1A1b Petroleum refining	0,18	0,17	0,15	0,18
1A2 Manufacturing Industries and Construction	2,53	2,72	2,58	2,51
1A3b Road Transport, exhaust	2,04	1,96	1,91	1,64
1A3b vi+vii Road transport, non-exhaust	4,62	4,63	4,76	4,72
1A3d ii National Navigation	0,46	0,39	0,35	0,32
Other mobile sources	1,14	1,12	1,10	1,09
1A4b i Residential plants	5,27	4,65	5,42	5,04
1A4c i Stationary, Agriculture/Forestry	0,54	0,56	0,55	0,53
1B Fugitive Emissions	0,06	0,07	0,06	0,06
2A2 Lime Production	0,18	0,16	0,21	0,17
2A7 Other incl. Mining & Construction	0,18	0,20	0,18	0,14
2B Chemical industry	0,24	0,15	0,19	0,14
2C Metal production	2,79	2,86	2,47	2,48
2D1 Pulp and Paper	3,77	3,57	3,38	2,55
3D Other Product Use	0,65	0,63	0,72	0,51
4 Agriculture	0,84	0,82	0,83	0,84
Other sources	0,81	0,81	0,89	0,83
Total	29,47	28,73	28,96	27,23

Overall the Swedish emission of $PM_{2.5}$ has decreased by 2.2 Gg or almost 8 %. The sectors responsible for the majority of the decrease are pulp and paper (1.2 Gg) and exhaust emissions from road transport (0.4 Gg).

The emission from residential plants has been relatively constant and the small fluctuations can be attributed to fluctuations in biomass consumption, e.g. the decrease in emissions from 2005 to 2006 corresponds to a decrease in biomass consumption of 8 %.

5.2.5 Comparison between countries

Because of the different national circumstances in the four Nordic countries, it is expected that the distribution of PM emissions between sectors would differ. This can for instance be due to different electricity production systems in the four countries or different industries being present. However, when comparing the sectoral shares of $PM_{2.5}$ emissions there are some interesting points that are worth noting. Table 5.9 shows the sectoral shares of $PM_{2.5}$ emissions for the four Nordic countries.

Table 5.9 Sectoral shares of $PM_{2.5}$ emissions for the Nordic countries in 2008.

Emission shares $PM_{2.5}$ 2008	Denmark	Finland	Norway	Sweden
1A1a Public Electricity and Heat Production	1,9%	2,0%	0,2%	12,8%
1A1b Petroleum refining	0,4%	0,1%	0,2%	0,7%
1A2 Manufacturing Industries and Construction	4,3%	7,1%	3,5%	9,2%
1A3b Road Transport, exhaust	8,6%	6,0%	3,4%	6,0%
1A3b vi+vii Road transport, non-exhaust	3,4%	12,4%	1,4%	17,3%
1A3d ii National Navigation	0,9%	1,0%	1,2%	1,2%
Other mobile sources	4,2%	2,7%	4,5%	4,0%
1A4b i Residential plants	69,5%	49,4%	68,4%	18,5%
1A4c i Stationary, Agriculture/Forestry	1,5%	0,6%	0,0%	1,9%
1B Fugitive Emissions	0,2%	8,3%	0,4%	0,2%
2A2 Lime Production	0,0%	0,0%	0,0%	0,6%
2A7 Other incl. Mining & Construction	0,0%	0,3%	1,2%	0,5%
2B Chemical industry	0,0%	0,1%	1,2%	0,5%
2C Metal production	0,1%	2,0%	8,7%	9,1%
2D1 Pulp and Paper	0,0%	1,9%	0,4%	9,3%
3D Other Product Use	0,0%	1,2%	0,0%	1,9%
4 Agriculture	4,5%	1,0%	2,7%	3,1%
Other sources	0,6%	4,0%	2,4%	3,1%

From Table 5.9 it can be seen that Sweden has a very large share (12.8 %) of $PM_{2.5}$ emissions emitted from public electricity and heat production, which is very high compared to the other countries where the share is between 0.2 % and 2 %. Another big discrepancy is the non-exhaust emission from road transport. The share for Finland and Sweden is much higher than for Norway and Denmark. Sweden and Finland uses the same emission factors (SYKE, 2010). Some of the difference to Denmark can be explained by less use of studded tires in Denmark. The difference to Norway is caused by different emission factors, e.g. different assumptions regarding particle size distribution (Aasestad, 2008 & SYKE, 2010).

