Particulate matter emissions and abatement options in residential wood burning in the Nordic countries

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The authors also want to thank all the national experts that have answered our questions about emission factors, activity data and different kinds of measures to reduce PM emissions. Finally, we also want to gratefully acknowledge the Transboundary Air Pollution team at IIASA, especially Zbigniew Klimont, for providing us with the latest information about the PM module in the RAINS model.

Summary

This study concentrates on fine particulate matter emissions from the residential wood combustion sector in Denmark, Finland, Norway, and Sweden. The focus on the residential wood combustion is due to the importance of this sector when it comes to PM emissions in the Nordic countries compared to the rest of Europe. Further, the lack of regulations and the possible potential to decrease the PM emissions in this sector have been other driving forces.

The purpose with the project has been twofold: to compare and harmonise the data regarding $PM_{2.5}$ emissions and cost-efficient measures in the residential wood combustion sector in the Nordic countries, and to create a well working Nordic network for particulate matter emissions.

To enable a comparison of $PM_{2.5}$ emissions, activity data and emission factors in the four countries have been carefully studied. We have been able to compare activity data, as the main sectors were comparable in all the countries and official statistics give a reasonably reliable frame for total wooden fuel use in the residential sector in all countires. The data uncertainty for activity data was deemed to be relatively smaller than for the emission factors.

In the official reports of PM emissions only one emission factor is used for each country. The emission factors used in official reports differs considerably between the countries from 150 mg/MJ for Denmark to 1932 mg/MJ for Norway (TSP). The use of different emission factors highly affects the national inventories of total contribution of particulate matter emissions from the residential combustion sector. For instance, in Denmark the $PM_{2.5}$ emission from this sector is estimated to be 19%, while the corresponding number for Norway is estimated to 69%. The emission factors are strongly technology dependent and the official emission factor should preferably be a weighted average of the emission factors from different boilers and stoves. However, there are gaps of knowledge and measurements on technology dependent emission factors from different boilers and stoves in all the countries.

In the estimates of emission factors the existence of accumulator tanks, whether optimally sized or not are of great importance. Another important factor that has not been taken into account in this report, due to lack of knowledge, is the influence of the firing habits and fuel quality, which might cause greater uncertainty on emission factors than the use of different technologies.

In this study we have calculated the revised total $PM_{2.5}$ emission by using a common technology-dependent sector classification and harmonised emission factors. Country specific activity data were allocated to these technological subcategories using additional information from other studies and expert estimates. Emission factors were harmonised by taking into account available national and international measurement data and assigning appropriate values for each technological subcategory with expert judgement.

For Norway and Sweden revised total $PM_{2.5}$ emissions from residential combustion of wood are comparable with the official inventory data (Norway 40 000 contra 38 500 ton and Sweden 20 000 contra 17 500 ton). The estimated number for Finland is 7 900 ton which is much lower than the official number that is 15 000 ton. For Denmark it is the

opposite: the estimated amount of $PM_{2.5}$ from the residential sector has in this report been estimated to 13 000 ton, while the official number is only about 2 000 ton. Both official existing emission inventories and the more detailed revised emission estimates made in this project highlights the importance of this sector in the total $PM_{2.5}$ emissions.

The abatement costs were explored by listing technical and non-technical measures in the countries. There are no adequate data available from experiences of technically controlling PM emissions in residential wood burning. Therefore, the magnitude of costs for technical control was approached through a case study on a specific measure: replacement of old wood-boilers to modern pellet boilers and also installation of new pellets burners in old wood boilers. However, the uncertainties in these estimates are high. The abatement unit costs of replacing old functioning log boilers with new pellet boilers were estimated to vary between 5 000-16 000 euro/ton reduced $PM_{2.5}$ for a new boiler and between 3 000-13 000 for replacing only the burner. Comprehensive cost curves were not compiled due to un-existing data on the large-scale application of control techniques.

Based on the case study, $PM_{2.5}$ emission reduction efficiency by the replacement of manually fed boilers without accumulator tanks with modern pellet boilers is higher than 90%. The total effect on emission reductions was estimated to be approximately 18 000 tons per year in the Nordic countries. There are large uncertainties concerning the sectoral classification and calculation parameter values, however, the consistent presentation of existing knowledge greatly facilitates further assessment.

In this report the The Particulate Matter Emission and Costs Module (PM EMCO), version 8.0, which has been developed at the International Institute for Applied Systems Analysis (IIASA) has been discussed. RAINS includes already first estimates of investment and unit costs for fireplaces with non-catalytic and catalytic inserts as well as for non-catalytic and catalytic new domestic stoves.

This study has shown that single-family house boilers are already widely used in these countries and that they have a large future potential. The case study shows the importance of including options such as a shift to low-emission pellet boilers for single-family houses into the RAINS PM Module.

The participants of the Nordic Network for particulate matter emissions include:

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Content

Abbreviations

CEPMEIP	Co-ordinated European Programme on Particulate Matter Emission Inventories, Projections and Guidance
CLRTAP	Convention on Long-Range Transboundary Air Pollution
EF	Emission factor
EMEP	European Monitoring and Evaluation Programme
IIASA	International Institute for Applied Systems Analysis, Laxenburg, Austria
NMR	The Nordic Council of Ministers
OPET	Organisation for Promotion of Energy Technologies
PM	Particulate matter
PM_{10}	Particulate matter with an aerodynamic diameter of less than 10µm
$PM_{2,5}$	Particulate matter with an aerodynamic diameter of less than 2.5µm
PM EMCO	The particulate matter emission and cost module
RAINS	Regional Air Pollution Information and Simulation model
TAP	The Transboundary Air Pollution project
TNO	Netherlands Organisation for applied Scientific Research
TSP	Total Suspended Particles
UNECE	United Nations Economic Commission for Europe

1. Introduction

1.1 Purpose of this report

The purpose with the project has been twofold: to compare and harmonise the data regarding $PM_{2.5}$ emissions and cost-efficient measures in the residential wood combustion sector in the Nordic countries, and to create a well working Nordic network for particulate matter emissions. The results will be used to assess the background material and propose cost-efficient abatement measures included in the ongoing revisions of two major air pollution agreements in Europe. The first one is the Protocol to abate acidification, eutrophication and ground-level ozone, also known as the 1999 Gothenburg protocol (UNECE, 1999), signed within the framework of the 1979 Convention on Long-range Transboundary Air Pollution (CLRTAP) under the auspices of the United Nations Economic Commission for Europe (UNECE). The second one is the emission ceilings directive (EU, 2001) of the European Union.

The focus on the residential wood combustion was due to the importance of this sector when it comes to PM emissions in the Nordic countries compared to the rest of Europe. Further, the lack of regulations and the possible potential to decrease the PM emissions in this sector has been another driving force.

The project has aimed to take advantage of all the knowledge and experience of PM emissions in the Nordic countries and to point out the similarities and differences between the countries.

1.2 Method

The main work method was to collect and harmonise both official emission inventory data as well as other new information from ongoing research studies and other sources. The comparison was divided into four main blocks: activities, emission factors, emissions, and abatement measures including both technical and non-technical options. The work was limited to residential wood burning. The residential sector consists of single-family houses and recreational buildings, e.g. summer cottages. It does not include the use of medium-sized or larger boilers (used e.g. as joint heating of several buildings in a neighborhood), agricultural or public services. Wood fuel includes all fuel types made of hard wood (e.g. wood chips and pellets), but not straw or other types of biofuels (e.g. liquidized biomass products).

1.3 Limitations

This project provides resources for an initial harmonisation and reporting of primary PM emissions related data, focusing on residential wood burning.

The data available in the four countries are not always comparable. Data available in one country might not have been estimated in another country or the numbers differ that much that the numbers cannot possibly have been estimated with comparable methods/approaches. This inconsistency in data availability has made some comparisons incomplete.

1.4 The structure of the paper

The report is divided into eight chapters. The aim of chapter 2 is to provide information about the effects of PM emissions and to show the importance of the residential wood combustion sector in the Nordic countries.

Chapter 3 deals with the activity data needed to calculate the total emission and in chapter 4 the emission factors are discussed - officially reported emission factors as well as new findings.

In chapter 5 the emissions calculated with the new detailed activity and emission factor data are discussed.

Possible measures to reduce PM emissions are discussed in chapter 6 and a case study has been carried out where the costs of replacing an existing wood-boiler with a modern pellet-boiler have been estimated.

In chapter 7 the new PM module in the RAINS model (Regional Air Pollution Information and Simulation model) is described and the suggested activity data, emission factors and different measures used in the model are discussed.

Finally, chapter 8 includes general conclusions from the study together with recommendations for future work.

2. Background

2.1 Effects of PM emissions

Particulate matter is emitted directly into the atmosphere from a variety of stationary and mobile sources, but particles also form in the atmosphere from gaseous pollutants such as VOCs, NO_X, SO_X and NH_3. Depending on the type of source of emitted particles the chemical composition as well as the size distribution may vary. Since particulate matter with a diameter of less than 10 µm (PM_{10}) penetrates into the human thorax, air quality objectives have up to now been set in relation to the total mass concentration of such particles (COM, 2001). It has been known for a long time that airborne particles have an adverse effect on human health. However, new studies have shown health effects at concentrations previously considered safe and there is a growing concern in Europe over the impact on human health of particles (Färnlund et al, 2001; IIASA, 2003).

The likelihood of particulate matter affecting human health depends largely on their size. New evidence suggests that the fine or even ultra fine fractions of particulate matter ($PM_{2.5}$ and $PM_{0.1}$ respectively) can be affiliated with harmful effects (WHO, 2003). PM are associated with increased mortality, increased number of hospital admissions for respiratory diseases, exacerbation of asthma, coughing and small reductions in lung functions (Färnlund et al, 2001). There are still many uncertainties, and the precise mechanism of damage is still not known (COM, 2001).

This study focuses mainly on fine particulate matter ($PM_{2.5}$), but discusses also total suspended particles (TSP) and inhalable particulate matter (PM_{10}). In spite the fact that most measurements and literature are available for TSP emission factors and emissions, the importance of smaller particle sizes, especially $PM_{2.5}$, on health effects is a strong driving force for new research studies. To this end, official international emission inventories have already included $PM_{2.5}$ in their work. Therefore, we have attempted to compile existing knowledge to derive harmonised input data to calculate detailed $PM_{2.5}$ emissions from the residential wood burning sector. However, we readily admit the difficulty and uncertainties included in this aim, e.g. since there are no Nordic measurements on $PM_{2.5}$ emission factors yet available from this sector.

2.2 The importance of the residential wood combustion sector

In all the Nordic countries, annual national emission inventories of several pollutants, including PM, are calculated according to the requirements in the Draft Guidelines for Estimating and Reporting Emissions Data (UNECE, 2002). The nationally inventoried data are reported to UNECE, which subsequently publishes them in reports and on internet (EMEP-Webdab, 2003). These nationally submitted emissions data are used for different purposes by several international organisations, e.g. for compliance assessment and for modelling purposes of various kinds, including in the RAINS modelling activities. Activity data in RAINS for the year 2000 originate from international and national statistics, as well as the CEPMEIP (2002) database. As sources for historic activity numbers for energy use in stationary combustion Klimont et al. (2002) cite two sources: IEA (1998) and EC (1999a and 1999b). In RAINS activity data are first multiplied with respective *un*abated emission factors to get *un*controlled emissions. On top of this, control options are applied for a certain year with certain applicability.