For fugitive emissions Finland has a very large share compared to the other three countries, this is due to a high PM contribution from extraction of peat (SYKE, 2010).

The most interesting difference is perhaps the difference in share of residential plants, which is primarily wood burning. Denmark and Norway have shares of almost 70 %, while the share in Finland is roughly 50 %. In Sweden the share is only 18.5 %, which is very low compared to the other countries. The emission factors used by Sweden are lower than for the other countries. However, they are based on Swedish field and laboratory measurements (SEPA, 2010). Denmark has the highest aggregated emission factor. Denmark and Norway separates the emission calculation not only in technology (e.g. stoves and boilers) but also has further disaggregation. Denmark has four age classes for stoves and two age classes for boilers (Nielsen et al., 2010). Norway has two age classes for stoves.

For metal production and pulp and paper there are, as expected, large differences between the countries, due to the extent of which these activities occur.

5.3 Recalculations since 2007 submissions

Since the establishment of PM emission inventories is still relatively recent and the available knowledge changes rapidly. It is good practice to recalculate the time-series when new knowledge becomes available. To illustrate the changes over the recent years the emission estimates of $PM_{2.5}$ in 2005 from the 2007 submission and the 2010 submission are compared, see Table 5.10.

Table 5.10 Comparison between $PM_{2.5}$ emissions in 2005 from the 2007 and the 2010 submission (Gg).

	Denmark		Norway		Finland		Sweden	
	2007 submis.	2010 submis.	2007 submis.	2010 submis.	2007 submis.	2010 submis.	2007 submis.	2010 submis.
1A1a Public Electricity and Heat Production	0,50	0,51	0,80	0,80	0,11	0,10	3,18	3,17
1A1b Petroleum refining	0,10	0,10	0,07	0,07	0,08	0,08	1,10	0,18
1A2 Manufacturing Industries and Construction	1,35	1,35	3,74	3,74	0,30	1,33	4,75	2,53
1A3b Road Transport, exhaust	3,12	2,95	2,51	2,51	1,70	1,69	3,35	2,04
1A3b vi+vii Road transport, non-exhaust	0,90	0,90	1,75	1,75	0,51	0,52	1,89	4,62
1A3d ii National Navigation	0,43	0,31	0,52	0,52	0,55	0,54	0,45	0,46
1A3e, 1A4 b ii, 1A4c ii & 1A4c iii Other mobile sources	1,43	1,39	1,51	1,51	2,71	1,71	3,07	1,14
1A4b i Residential plants	17,67	15,90	15,32	15,32	35,35	35,38	5,03	5,27
1A4c i Stationary, Agriculture/Forestry	0,45	0,45	0,20	0,20	0,01	0,01	0,05	0,54
1B Fugitive Emissions	0,04	0,04	2,63	2,63	0,16	0,16	0,11	0,06
2A2 Lime Production	0,00	0,00	0,01	0,01	0,00	0,00	0,21	0,18
2A7 Other incl. Mining & Construction	0,00	0,00	0,14	0,14	0,50	0,50	2,57	0,18
2B Chemical industry	0,00	0,00	0,02	0,02	0,65	0,65	0,24	0,24
2C Metal production	0,00	0,01	0,99	0,99	4,77	4,83	1,12	2,79
2D1 Pulp and Paper	0,00	0,00	1,40	1,40	0,20	0,20	3,77	3,77
3D Other Product Use	0,00	0,00	1,34	1,34	0,00	0,00	0,64	0,65
4 Agriculture	1,67	1,37	0,56	0,56	1,10	1,10	0,66	0,84
Other sources	0,13	0,15	0,57	0,57	0,91	0,91	0,70	0,81
Total	27,79	25,43	34,08	34,08	49,62	49,69	32,89	29,47

There can always be minor changes in emission estimates due to revised activity data etc. However, larger recalculations are most often caused by changes in methodology or changes in emission factors.

In Table 5.10 it can be seen that Finland has not recalculated the time-series of air pollutant emissions (SYKE, 2010).

Norway has done some recalculations, however, the impact on the national total is very small (0.07 Gg or 0.1 %). The main change is a reallocation due to a change in the reporting format (Mobile combustion from machinery in manufacturing industries and construction (1A2) was previously reported under Other mobile sources and machinery 1A3e ii).

Denmark and Sweden are the countries where the largest recalculations have been performed.

For Denmark the total national emission of $PM_{2.5}$ in 2005 has decreased by 2.4 Gg corresponding to 8.5. %.The reason for the decrease is mainly a recalculation of the $PM_{2.5}$ emission from residential plants. However, recalculations in road transport, agriculture and national navigation have also contributed to the lower emission estimate. For residential plants the decrease is due to increased wood consumption in the official energy statistics (change introduced in 2008) and new emission factors for old and new wood stoves (change in 2010). The change for national navigation is due to a change in methodology where a new bottom-up model was made to estimate emissions. For road transport the changes are a combination of new emission factors and new activity data (Nielsen et al., 2008; Nielsen et al., 2010).

For Sweden the total national emission of $PM_{2.5}$ in 2005 has decreased by 3.4 Gg corresponding to 10.4. %. In the Swedish inventory many sectors have been recalculated. The recalculation for refineries is due to a change in emission factors for refinery oil and refinery gas. The changes in manufacturing industries and construction are also coupled with changes in the corresponding process sectors. Some of the main reasons identified are changed emission factors for 1A2d (Pulp and paper), changes for the two largest iron and steel plants, changes for all non-road machinery both in industry, households and agriculture, changes in PM emission estimates from construction (2A7) and reallocation of emissions from iron ore mining, dressing, sinter and iron ore pellets production to 2C1. Previously these emissions were reported in 2A7 (SEPA, 2009; SEPA, 2010).

5.4 Improvements in completeness

This chapter examines the development in completeness for the four countries since the 2007 submissions. The completeness of the 2007 submissions is described in Chapter 2.3.

Since the 2007 submissions the reporting format under the Convention on Long-Range Transboundary Air Pollution has changed. This has meant that several new categories have been introduced. Many of the new categories specifically target PM emissions. These categories are for instance: Quarrying and mining of minerals other than coal; Construction and demolition; Storage, handling and transport of mineral products; Storage, handling and transport of chemical products; Storage, handling and transport of metal products; Wood processing; Farm-level agricultural operations including storage, handling and transport of agricultural products and Off-farm storage, handling and transport of bulk agricultural products (NFR categories 2A7a, 2A7b, 2A7c, 2B5b, 2C5f, 2D3, 4D2a and 4D2b).

Some countries have previously reported emissions from some of these activities under other categories, and in that case only a reallocation of emissions has taken place. However, few countries have estimated all of these categories and therefore these are not included in this chapter.

5.4.1 Denmark

Denmark still reports several categories as not estimated (NE), most noticeably in the industrial processes sector. Denmark has not estimated PM emissions from any of the new source categories introduced in the new NFR format. However, Denmark has included PM emissions from several source categories since the 2007 submission. These sources include field burning of agricultural waste (sector 4F), cremations and incineration of carcasses (sector 6C) and accidental fires (sector 6D).