Particulate matter air pollution is caused by diverse sources, such as from fuel combustion or industrial processes, but also by e.g. road abrasion and from handling of raw materials. One major source of primary particle emissions is fuel combustion, including mobile sources such as diesel and gasoline-powered vehicles and stationary power plants (IIASA, 2003).

In the Nordic countries the residential combustion sector is a very important sector, which contributes to a large share of estimated PM emissions from both stationary combustion as well as the total emissions. In the nationally submitted data to UNECE, the emissions of $PM_{2.5}$ from residential plants in Denmark is estimated to about 50% (Figure 1) of the $PM_{2.5}$ emissions from stationary combustion. The corresponding number for Finland is 63% (Figure 2), for Norway even higher 98% (Figure 3) and for Sweden 69% (Figure *4*). In the nationally submitted particle emissions estimates presented in figures 1-5, all fuels used in the residential sector are included. In the submissions emissions from individual fuels are not reported separately, but most of the particle emissions from residential combustion arises from biomass combustion (Figure 5, data for Norway could not be calculated since no official emission factor for $PM_{2.5}$ was available). The figures below (1-4) show emissions only from stationary combustion, while figure 5 compare emissions of $PM_{2.5}$ from residential plants with national total emissions including all sources. Please note the different scales on the y-axis for the countries.

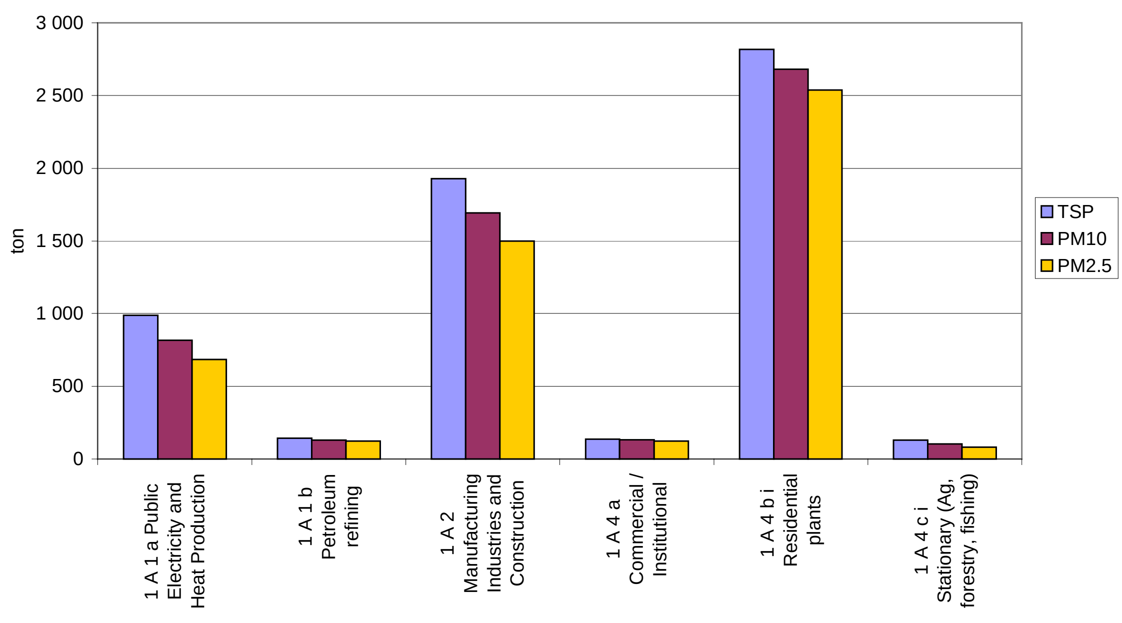


Figure 1. Annual PM emissions from stationary combustion in Denmark in 2000. The data are official inventory results from table IV 1A of the national emission as defined by Draft Guidelines for Estimating and Reporting Emissions Data (UNECE, 2002).

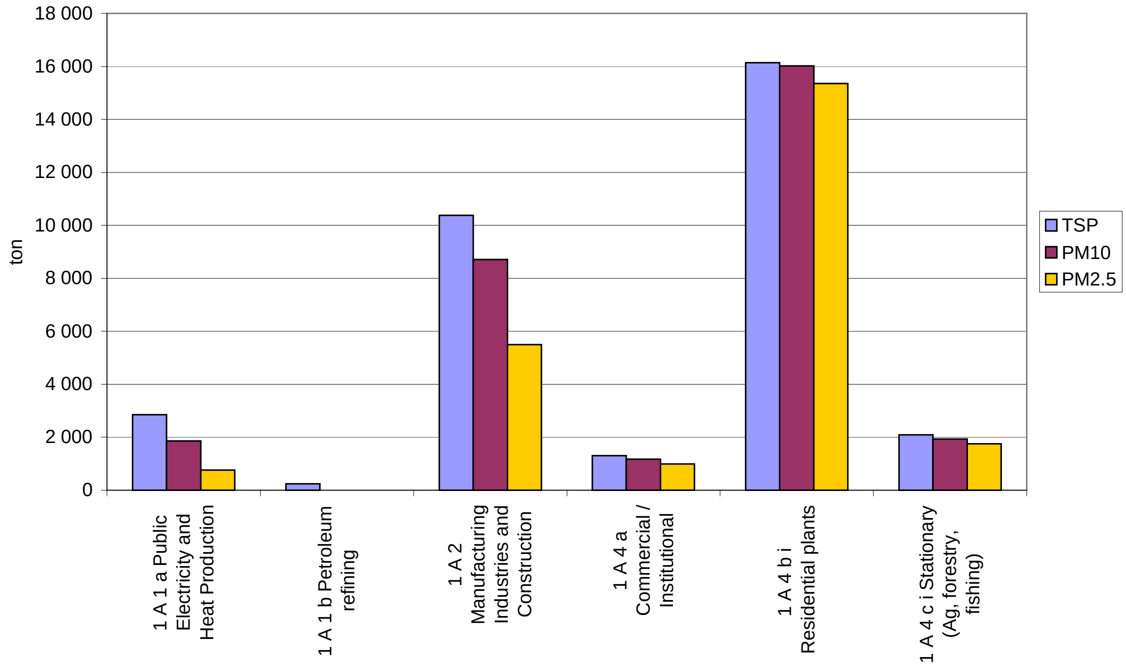


Figure 2. Annual PM emissions from stationary combustion in Finland in 2000. The data are official inventory results from table IV 1A of the national emission as defined by Draft Guidelines for Estimating and Reporting Emissions Data (UNECE, 2002).

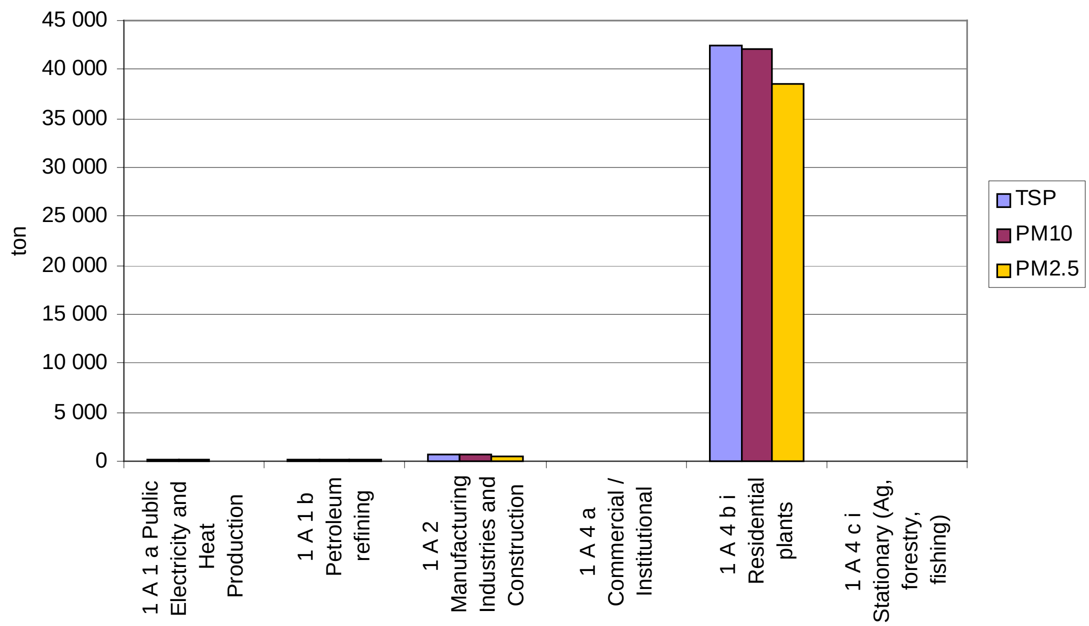


Figure 3. Annual PM emissions from stationary combustion in Norway in 2000. The data are official inventory results (personal communication G. Haakonsen, 2003).

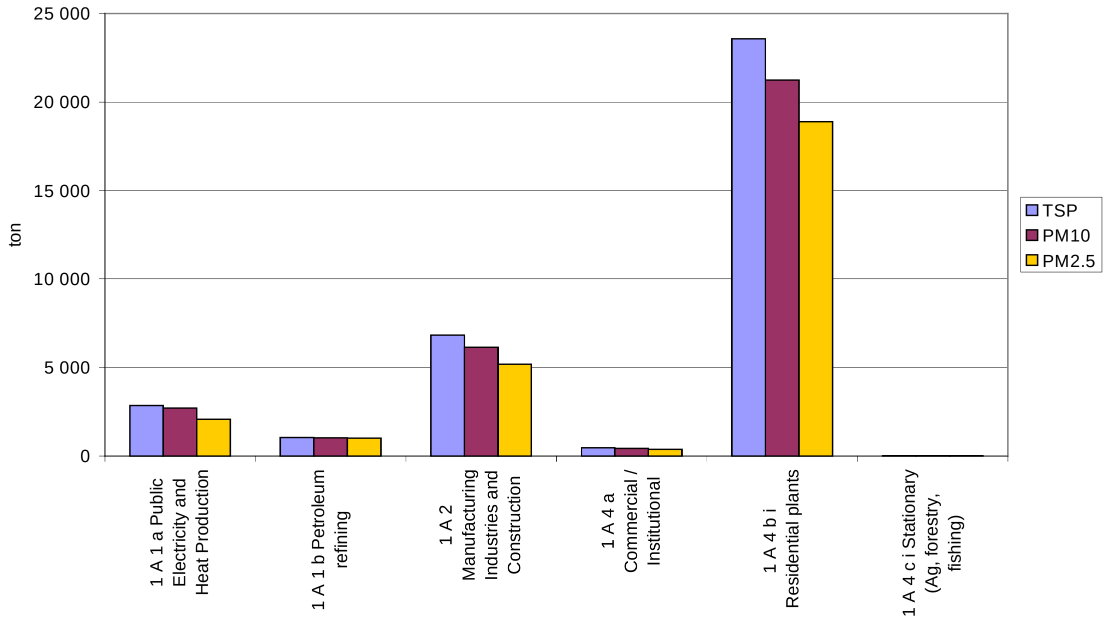


Figure 4. Annual PM emissions from stationary combustion in Sweden in 2000. The data are official inventory results from table IV 1A of the national emission as defined by Draft Guidelines for Estimating and Reporting Emissions Data (UNECE, 2002).

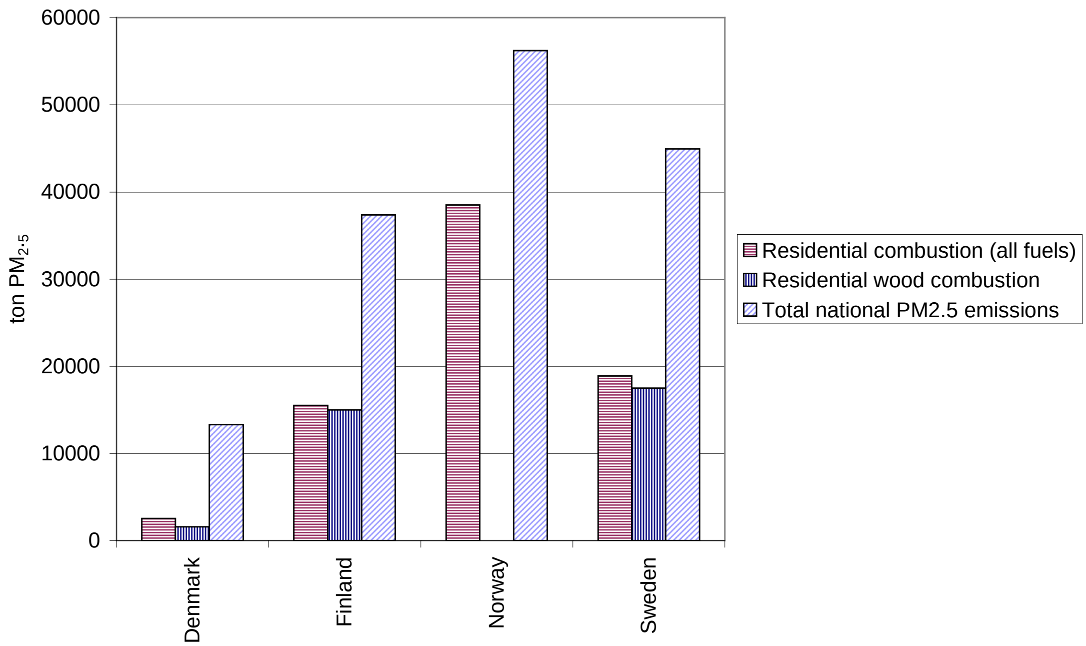


Figure 5. The officially submitted emission of $PM_{2.5}$ from the residential combustion sector (all fuels), the amount that arises from only residential wood combustion (calculated from official emission factors in table 2 and activity data in chapter 3), in comparison to officially submitted national total $PM_{2.5}$ emission, in the Nordic countries in 2000. (National total emissions of $PM_{2.5}$, Denmark 13 290 ton, Finland 37 380 ton, Norway 56 200 ton and Sweden 44 950 ton). Data for wood combustion could not be calculated for Norway since no official emission factor for $PM_{2.5}$ was available.

The contribution from the residential combustion sector to the total national $PM_{2.5}$ emissions, as submitted to UNECE, differs between the four countries. In Denmark the combustion from the residential plants stands for about 19%, in Finland 41%, in Norway 69% and in Sweden 42% (Figure 5). These numbers can be compared with the nationally estimated contributions from the transport sector, which are estimated to 35% in Denmark, 16% in Finland, 9% in Norway and 10% in Sweden (UNECE, 2002; SSB, 2003). It is however necessary to point out that emission inventories of particulate matter have rather recently been attended to more closely, why estimated national total emissions should be interpreted with some caution. The experiences from estimating PM emissions from all the possible various sources are not as large as for many other pollutants that have been more closely studied for a longer period of time. Thus, there may be variations in the nationally submitted data from different countries, e.g. as to the completeness of coverage of sources and to the degree of certainty in the estimates as such. Nevertheless, the conclusion that can be drawn from these figures is that the $PM_{2.5}$ emission from the residential combustion sector is of major importance in the Nordic countries, especially in Finland, Norway and Sweden. One reason for the low figure for Denmark is the use of lower emission factors when estimating the national emissions of PM from residential combustion of biofuels, which will be further discussed in chapter 4.

3. Activity data

3.1 Estimation of activity data in residential wood combustion

Several aspects have to be taken into consideration when discussing and selecting activity data for estimation of emissions from combustion in the residential sector. In this project the aim was to only include residential combustion of wooden fuels (incl. firewood, wood chips, pellets).

Firstly, the amount of fuel used and the kind of wooden fuel used, have to be known. Secondly, it is necessary to estimate the national composition of equipment and technology used for combustion. In addition the firing habits and the type of technology used highly influence the emission factors and the total emission of PM.

The information available concerning these aspects of the activity data differs in the Nordic countries. The amount of wooden fuels used in residential combustion is reported in official statistics, but the level of detail and the grouping of areas of use vary considerably. Furthermore, even less information is available and a larger proportion of expert judgement has to be applied concerning the firing habits and amount of fuels used in the various combustion equipment.

In this project an attempt was made to standardise the information on fuel use in different appliances in the Nordic countries in a way that would facilitate the calculations of emissions and control potential. Table 1 and Figure 6 show the result of this attempt, as a classification of activity data of the wooden fuel use in different combustion devices by country. The classification is the result of separating technologically different burning types, and the (potential) availability of both activity data and measurements to determine emission factors for the subcategories. Especially the last one is a limiting factor in obtaining reliable emission estimates from this sector. The total activity volume is obtained from official country statistics and is the same as used in official emission reporting for 2000 (except for Sweden, as described further in chapter 3.2.4). The categorisation of the total activity data on residential wooden fuel use in Table 1 is a combination of more detailed official statistics, information from research projects and expert judgement, further described below for each separate country. The distinctions between the groups of technical equipment are not always clear-cut.

The group "conventional stoves" includes masonry heaters and stoves, conventional kitchen stoves, masonry ovens and sauna stoves. In this group the extent of use is highly uncertain and may vary greatly between users. Some appliances are probably only used occasionally or maybe not at all, while others are used regularly during the colder season as support to the main heating system. The presented figures on the fuel used in this group are of necessity a simplification of reality, but estimated at best available knowledge. This also accounts for the open fireplaces, where firing habits vary greatly.

Conventional boilers with accumulator tanks are placed under modern/low-emission boilers. PM emissions from boilers equipped with accumulator tank are lower than if an accumulator tank system is not installed, since the existence of an accumulator tank permits more efficient firing.

Table 1. Annual energy consumption in the residential sector in different appliances in the Nordic countries (2000).

Main category	**Residential wood combustion TJ/year**			
	Denmark	*Finland*	*Norway*	*Sweden*
Conventional manually fed boilers without acc. tank	**6 100**	**2 700**	**1 200**	**17 000**
Conventional stoves	**4 300**	**28 900**	**19 100**	**14 100**
• Conventional masonryheaters and stoves		8 000		4 300
• Conventional iron stoves	4 300	1 100	19 100	1 800
• Kitchen range/stoves		5300		8 000[a]
• Masonry ovens		5900		
• Sauna stoves		8 600		
Modern/low-emission boilers	**1 570**	**6 900**		**6 300**
• Pellet boilers	1 100	100		1 800
• Automatically fed boilers other than pellet		1 400		
• Conventional manually fed boilers with accumulator tank	470	5 400[a]		3 500
• Other low emission (e.g. certified) log boilers				1000[c]
Modern/low-emission stoves			**1 500**	**400**
• Pellet stoves				400
• Modern (e.g. certified) iron stoves/masonry stoves			1 500	
Open fireplaces		**600**	**860**	**3 400**
Total	**12 000**	**39 100**	**22 700**	**41 200[b]**

a) Sum of kitchen stoves and masonry ovens.
b) Consumption in 2001.
c) Boilers with accumulator tank.

The total wooden fuel use in residential combustion amounts to approximately 12 000 TJ/year in Denmark, 23 000 TJ/year in Norway, and approximately 40 000 TJ/year in Finland and Sweden (Figure 6). In Denmark approximately 50% of the energy from wooden fuel is used in conventional boilers and 35% in conventional stoves. In Finland, the fraction used in conventional stoves is dominating, more than 70%, while the share for conventional boilers and low-emitting boilers together only amounts to approximately 25-30%. In Sweden, the situation is the other way around, the boilers (conventional and low-emitting) use almost 55-60% of the fuel, while the share for conventional stoves is estimated to about 35%. In Norway, the fraction of wooden fuels used in boilers is small, only about 5% while almost 85% is used in conventional stoves. The fraction of wooden fuel estimated to be used in modern low-emitting appliances (boilers and stoves) are 20%, 16%, 12% and 7% for Finland, Sweden, Denmark and Norway respectively.

Of the population of boilers, the fraction of low emitting boilers is the largest in Finland, above 70%, while in Sweden and Denmark they add up to about 30% and 20% respectively. In Norway the share of low-emitting boilers is negligible, while Norway has the largest share of low-emission stoves.

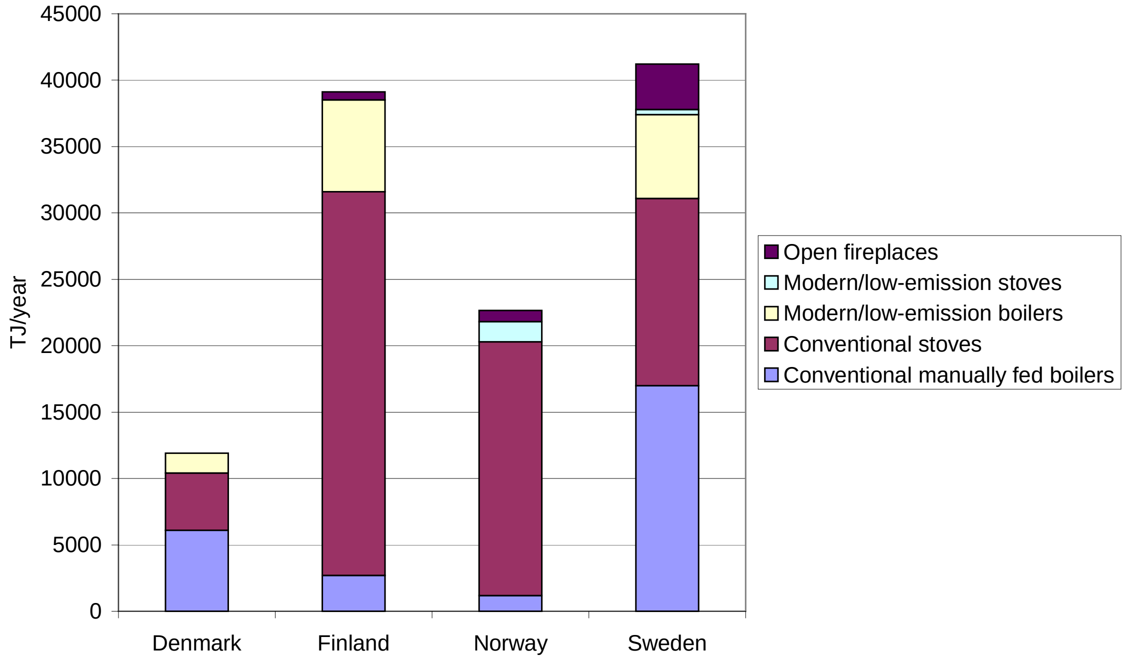
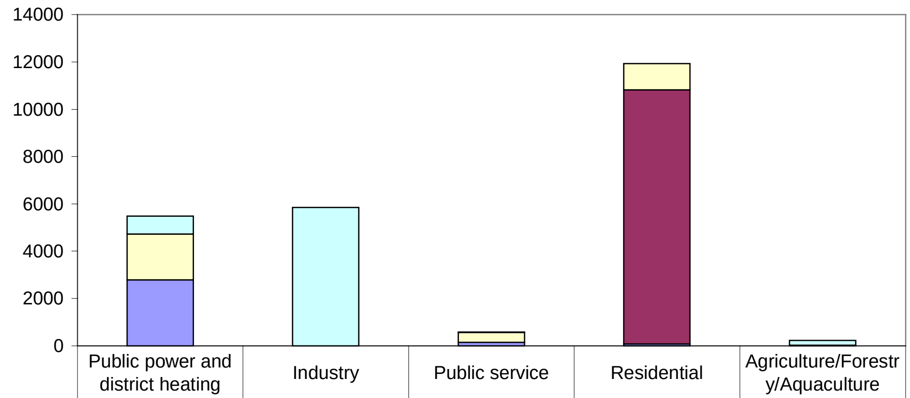


Figure 6. Wooden fuel use, total and in different combustion equipment in the Nordic countries in the residential sector (TJ/year, see explanations in Table 1).