5.4.2 Finland

Finland does not use the notation key NE for emissions of PM. For some categories that are reported as NA (not applicable) there is an incorrect use of the notation keys. For instance for NFR category 1B2c (Venting and flaring) Finland reports emissions of all substances as NA, though the correct notation key would be IE, as it currently is not possible to separate these emissions from the total releases reported by the plants (including venting and flaring). For NFR sector 2A1 (Cement Production) Finland also reports PM emissions as NA for the same reason, though the notation key should also be IE here.

5.4.3 Norway

Norway reports many categories as NE, this has not changed since the 2007 submission. Most noticeably all PM emissions from animal husbandry are reported as NE.

5.4.4 Sweden

Since the 2007 submission Sweden has estimated PM emissions from pipeline compressors (1A3e ii) and for several animal categories, including cattle, swine and some types of poultry. Some animal types such as sheep and goats are reported as NE. In the new reporting format waste incineration has been split into several subcategories. Sweden reports emissions from industrial waste incineration and small scale waste burning but not for clinical waste incineration and cremations. Some of the "old" categories still reported as NE includes road paving with asphalt and solid waste disposal on land.

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6 Conclusions

This project has conducted a study of the particulate matter (PM) inventories in the Nordic countries. The focus has been on the two major sources road transport and residential combustion.

For road transport both exhaust emissions and non-exhaust emissions such as tyre and brake wear and road abrasion have been included. For residential combustion the work has focussed on wood burning in stoves and small scale boilers, since this is the predominant source of PM emission from the residential sector.

The main goal of this project was to asses the quality and completeness of the PM emission inventories in the Nordic countries. The basis for the evaluation was the countries submissions to the Convention on Long-Range Transboundary Air Pollution (CLRTAP) under the United Nations Economic Commission for Europe (UNECE) in 2007, where the latest reported year was 2005.

The emission inventories for PM in the Nordic countries have somewhat different key sources compared to other parts of Europe; this is caused by different climatic conditions and other structural differences.

An overview of the PM emissions for the Nordic countries are provided in Chapter 2 showing the overall emissions of PM from the Nordic countries distributed on source sectors. A key source analysis for 2005 (2007 submission) is made for the overall Nordic inventory for both PM_{10} and $PM_{2.5}$. For both PM_{10} and $PM_{2.5}$ residential plants, exhaust emissions from road transport and non-exhaust emissions from road transport are in the top five. The other two categories finishing the top five for PM_{10} are agriculture and manufacturing industries and construction. For $PM_{2.5}$ the two other sources included in the top five are manufacturing industries and construction and non-road machinery. Residential plants accounts for 39 % of the PM_{10} emission and 50 % of the $PM_{2.5}$ emission. The top five categories account for 71 % of the PM_{10} emission and for 76 % of the $PM_{2.5}$ emission.

However, there are considerable differences between the four countries, where PM inventories are available. In Sweden the PM emission from residential plants comprise a very low share of total emissions compared to Denmark, Finland and Norway. Sweden on the other hand has significantly higher emissions from public electricity and heat production compared to the other countries. Detailed accounts of the key sources for each of the four countries are included in Chapter 2.

The ratio between the reported emissions of PM_{10} and $PM_{2.5}$ was calculated for each country. Norway has the largest share of $PM_{2.5}$ compared to PM_{10} (88 %), whereas Finland has the lowest (66 %). Denmark and Sweden are right in the middle with 73 and 76 % respectively.

For residential plants Sweden calculated all particulate matter emissions as $PM_{2.5}$. Norway calculated 99.9 %, while Finland reported 92 % and Denmark reported 89.6 %.

The completeness of the inventories was assessed with particular emphasis on the categories where emissions were reported by one or more countries, while the other reported notation keys. It is found that the PM emission inventories generally are complete and that the sources reported as not estimated only are expected to have minor contributions to the total PM emissions. The completeness of the 2007 submission is in Chapter 5 compared with the status of completeness in the 2010 submission. The recalculations for the year 2005 between the 2007 submission and the 2010 submission are also presented and discussed. Several of the countries have included new PM emission source categories since the 2007 reporting, which means that the completeness of the PM emission inventories has increased. However, there are still - for three of the four countries - categories, which are reported as not estimated. Finland does not report any categories as not estimated, this may be due to different use of notation keys, since some PM emissions are reported as NA (not applicable) while other countries report emissions from the same categories. The inclusion of new categories has not had any influence on emission levels; the total impact of recalculations for 2005 performed by Denmark and Sweden is a reduction in emissions despite the inclusion of new emission source categories.