3.2 Status and availability of relevant activity data in the Nordic countries

3.2.1 Denmark

The total use of wooden fuel in Denmark is presented in Figure 7 for different categories of use. Firewood that has not been traded (private woodcutting) is considered to account for a considerable part of total consumption of firewood in the residential sector. It is important that this part of the consumption is included in energy statistics, as it currently is. The Danish Energy Agency has stated that the consumption of firewood is calculated as described in the note *Firewood Statistics* (dk-Teknik and Danish Energy Agency, 2000). The method includes a qualified estimate of the share of total consumption that is not traded. Each year Statistics Denmark publishes data concerning traded firewood. The total consumption is estimated to be 3 times this consumption. The factor 3 is determined from three independent questionnaires where the origin of firewood used in residential combustion was examined. The data on consumption of firewood in the residential sector from the energy statistics are thus uncertain but the best estimate that can currently be given.



	Public power and district heating	Industry	Public service	Residential	Agriculture/Forestry/Aquaculture
Wood waste	760	5850	4	0	203
Wood pellets	1934	0	426	1112	0
Fire wood	0	0	0	10743	0
Wood chips	2793	0	146	81	27

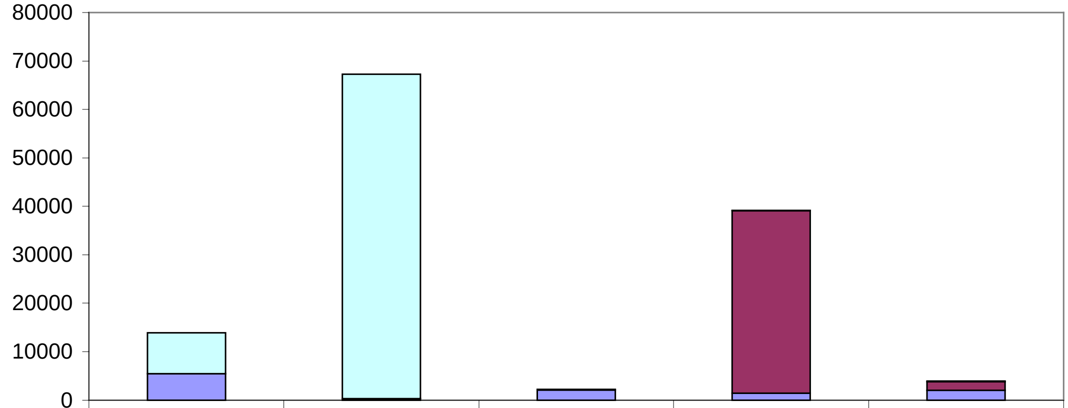
Figure 7. Wooden fuel consumption in TJ/year of wood chips, firewood, wood pellets and wood waste in different sectors in Denmark in 2000.

The Danish energy statistics distinguishes between wood chips, firewood, wood pellets, and wood waste. In the national inventories these fuels are aggregated and marked wood. If the emission factors differ considerably depending on wood category it might be desirable to disaggregate wood consumption in future national inventories.

There are about 300 000 stoves in Denmark and 90 000 small-scale boilers using wood. Further there are some open fireplaces. The dominant wood type used in the domestic sector is firewood. About 10 % of the wood is pellets mostly used in small boilers with automatic fuel feeding systems. Almost all stoves in Denmark are either conventional or non-catalytic stoves. There are about 65 000 conventional boilers (old firewood boilers) and 25 000 modern boilers. For the modern boilers 20 000 are pellet boilers and 5 000 new firewood boilers with accumulator tanks (Nikolaisen, 2003).

3.2.2 Finland

The Finnish energy statistics (Statistics Finland, 2001) distinguishes between domestic firewood, forest residue chips, construction and demolition wood, pellets, bark, sawdust, wood residue chips, black liquor and others and includes all end-use sectors such as industry, large-scale combustion etc. Figure 8 shows a summary of the official Finnish energy statistics concerning wooden fuels.



	Public power and district heating	Industry	Public service	Residential	Agriculture/Forestry/Aquaculture
Wood waste	8430	66970	0	0	0
Wood pellets	0	300	100	100	100
Fire wood	0	0	0	37700	1800
Wood chips	5460	0	2100	1400	2000

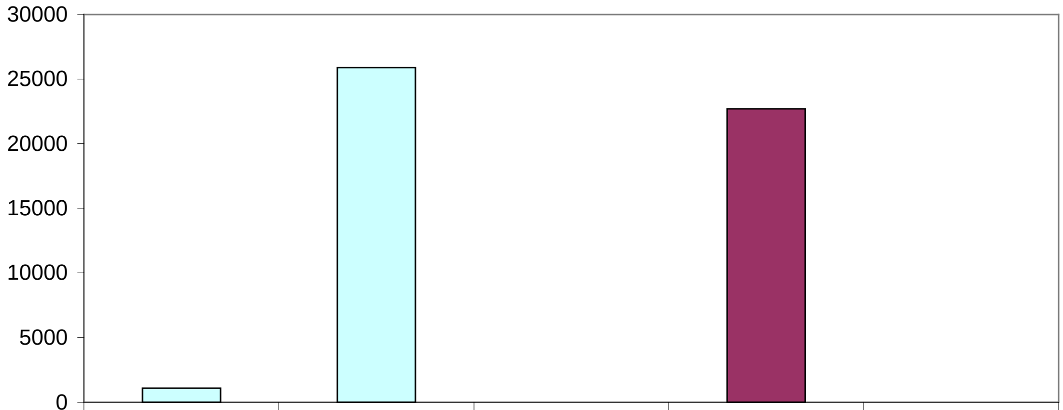
Figure 8. Wooden fuel consumption in TJ/year of wood chips, firewood, wood pellets and wood waste in different sectors in Finland in 2000.

The domestic heating with wood combustion is divided into residential buildings (4 sub-sectors), commercial and public buildings and agricultural buildings in the statistics.

There are about 2 200 000 small-scale wood-burning devices in Finland of which 1 200 000 in detached houses, 800 000 in recreational houses and 200 000 in semidetached houses and blocks of flats. In addition, there are 1 500 000 sauna stoves. Roughly 10% of the residential buildings in Finland use wood as primary heating source, and they consume about 65% of all wooden fuel. The most important types of stoves in Finland are: masonry heaters (stoves made of stones/bricks, that are accumulating the produced heat, batch fed, used often as a supplementary heating device), pellet heating stoves, stoves for saunas, masonry ovens (used for baking, mainly at country-side), kitchen and iron stoves (used for cooking and for heating purpose in small recreational buildings), open fireplaces (used primarily for aesthetic effects). The fuel used is predominantly firewood (logs), but the amount of pellets used in the domestic sector is increasing.

3.2.3 Norway

The total wooden fuel consumption in Norway is presented in Figure 9.



	Public power and district heating	Industry	Public service	Residential	Agriculture/Forestry/Aquaculture
Wood waste	1071	25878	0	0	0
Wood pellets	0	0	0	0	0
Fire wood	0	0	0	22700	0
Wood chips	0	0	0	0	0

Figure 9. Wooden fuel consumption in TJ/year of wood chips, firewood, wood pellets and wood waste, different sectors in Norway in 2000.

The Norwegian Energy Statistics includes only one column summarising fuel wood, black liquor and waste (Statistics Norway, 2003). The activity numbers (in PJ) for net domestic consumption, manufacturing, mining and quarrying, and other sectors are relatively high, and it is difficult to derive activities for wood fuels alone.

Therefore, the activity numbers for wood fuel consumption in domestic households and in industry used in this report are based on personal communication with Gisle Haakonsen, Statistics Norway (SSB 2003; see also Haakonsen and Kvingedal, 2001). They are derived from the Norwegian energy budget for year 2001, given in kiloton of fuel.

The mass unit (kton) was transferred into TJ/a (Figure 10) by using the following assumptions: For wood logs a heat value of 19,75 kJ/kg was taken. The relatively high value is an average based on information from the literature for dry birch and pine wood logs, the major wood fuels used in Norwegian households. A survey based on a questionnaire has shown that also other types of fuels than wood are used, for instance newspapers, cardboard, and milk cartons. These fuel types are not included in the Norwegian inventory.

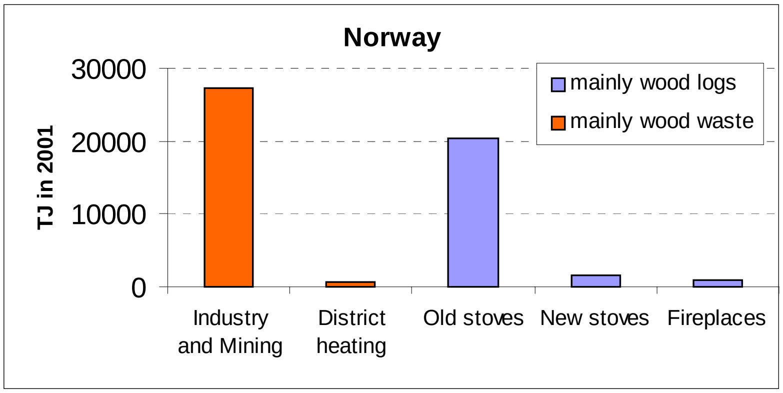


Figure 10. Consumption of wood fuel in TJ/year in the industrial and domestic sectors in Norway in year 2001.

About 57% of Norwegian households have stoves installed. 89 % of the stoves were installed before 1998 and are conventional stoves, 7% are new stoves installed since 1998 (catalytic stoves or stoves with emission reduction technology other than catalytic) and 4% are open fireplaces (Haakonsen and Kvingedal, 2001).

Although the potential of pellet production is great, pellet boilers and stoves are so far not very common in Norway. According to Malisius et al. (2000) there were only eight pellet burners larger than 200 kW existing at the end of the 1990ies, mainly in public buildings. Four more were planned for central heating in year 2000. The number of small pellet burners (20-50 kW) was about 30, and the number of pellet stoves was estimated to be 140 in 1999.

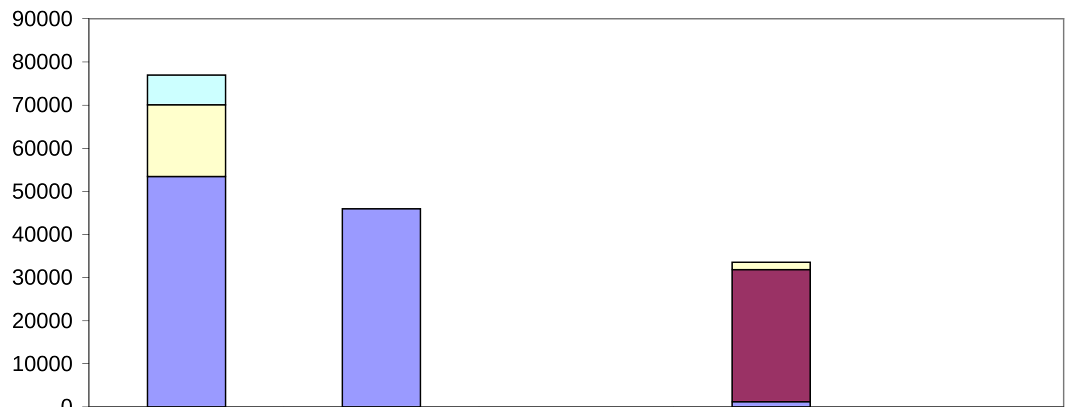
3.2.4 Sweden

According to the Swedish energy balance for 2001, a total of 349 552 TJ from biofuels were produced, including a variety of fuels used, such as wood, black liquor, wood waste, peat etc. Energy industries contributed with 123 297 TJ (35%), industry 184 387 TJ (53%) and “other”, including the residential combustion 41 868 TJ or 12% (Statistics Sweden, 2002b).

The statistics concerning residential wooden fuel use from Statistics Sweden (2002b) show lower consumption than is estimated in a newer inventory (Löfgren, 2002) which used the chimney sweepers register as a source. The intervals of sweeping (from every 8th week to every 3rd year) are set according to the frequency of use of the boiler, stove or fireplace as a wooden fuel combustion device. Based on this register and assumptions concerning the amount of wooden fuel used for different categories of combustion devices, in combination with the known intervals of sweeping, a total wooden fuel consumption in the residential sector of approximately 50 000 TJ is estimated by Löfgren (2002). The amount from the energy statistics (Statistics Sweden, 2002b and Schöllin, 2003) amounts to approximately 35 000 TJ for 2000 and 41 200 TJ for 2001. According to Löfgren (2002) the reason for this discrepancy could be an underestimation in the official statistics of the consumption for open fireplaces and other devices that are not used as primary heating sources. For the purpose of this project, a total wooden fuel consumption in the residential sector in Sweden of 41 200 TJ was used. This value is equal to the consumption used in the national official inventory calculations for 2001, and between the official energy statistics for 2000 of 35 000 TJ and the estimates made by Löfgren (2002) of 50 000 TJ.

The Swedish energy statistics distinguishes between firewood, woodchips and pellets for combustion in domestic detached houses, residential blocks of flats, small-scale district heating and for commercial buildings (Statistics Sweden, 2002a and 2002b). For the domestic use of firewood, wood chips and pellets the estimates are based on regular questionnaires to residential homeowners. The dominating fuel is firewood while pellets and wood chips only contribute to a smaller share in the domestic sector.

In Figure 11 the wooden fuel use separated on fuel types in Sweden in 2000 is presented (personal contact with Schöllin, 2003). There are sometimes problems in distinguishing between different bio-fuels used in industry, since a very large proportion is black-liquor and other by-products in e.g. the pulp and paper industry. Thus only the use of wood chips in industry has been included in Figure 11. The difference in total wooden fuel use in the residential sector, according to the official statistics, is rather large between 2000 and 2001, as discussed above. For the purpose of this report, a total wooden fuel use of 41 200 TJ (official number for 2001) was used, and the detailed information presented in Figure 11 concerning 2000 was used as an information source for the classifications as presented in Table 1.



	Public power and district heating	Industry	Public service	Residential	Agriculture/Forestry/Aquaculture
Wood waste	6955				
Wood pellets	16609			1732	
Fire wood				30654	
Wood chips	53421	45930		1166	

Figure 11. Wooden fuel consumption in TJ/year of wood chips, firewood, wood pellets and wood waste, different sectors in Sweden in 2000.

The populations of boilers and stoves in Sweden were investigated during the 1990ies and reported in 1998 (Naturvårdsverket, 1998). At that time the consumption of biofuels for residential firewood combustion was estimated to 11-12 TWh (39 600-43 200 TJ) which corresponded to approximately 25% of the total energy use for heating purposes in domestic and other small houses. It was possible to use firewood in about 440 000 domestic boilers and in about 150 000 boilers in agricultural buildings, giving a total of 590 000 boilers. It was estimated that 2/3 of these could use other fuels, such as oil or electricity. From these estimates it can be deducted that approximately 200 000 boilers were exclusively using wood. Of the 590 000 boilers that could use firewood, 413 000 (30%) were estimated to have an accumulator tank installed in 1998. Later projections, based on these data and new inventories in some regions in Sweden (Löfgren, 2002), indicate that the fraction of boilers equipped with accumulator tank today could be much higher at least locally since in some communities with air-pollution problems it has been an issue to reduce emissions. In this project, concerning national estimates the share of boilers with accumulator tank was however assumed to be approximately 30%, in accordance with estimates by Löfgren (2002) for national conditions.

During 2002 new inventories concerning the number and use of equipment for biofuel use in the domestic sector were made (Löfgren, 2002, Gustavsson, L.). These inventories show that there are about 173 000 older boilers and 100 000 newer boilers that predominantly are fed with firewood (the total number that can use firewood is larger). Less than 15% of these approximately 275 000 boilers predominantly using firewood meet environmental standards according to Boverkets Byggregler (Boverket, 2002).

In addition to the boilers, there are approximately 1 100 000 smaller local fireplaces (e.g. stoves, open fireplaces) of which 345 000 are swept each year, which indicates that they are used rather frequently for heating purposes (Löfgren, 2002).

The average lifetime of boilers is estimated to be 20-25 years (Naturvårdsverket, 1998). A modernisation of the population is underway, since older equipment is gradually exchanged to new, more environment-friendly technologies. The exchange rate is estimated to be 15 000-20 000 boilers/year. As for accumulator tanks, a gradual installation of approximately 10 000 tanks/year as a complement to old boilers is estimated (Naturvårdsverket, 1998). Both an increased share of equipment with accumulator tanks and the exchange of old boilers for newer ones will influence the emissions of particulate matter.

3.3 Uncertainty

Generally, the statistics concerning residential wooden fuel combustion are rather uncertain. This applies especially for residential wood burning, since the proportion of privately obtained firewood is difficult to measure. Adjustments are made to cover this known deficiency in the official statistics in all countries, but it is nevertheless somewhat difficult to evaluate how comparable the figures actually are between the countries. Considering the efforts made in this project, in comparing official statistics with estimates from research projects and other sources, the values on total consumption of residential wooden fuels in each country should be reasonable.

As for the amount and types of wooden fuels used and the firing habits, in the different kinds of boilers, stoves and open fireplaces, the uncertainty is high. This is especially true from the point of view of comparing the Nordic countries, since the available information in the countries vary concerning how much that is actually known from investigations and how large a proportion of expert judgement that had to be made.

3.4 Improvements of activity data

Obviously, there are several problems encountered in compiling activity data for residential combustion. The fuel statistics as such, include assumptions on privately obtained firewood. The statistics in the Nordic countries are not always comparable since the split of fuels in subgroups, as well as the split on different areas of use varies.

Harmonisation work like this (result-oriented research-based cooperative effort) proved very useful. Currently, official emission inventories do not have detailed subcategories in the residential sector to calculate the emissions by using the more detailed activity data and emission factors explored in this study. Countries can naturally make their own inventory calculations in finer detail before aggregating results into the official classification, but these are not harmonised between the countries. Although the official inventory classification may not need refinement, semi-official suggestions could be made on how to divide the sector in general to improve the emission estimates from residential wood burning and to facilitate possible future data comparisons between the countries.

The largest problem, however, and the one most difficult to solve is to what extent different types of combustion equipment is used and how it is used (firing habits). Some special, country-specific inventories have been made, as referred above, but more research is needed to establish good knowledge in this field.

We suggest that the most feasible way to get new and better information on residential wood burning activities is to make limited questionnaires in countries and then to extrapolate results when feasible. Such a questionnaire would include information on combustion equipment, fuel sources and quality, heating intervals and burning habits.

4. Emission factors

For all the Nordic countries combustion of wood in the domestic sector is an important source of particulate matter emissions (Figure 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 situation.

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.

4.1 Emission factors used in official reports

4.1.1 Domestic use of wood

Table 2 shows the emission factors for wood stoves and boilers used in the official emission inventory reports for the year 2000 for Denmark, Finland, Norway and Sweden. The fraction of $PM_{2.5}$/TSP ranges from 0.8 in the Swedish emission factors, to 0.9 in the Danish (from TNO) and 0.96 in the Finnish emission factors.

Table 2. Emission factors for wood stoves and boilers used in official inventory reports for the year 2000 (mg/MJ).

Fractions	**Denmark**		**Finland**		**Norway**		**Sweden**	
	EF	*Ref.*	*EF*	*Ref.*	*EF*	*Ref.*	*EF*	*Ref.*
TSP	150	1	400	2	1932	4, 5	650	6
PM_{10}	143	1	400	3	1932	4, 5	590	6
$PM_{2.5}$	135	1	384	3	-	-	520	6

1. TNO, 2003.
2. Statistics Finland, 2001 (estimation of emission factor based on literature).
3. The PM_{10}/TSP and $PM_{2.5}$/TSP fractions are taken from Karvosenoja 2001.
4. Gisle Haakonsen and Eli Kvingedal, 2001.
5. Average value for traditional stoves, new stoves and fireplaces.
6. Expert judgement based on ongoing measurement projects.

Denmark

The only measurements carried out in Denmark are the measurements in laboratory when stoves are approved. In these measurements a wood consumption rate of 1.6 kg/hour is used and the average emission factor was estimated to be 30 mg TSP/MJ (stoves tested for certification at the Danish Technological Institute). As seen from Table 2 the TNO emission factors are used for both stoves and boilers in the Danish particle emission inventory for 2000 (TNO, 2003). The TNO institute in the Netherlands has calculated an European emission inventory within the CEPMEIP project and provided default emission factors in the reporting guidelines prepared jointly with EMEP and IIASA. TNO gives default TSP emission factors in the interval 150 to 300 mg/MJ. In the calculations of the PM emissions for Denmark, TNO used the TSP emission factor 150 mg/MJ for combustion of wood, whether it is combusted in e.g. an institutional boiler or a residential stove. The TSP emission factor 300 mg/MJ is only used for countries where the general emission level is expected to be high. TNO has stated that 90% of the TSP is $PM_{2.5}$.