The methodologies used in the countries for estimating PM emissions from residential wood combustion and road transport are described for the Nordic countries and the differences between them is discussed. For road transport different models are used in the Nordic countries. The differences include different classifications of vehicles, different age classes, different driving condition and different driving modes. Due to the different models there are also differences in emission factors.

For residential wood combustion the differences concern the emission factors used and also the level of disaggregation in the emission calculations. The emission factors used in Sweden are lower compared to the other three countries. This can probably be attributed to a different sampling method in the measurements upon which the Swedish emission factors are based. The importance of sampling method, operating conditions and other variable is discussed in Chapter 4.

The variability of emission factors for residential wood combustion is discussed and it is illustrated that the emission factors can vary by several orders of magnitude. The importance of the sampling method used to perform the measurements is clearly of great significance. It is shown that measurements performed in a dilution tunnel can result in emission factors that are 2.5-10 times higher compared to in-stack measurements in the hot flue gas.

Several studies have also shown great variations in emission factors depending on such variables as wood species, water content of the wood, log size, batch size and the general operating conditions such as the air flow etc. This results in emission factor ranges of e.g. 11-4667 g pr GJ for the same appliance under different operating conditions.

It is also clear that the emissions vary between different types of appliances. Stoves and boilers have different emission characteristics depending on age and whether the boiler is with or without an accumulation tank. Pellet stoves and boilers have very low emission factors compared to traditional stoves and boilers fired with wood logs. The different emission factor studies carried out for pellet stoves and boilers also show very similar low results for PM emissions. In the studies reviewed it seems that wood log fired boilers generally have lower emission factors than stoves. It is also very clear that a technological development has ensured that new or modern stoves and boilers have lower emission factors compared to old stoves and boilers. The emission range also narrows significantly in the studies measuring newer or modern technologies.

The overview of the current status of PM emission inventories in the Nordic countries based on the countries 2010 submission to the UNECE Convention on Long-Range Transboundary Air Pollution shows that only small recalculations have been made. The largest recalculation for $PM_{2.5}$ is for Sweden where the emission for 2005 in the 2010 submission is 3.4 Gg less than in the 2007 submission corresponding to a decrease of 10.4 %.

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REVIEW, IMPROVEMENT AND HARMONISATION OF THE NORDIC PARTICULATE MATTER AIR EMISSION INVENTORIES

Emission inventories for stationary combustion plants are presented and the methodologies and assumptions used for the inventories are described. The pollutants considered are SO_2, NO_x, NMVOC, CH_4, CO, CO_2, N_2O, NH_3, particulate matter, heavy metals, dioxins, HCB and PAH. The CO_2 emission in 2008 was 16 % lower than in 1990. However, fluctuations in the emission level are large as a result of electricity import/export. The emission of CH_4 has increased due to increased use of lean-burn gas engines in combined heating and power (CHP) plants. However, the emission has decreased in recent years due to structural changes in the Danish electricity market. The N_2O emission was higher in 2008 than in 1990 but the fluctuations in the time-series are significant. A considerable decrease of the SO_2, NOx and heavy metal emissions is mainly a result of decreased emissions from large power plants and waste incineration plants. The combustion of wood in residential plants has increased considerably in recent years resulting in increased emission of PAH, particulate matter and CO. The emission of NMVOC has increased since 1990 as a result of both the increased combustion of wood in residential plants and the increased emission from lean-burn gas engines. The dioxin emission decreased since 1990 due to flue gas cleaning on waste incineration plants. However in recent years the emission has increased as a result of the increased combustion of wood in residential plants.

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