In Denmark emission measurements in residential areas with many stoves have taken place during the winter 2002/2003 but no analysis of the results are available yet. At present no additional emission measurements are planned in the country.

Finland

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

A new 3-year project *Fine particle emissions from wood combustion* started early 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 will be measured in the project and the results will be available during 2003 or 2004.

Norway

Norwegian measurements have shown that emissions of particles strongly depend on the wood load (kg wood/hour) (Haakonsen and Kvingedal, 2001). Figure 12 shows the emission of PM for various combustion technologies as a function of average wood consumption. It 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. Investigations show that a typical load is 1.0 to 1.25 kg wood/hour resulting in a TSP emissions of about 40 kg/tonnes wood for conventional stoves (older than 1998) or 2 105 mg/MJ assuming a lower heating value of 19 GJ/tonnes of dry wood. The average PM_{10} emission factor is 1932 mg/MJ, while Haakonsen and Kvingedal (2001) recommend to use an emission factor for new stoves of 42 mg/MJ. Since the emission factor strongly depends on the wood consumption, Haakonsen and Kvingedal (2001) recommend that further investigation 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.

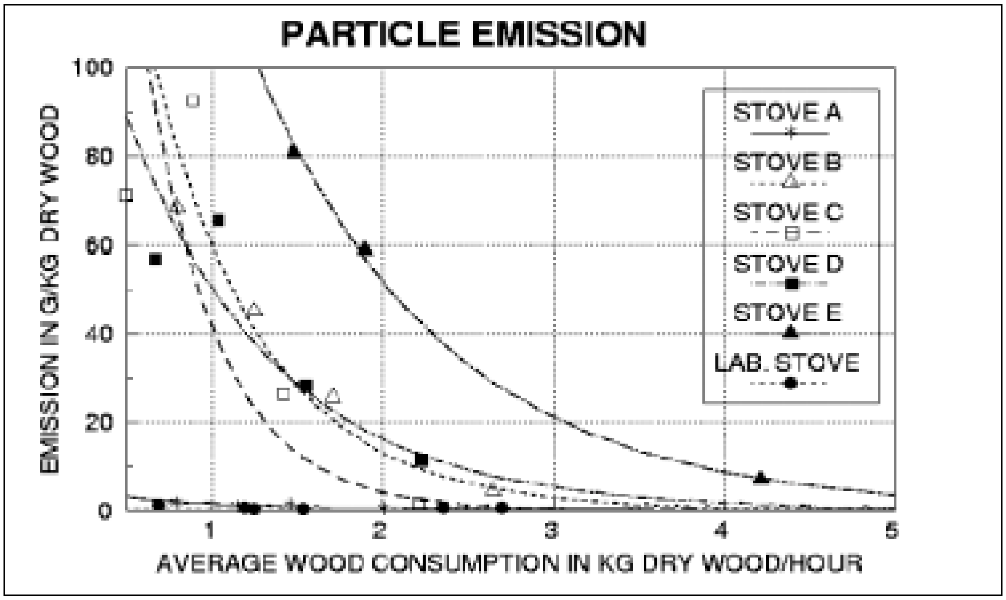


Figure 12. PM emission of 6 wood fired stoves. Dependency of wood consumption rate. A: catalytic stove, B-D: old stoves, E: open fireplace (Haakonsen and Kvingedal, 2001).

Sweden

The emission factors for official reporting shown in Table 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. There is at present more information 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.

4.1.2 Conclusions

The comparison of emission factors for wood combustion used in official reports in the Nordic countries shows a range from 150 to 1932 mg/MJ for TSP indicating a large variability of an order of magnitude. A similar range would not be consistent for $PM_{2.5}$ as there is no value for Norway, but the range 135-520 mg/MJ may give some idea on the variability. However, the lowest value for TSP (150 mg/MJ) was based on a default recommendation. The official emission factors based on measurements in Finland and Sweden and the official Norwegian emission factors indicate that the TNO defaults are too low, at least for Nordic conditions. Further studies of the emission factors for wood combusted in residential plants are important in order to improve the quality of the PM emission inventories. These studies should include field test emission measurements and surveys of fuel habits and plant types. There is also a need of increased knowledge of PM size distribution.

4.2 Additional information on emission factors

As discussed in section 4.1 the emission factors used for carrying out the official PM emission inventories are only on a general level for Denmark, Finland and Sweden. The Norwegian emission estimates are based on an aggregated emission factor for traditional/conventional stoves, new stoves and open fireplaces. In order to improve the reliability of total emissions and be able to suggest possible reduction measures, it is necessary to have estimates for technology dependent emission factors. For the Nordic countries it is relevant to categorise the stoves and boilers as given in Table 3. The table contains the values stated by Finland, Norway and Sweden, as no technology dependent emission factors are available for Denmark.

Table 3. Technology dependent emission factors, measurement data.

Main category	**Emission factors mg/MJ (TSP)**			
	Denmark	*Finland*	*Norway*	*Sweden*
Conventional manually fed boilers without acc. tank		**300 [a]**		**900 [c]**
Conventional stoves				
• Conventional masonry heaters and stoves				
• Conventional iron stoves			2100[b]	
• Kitchen range/stoves		150 [a]		
• Masonry ovens				
• Sauna stoves				
Modern/low-emission boilers				
• Pellet boilers				35 [c]
• Automatically fed boilers other than pellet		100 [a]		
• Conventional manually fed boilers with acc. tank				95 [c]
• Other low emission (e.g. certified) log boilers				30 [c]
Modern/low-emission stoves				
• Pellet stoves				30[c]
• Modern (e.g. certified) iron stoves/masonry stoves			330 [b]	
Open fireplaces			**910 [b]**	

a) Expert estimate (N. Karvosenoja) based on TSP measurements by Hahkala M., Jormanainen P., Puustinen H. and Pohjola V. 1986b.
b) Based on PM_{10} measurements cited in Haakonsen, G., Kvingedal, E. (2001).
c) Based on TSP measurements by Johansson, L., Gustavsson, L. Tullin, C. and D. Cooper (2003b).

Table 3 contains a comparison of available technology dependent emission factors. The emission factors are based on measurements and investigations in the Nordic countries. The Finish emission factors are expert estimates by N. Karvosenoja based on TSP measurements by Hahkala et al. (1986b). The Norwegian emission factors are based on measurements on various types of stoves and assumption on the wood load. The Swedish emission factors are based on TSP measurements on conventional and modern boilers carried out by Johansson et al. (2003b).

The factors in Table 3 are used in the calculations of the revised emission estimates in Chapter 5.

4.3 Uncertainty of emission factors

In official emission inventories the categories are relatively aggregated. Table 3 is summarising the technology dependent emission factors available for a more detailed sub-categorisation. The values are based on both national measurements and expert estimates, based on international data.

Although very few national measurements are available, the emission factors seem to be strongly combustion technology dependent. Therefore, if input data are available with the same subcategory detail, this can improve the reliability of emission estimates. The differences between the countries seem to be less important, although this is difficult to judge given the scarce data.

The uncertainty from the fuel quality (e.g. dry vs. moist logs) and firing technique (e.g. continuous manual feeding vs. batch burning) were not assessed at all. Quantitative and even qualitative data and information of these is practically not available at comprehensive level, although some case studies made for other purposes may provide some insight in this area. It must be acknowledged, however, that the fuel quality and firing techniques, which often vary between the countries, can have a very strong influence on emission factors.

5. Revision of $PM_{2.5}$ emissions

5.1 Revised $PM_{2.5}$ emission factors

From the compiled available knowledge about activity data and emission factors for various technologies in the Nordic countries, as described in chapter 3 and 4, harmonised $PM_{2.5}$ emission factors were assigned for all relevant technologies for the four Nordic countries (Table 4).

Country specific average emission factors for the four main categories (bold) were calculated from the emission factors assigned for the subcategories and the actual wood consumption in the technological subcategories for each country (from Table 1). Since the wood consumption in the technological subcategories differs between the countries, the calculated emission factors in the main categories (bold) also differ between the countries (Table 4).

The country specific total average $PM_{2.5}$ emission factor for residential wood combustion in the bottom of Table 4 gives an indication on the large variability in general for this sector. It is notable that the resulting average emission factors for the whole residential combustion sector differ considerably between countries. This is because of the fact that technology-specific emission factors are strongly different for different types of combustion devices, and activity distribution for these are different for the countries. Therefore the resulting calculated country specific average emission factors are considerably higher in countries where a large proportion of wood is combusted in devices with high emissions factors, e.g. conventional iron stoves, as in Norway and Denmark.

The calculated total average emission factor for $PM_{2.5}$ varies from 200 to 1800 mg/MJ, almost an order of magnitude. It relatively closely resembles the emission factors already employed by official inventories (see Table 2) ranging from 135 to 520, or 1932, mg/MJ, depending on how the value for Norway would be interpreted.

Table 4. $PM_{2.5}$ emission factors estimated in this project. The average emission factors were calculated as a weighted average based on the activity and emission factors for each specified technology. An empty slot in the table indicates no activity exists.

Main category	**Emission factors mg/MJ $PM_{2.5}$**			
	Denmark	*Finland*	*Norway*	*Sweden*
Conventional manually fed boilers without acc. tank*	**700**	**700**	**700**	**700**
Conventional stoves (average)*	**2000**	**170**	**2000**	**340**
• Conventional masonry heaters and stoves		100		100
• Conventional iron stoves	2000	2000	2000	2000
• Kitchen range/stoves		100		100
• Masonry ovens		100		100
• Sauna stoves		100		
Modern/low-emission boilers (average)*	**45**	**79**	**30**	**58**
• Pellet boilers	30	30	30	30
• Automatically fed boilers other than pellet		80		
• Conventional manually fed boilers with acc. tank	80	80		80
• Other low emission (e.g. certified) log boilers				30
Modern/low-emission stoves (average)*			**300**	**20**
• Pellet stoves				20
• Modern (e.g. certified) iron stoves/masonry stoves			300	
Open fireplaces		**800**	**800**	**800**
Average for wood residential combustion*	**1100**	**200**	**1800**	**480**

* calculated country specific emission factors from activity and harmonised EF in underlying sub categories

5.2 Revised $PM_{2.5}$ emissions

Table 5 gives revised annual $PM_{2.5}$ emissions assuming harmonised constant emission factors within the technological sub-categories in Table 4 for all Nordic countries.

Table 5. Revised annual $PM_{2.5}$ emissions calculated with newly allocated input data obtained in this project. The activity data are for year 2000.

Main category	**Emissions ton $PM_{2.5}$**			
	Denmark	*Finland*	*Norway*	*Sweden* [b]
Conventional manually fed boilers without acc. tank	**4 300**	**1 900**	**840**	**11 900**
Conventional stoves (sum)	**8 600**	**4 900**	**38 200**	**4 800**
• Conventional masonry heaters and stoves		800		430
• Conventional iron stoves	8 600	2 200	38 200	3 600
• Kitchen range/stoves		530		800 [a]
• Masonry ovens		590		
• Sauna stoves		860		
Modern/low-emission boilers (sum)	**70**	**550**		**360**
• Pellet boilers	32	3		54
• Automatically fed boilers other than pellet		110		
• Conventional manually fed boilers with acc. tank	38	430		280
• Other low emission (e.g. certified) log boilers				30
Modern/low-emission stoves (sum)			**450**	**8**
• Pellet stoves				8
• Modern (e.g. certified) iron stoves/masonry stoves			450	
Open fireplaces		**480**	**690**	**2 700**
Total	**12 900**	**7 900**	**40 200**	**19 800**

a) Sum of kitchen stoves and masonry ovens for Sweden
b) Activity data for 2001.

5.3 Comparison with the official reported emissions

Table 6 compares the emissions of $PM_{2.5}$ from residential wood combustion, as derived from data used for official reporting, with the revised emissions estimated in Table 5. For Denmark the revised estimates result in considerably higher $PM_{2.5}$ emissions, almost 13 000 tons as compared to 1 600 tons. For Finland the revised estimates result in lower emissions, approximately 8 000 tons instead of 15 000 tons. For Sweden the differences are smaller. From Norway no official average emission factor used for estimates of emissions of $PM_{2.5}$ was available and the corresponding comparison could not be made. However, total reported emissions of $PM_{2.5}$ from residential combustion in Norway, including all fuels, is 38 500 tons, which is rather similar to the approximately 40 000 tons estimated in this project.

It should be noted that the high average emission factors, and thus also emissions, in Norway and Denmark estimated in this study are mainly caused by high emission factor estimate for conventional iron stoves. This estimate is based on Norwegian measurement study. The use of the estimate for Danish iron stoves should be evaluated. The emission estimates of this study should be considered as first estimates using alternative method, rather than proposals for official numbers.

Table 6. Comparison of $PM_{2.5}$ emissions from residential wood combustion calculated from activity and emission factors used in official reporting, and emissions estimated from detailed, technology specific activity and emission factors in this project (ton).

	Denmark	**Finland**	**Norway**	**Sweden**
Derived from official data	1 600	15 000	38 500*	17 500
Estimated in this project	12 900	7 900	40 200	19 800

* combustion of all fuels

5.4 Uncertainty of revised total emissions

The detailed calculation of fine particulate matter emissions from residential wood burning employed a classification, which was based on the technological differences in burning but a compromise of data availability for activities and emission factors. The classification used in this study was also more detailed than used by the official inventories.

The Danish activity data input was for total wood combustion, based on national statistics and allocated to different wood fuel types. The allocation to subcategories was done with expert judgement. The single default emission factor for the whole sector was replaced with data from other countries.

The Finnish activity data input was for total wood combustion, based on national statistic and allocated to different wood fuel types. The allocation to subcategories was done using questionnaire studies (Tuomi, 1990; Tuomi and Mattila, 1996) and with expert judgement (Karvosenoja, 2001). The emission factors based on expert judgement for three technology subcategories were supplemented with data from other countries.

The Norwegian activity data were available for technological subcategories. The emission factors based on measurements from three technology subcategories were supplemented with data from other countries.

The Swedish activity data were available for total wood combustion, and allocated to different wooden fuel types, based on national statistics. The allocation to technological sub categories was made by combining information from national investigations (e.g. Löfgren, 2002, Gustavsson, 2002) and expert judgement. Emission factors based on measurements were available for five technology subcategories, and were supplemented with data from other countries.

A suitable technological sub-categorisation, for which activity and emission factor data are (potentially) available, can improve total emission estimates. However, within certain sub-categories combustion appliances may differ between countries in terms of emission factors. Therefore the applicability of emission factor estimates from country to country, e.g. the use of high Norwegian emission factors on conventional iron stoves in other countries, should be evaluated.

The fuel quality and burning techniques may have a greater uncertainty than the burning technology. However, they are extremely difficult to quantify. Since they affect some technological sub-sectors more strongly than others (e.g. manually fed iron stoves vs. automatically fed pellet boilers), the most uncertain sub-sectors may be pointed out for more assessment work.

6. Measures and their costs

There are many different – both technical and non-technical – possibilities to reduce PM emissions. However, most of these abatement options cost money or demand a special effort, such as the gathering of information. Thus, if it is a political wish to reduce the emission of particulate matter, the governments have to create incitements for these abatement options to be implemented. There are several possibilities to encourage the market to use environment-friendly technology, use less energy or change to other fuels. These include economic instruments, such as subsidies and taxes, command-and-control regulation and information campaigns.

Both the cost-efficiency, the implementation possibility, and the emission reducing potential are important factors when considering which abatement options to choose. The most economical means to attain policy goals for emission reductions would be to implement control measures in their cost-effectiveness order. However, there can be many aspects of air pollution abatement policy, which may change or revise the order of putting various control options into effect. The cost-efficiency and reduction potential of the abatement options may be difficult to estimate in practice and may also vary from country to country. This makes it difficult to point out one option before the others and thus, this is not the aim of this report.

Instead, some of the possible abatement options that either can be or are used in Denmark, Finland, Norway and Sweden are stated and discussed in this chapter.

6.1 Political instruments, measures and regulations

The following section summarises some non-technical measures which can reduce PM emissions from residential wood combustion. It is also stated if and how these measures have been used in the four Nordic countries. The categorization of technical versus non-tecnical measures may seem a bit artificial, since the non-technical measures such as subsidies, standards, eco-labelling etc. are measures that create incitements for the use of the technical measures. Therefore, the non-technical measures (except perhaps for information campaigns) cannot reduce PM emissions without the technical measures. On the other hand, the technical measures are not relevant in a political regulation context unless a non-technical measure is also used (such as a standard, subsidy etc.) Thus, it is not relevant to see non-technical measures as substitutes to technical measures or vice versa. However, the categorization is a useful way of structuring the outline of the PM reducing measures.

6.1.1 Subsidies

Subsidies are economic instruments that can be used to make it profitable for consumers or producers of wood combustion devices to adopt more environment-friendly technologies. Subsidies could be used in the short run to encourage people to e.g. change from an old wood boiler to a new pellets boiler, but in the long run subsidies have many disadvantages. The most important disadvantage is that subsidies cause distortion on the market so that e.g. pricing and product development are not optimal.

At the moment there are no subsidies for domestic wood use in Denmark and Sweden. The Danish subsidy system, which is described in Table 7, was discontinued in 2001. In Oslo Kommune in Norway, households are granted a subsidy of NOK 1 500 for exchanging high emission domestic stoves. In Finland there is an investment subsidy of 15% for changing a heating system to pellet heating. The subsidy is applied only for buildings with 3 or more apartments, and therefore it is not widely used at the moment.

Table 7. Subsidies in use or planned.

Country	**Implementation**		**Application**	**Comments**
	In use	*Planned*		
Denmark	1995-2001		Installation of a low-emission boiler.	10 to 30 % of the investment cost, depending on efficiency and the emission of dust and CO.
Denmark	1995-2001		Conversion of electrical heating to heating with biomass.	DKK 5 000 plus DKK 100 per m^2 heated dwelling area if biomass contributes with at least 90% of the energy required for heating.
Finland	x		Subsidy to exchange current heating system to low emission pellet boiler.	15 % of the investment cost, applied only for buildings with 3 or more apartments, i.e. in practise only semi-detached houses and apatment buildings.
Norway	x		Subsidy to exchange high emission domestic stoves.	Campaign, e.g., in Oslo in 1999-2000: Offer of NOK 4 000 to exchange old, high emission stoves by new ones; now fixed offer of NOK 1 500.
Norway	x		Financial support/subsidy to project founding .	Enova SF (government owned entity) supports projects dealing with renewable energies: respective projects may receive grants equivalent to 15 to 20% of project costs.
Norway	x		Mortgage loan / grant to house builders.	The Norwegian State Housing Bank offers an extra NOK 140 000 as mortgage loan and NOK 10 000 as a grant to house-builders who intend to invest in alternative forms of energy solution (including use of bio-fuel).
Norway	x		Tax exemption.	Investments in several renewable energy sources have been exempted from tax (7% investment tax).
Sweden				None

6.1.2 Testing, certificates and emission limits

There are certified tests of combustion equipment or certificate systems in use or planned in all the Nordic countries (see Table 8). Furthermore, there are a number of European standards that are voluntary for the countries (see appendix 1). In the Nordic countries there are also an ecolabelling scheme in force called “The Swan” (see appendix 1).

In Denmark, the EU-based standardisation for boilers and stoves are used. In Finland there is no system at the moment, but in the future only boilers and stoves fulfilling EU-standards are planned to be installed. To limit PM emissions, standardisation for closed wood-burning stoves was introduced in Norway in 1998. In Sweden, the European standards are used as Swedish standards. There is also a so-called P-marking certificate available by the Swedish National Testing and Research Institute, which involves verification that the product fulfils applicable requirements in respect of standards, codes of practice for the sector concerned, regulations etc. (SP, 2003). Sweden is also the only Nordic country that uses emission limits in densely built up districts.

Table 8. Testing, certificates and emission limits.

Country	Implementation		Application	Comments
	In use	*Planned*		
All countries	x		European standards	European standards available for all countries, but not compulsory, see appendix 1.
All countries	x		The Swan	Nordic ecolabelling implemented 1989 to provide information to consumers to enable them to select products that are less harmful to the environment - see appendix 1.
Denmark	x		Standardisation of heating boilers	DS/EN 12809 "Residential independent boilers fired by solid fuel – nominal heat output up to 50 kW. Requirements and test methods".
Denmark	x		Standardisation of heating boilers	EN 303-5 "Heating boilers - Part 5: Heating boilers for solid fuels, hand and automatically stocked, nominal heat output up to 300 kW – Terminology, requirements, testing and marking". Not compulsory, subsidies were connected 1995-2001.
Denmark	x		Standardisation of stoves	DS 887 "Solid fuel stove for room heating – requirements and test methods". Solid fuel stove for room heating: Requirements and test methods.
Finland		2004-2006	Standardisation of heating boilers	Possibly EN 303-5, class 3. Planned to be compulsory for new installations.
Finland		2004-2006	Standardisation of stoves	Possibly EN 13 240 and EN 13 229. Planned to be compulsory for new installations.
Norway	x		Standardisation of closed wood-burning facilities	NS 3 059 (1998). Limit TSP emission value of 10 g/kg for installations with catalyst and of 20 g/kg for installations without catalyst for all closed facilities produced after 01.07.1997. Older facilities can only be relocated in the same building. Historic stoves (produced before 1940) can also be reinstalled in other buildings.
Sweden	x		Standardisation of boilers and stoves	Almost all European standard are to be established as Swedish standard within 6 months.
Sweden	x		Type-testing quality approval symbol	P-marking. SP Swedish National Testing and Research Institute's own type-testing quality approval symbol.
Sweden	x		Emission limits in accordance to BFS 1998:38	Solid biofuel boilers < 50kW: 150 mg OGC/m^3 at 10% O_2. Closed fireplaces for biofuels: 250 mg OGC/m^3 at 13% O_2. Only in densely built-up districts.

6.1.3 Prohibitions

Another non-technical measure that can be used to decrease PM emission is the prohibition of small-scale combustion in certain areas and during certain times. The possibility of prohibiting combustion of wood and demanding a certain fuel quality are in use in Sweden. Local authorities are allowed to temporarily prohibit residential combustion during certain times and demand limitation of 25% for wood moisture content. In the other countries there are no possibilities today of prohibiting residential combustion, see Table 9.

Table 9. Prohibitions in the Nordic countries.

Country	**Implementation**		**Application**	**Comments**
	In use	*Planned*		
Denmark				None
Finland				None
Norway				None
Sweden	x		Small-scale combustion prohibition	Miljöbalken (the environmental law) makes it possible for local authorities to temporary prohibit small-scale combustion during certain times.
Sweden	x		Wood moisture contents	Miljöbalken (the environmental law) makes it possible for the local authorities to demand a maximum of 25% moisture content in the wood.

6.1.4 Information and recommendation campaigns

How the wood is combusted has shown to have substantial effect on the PM emission factors. Therefore, information campaigns can be an efficient and cost-effective way to reduce emissions. Information campaigns are in use in all the Nordic countries (see Table 10) and they are mainly related to questions such as how to use the wood in a proper way. They provide information about efficient and low-emission ways of wood combustion.

Table 10. Information campaigns.

Country	**Implementation**		**Application**	**Comments**
	In use	*Planned*		
Denmark	x		Information campaign in promoting the use of small-scale boilers and stoves, 1997.	Booklet published by the Centre for Biomass Technology "Small Woodstoves and Wood Boilers – an information Campaign FIRE AWAY" (1997).
Denmark	x		Danish Technological Institute	Danish Technological Institute has a homepage with different pieces of good advice in relation to the correct use of stoves.
Finland	x		OPET Finland	Part of EU Organisations for Promotion of Energy technologies (OPET). The main activities in small-scale wood combustion sector in Finland are public information campaigns and promotion of pellet markets in Finland.
Norway	x		Enova SF	Enova SF, government owned entity responsible for state efforts to bring about a shift in energy production and use: inter alias promotion of environment-friendly forms of energy production.
Sweden	x		Information papers on how to use boilers and stoves correctly.	Information provided by different municipals on how to use wood-burners in an efficient way.

6.2 Technical measures

Table 11 presents technical measures which reduce PM emissions. In general, the efficiencies for technical PM reduction are relatively high, from 50% to 90% when applied to high emission appliances. Utilisation potential differs from country to country and it is not estimated in this study. A case study for fuel switch to pellets by boiler or burner replacement has been carried out to study the potential and costs in more detail, see chapter 6.3.

Table 11. Technical measures.

Measure	Reduction efficiency	Comments	Current status
Installation of an accumulator tank	70%[1]	Installation of an accumulator tank on boilers that do not have any at present.	Large potential especially in Sweden and Finland.
Change of accumulator tank	No estimates available	Change of accumulator tank to a more efficient tank, which better fits the size of the boiler and the need of energy.	Large potential especially in Sweden and Finland.
Fuel switch to pellets	50-90%[2]	Pellet boilers typically have lower emissions and better heat production efficiency than wood boilers.	This measure is already relatively common in Sweden and increases strongly in Finland.
Pellet burner to old boiler	50-90%[2]	Pellet burners can be installed to old boilers in many cases. Heat production efficiency often remains lower than with pellet boilers.	Large potential especially in Sweden and Finland.
Catalyse for wood-burner	30 %[3]	Catalyses reduce emissions of PM, VOC and CO.	Not in use in the Nordic countries at the moment. Installations in the US.
Secondary combustion chamber	30%[3]	Flue gases with unburned hydrocarbons are directed into a secondary chamber where they are mixed with fresh preheated air and after burned.	Used mainly in the US.

1. Energimagasinet, 2003.
2. Johansson et al., 2003a.
3. US-EPA, 1998.

There are also other measures that can be used to decrease PM emission, especially when it comes to energy conservation measures. For instance, the houses could be better insulated and the use of triple glazed windows could increase. Another solution could be to change to other heating systems such as heat pumps where a bulk of the energy is derived from heat radiated from the earth.

6.3 Case study

6.3.1 Aim

In this case study the costs and PM emission reduction of replacing old high-emission log boilers that are used without accumulating tanks with modern low-emission pellet boilers in the domestic sector will be explored. The case study does not make any kind of assumptions about how the shift from old to new boilers should be implemented or initiated.

6.3.2 Method

The costs of abatement options to reduce $PM_{2.5}$ have been estimated in integrated assessment models, e.g. the RAINS-model of IIASA, see chapter 7. Several cost estimates are available for large-scale combustion processes, e.g. power plants. However, although residentail wood combustion seems to be the main stationary source for primary PM emissions in the Nordic countries, there is a lack of cost estimates for this sector.

In this case study the costs of replacing old high-emission log boilers that are used without accumulating tanks with modern low-emission pellet boilers in the domestic sector will be explored. The heating cost for a typical single-family household will be calculated comparing an old boiler without any investment cost and a new pellet boiler, including investment, i.e. the case corresponds to a situation where an old functioning boiler will be replaced.

In addition to this study the costs of only installing a new pellet burner in an old boiler has been investigated. It is possible to install an automatically fed pellet burner to most of the old manually fed log boilers. This option is relatively common in Sweden. The heat production efficiency is approximately 15% higher when installing a new pellet burner in an old boiler, compared to an old log boiler. (personal communication, C.-Å. Boström, 2003)

The main calculation parameters are given in Table 12 and

Table 13. The parameters are divided into two groups: those that are common for all countries and those that are country-specific.

Table 12. Common parameters (Helynen et al. 2002 and authors' expert estimate).

Parameters	**Old log boiler**	**New pellet boiler**	**Old boiler with new pellet burner**
Net heat production efficiency (%)	65	83	75
Fuel calorific heating value (MJ/kg)	15.0	17.0	17.0
Labour need (h/a)	68	30	30
Labour price (euro/h)	3.3	3.3	3.3
Maintenance (% of investment/a)	3	3	3
Other variable costs (euro/MWh)	2.0	2.0	2.0
Interest rate (%)	-	4	4
Technical lifetime (a)	-	20	20
$PM_{2.5}$ emission factor (mg/MJ)	700	30	30

Table 13. Country-specific parameters (SNS, 2003; Puuenergia, 2003; IFE, 2003; Baxi, 2003; Helynen et al. 2002, and authors' expert estimates) .

Parameters	**Denmark**	**Finland**	**Norway**	**Sweden**
Produced heat in an average single-family house (MWh/a)	17.3	25	16	25
Log fuel price (euro/ton)*	91 40	76 33	158 63	69 27
Pellet fuel price (euro/ton)	210	125	226	185
Price of a pellet boiler, incl. installation (euro)	6 900	7 000	7 100	7 540
Price of a pellet burner with old boiler, incl. install (euro)	4 100	4 100	4 100	4 313
Country-level potential, log boilers without acc. tank (PJ)	6.1	2.7	1.2	17.0

*The prices are for chopped logs which have been purchased (top) contra self collected (bottom).

6.3.3 Results

Heat production prices, unit costs for $PM_{2.5}$ reductions by boiler replacement and the implications at country level are given in Table 14. Heat production prices in old log boilers do not include investment costs. For log boilers the prices and respective unit and reduction costs are given for logs both purchased and collected from own woods. In the latter case, the Danish prices are based on wood logs, which the user himself chops and collects from the wood. The results from the case study when only the pellet burner is replaced to an old boiler, is given in Table 15.

The unit costs for PM abatement vary from country to country, from 5 000 euro/ton $PM_{2.5}$ to 16 000 euro/ton for boiler replacement, and from 2 800 euro/ton to 13 000 euro/ton for installing only the pellet burner. The major reason for the variability is the prices of purchased/collected wood logs. The heat production prices and unit costs in the cases where only the pellet burner is installed to an old boiler are slightly lower than when the whole boiler is replaced. The $PM_{2.5}$ emission reduction at country level - if all old log boilers that are not equipped with accumulator tanks are replaced - vary from less than 1000 ton/a in Norway to more than 10 000 ton/a in Sweden. The PM reduction potential depends on the potential in activity. Especially in Sweden the amount of wood combustion in boilers that are used without accumulator tank is important.

Table 14. The costs of replacing an old log burner and boiler with a new pellet burner and new boiler.

	Denmark	Finland	Norway	Sweden
Heat production price, old log boiler (euro/MWh)*	62 43	49 33	89 54	47 31
Heat production price, new pellet boiler (euro/MWh)	103	67	112	85
Unit cost for $PM_{2.5}$ abatement, log -> pellet (euro/ton$PM_{2.5}$)*	11 100 16 100	5 000 9 200	6 300 15 600	10 200 14 300
PM emission reduction at country-level (kton/a)	4.1	1.8	0.8	11.5
PM emission reduction cost at country-level (Meuro/a)*	46 66	9 17	5 13	117 165

* The prices are for chopped logs which have been purchased (top) contra self collected (bottom).

Table 15. The costs of replacing the old burner with a new pellet burner leaving the old boiler.

	Denmark	Finland	Norway	Sweden
Heat production price, pellet burner (euro/MWh)	92	59	99	77
Unit cost for $PM_{2.5}$ abatement, log -> pellet burner (euro/ton$PM_{2.5}$)*	8 200 13 200	2 800 7 000	2 800 12 200	8 100 12 200

* The prices are for chopped logs which have been purchased (top)contra self collected (bottom).

6.3.4 Conclusions from the case study

The $PM_{2.5}$ reduction potential in old wood heating boilers is estimated roughly to 18 kton/a in the Nordic countries, which is 12% of total emissions. However, the estimate retains a great uncertainty. The used estimate of the $PM_{2.5}$ emission factor of old boiler without accumulating tank, 700 mg/MJ, has been estimated in several Swedish measurements, latest in the BHM-project (Johansson et al. 2003b). However, the emission factors may vary considerably between individual boilers and boiler users, depending on e.g. boiler size and type, fuel quality and firing habits. Furthermore, the estimates on country-level emission reduction potentials, i.e. the quantities of wood combusted in manually fed boilers, are uncertain. Especially, the information on accumulating tank use is scarce.

The investment costs for pellet boilers do not vary substantially from country to country, while the wood fuel costs for both logs and pellets vary considerably. In addition, the log price is strongly dependent on whether the logs are purchased or collected from own woods. Fuel prices are country average prices and there is quite a substantial variation also within the countries.

The unit costs are estimated to 5 000-11 000 euro/ton reduced $PM_{2.5}$ for the case of purchased wood logs and 9 000-16 000 euro/ton $PM_{2.5}$ for self-collected. This indicates that the assumed log price has a substantial effect on cost. The price of pellets does not vary so strongly.

In addition to the case where the whole boiler system is replaced, a case of only installing a new pellet burner in an old log boiler was investigated. In this case the unit costs were lower (3 000-13 000 euro/ton $PM_{2.5}$, instead of 5 000-16 000 euro/ton). Installation of pellet burner is a reasonable option especially when the log boiler is still relatively new and well functioning.

The unit costs are high when compared to e.g. electrostatic precipitator (ESP) retrofit installation in small (3 MW) solid fuel boilers, where unit cost is typically around 300-500 euro/ton TSP (Lammi et al., 1993). On the other hand, the marginal cost for adding particle filters on heavy duty vehicles was estimated to be 70 000 euro/ton PM_{10} in a Danish study (Denmark's Road Safety and Transport Agency et al., 2001), i.e. fuel switch to pellets in this case study is considerably more cost-efficient. However, since the use of particle filters may help to reduce the particle pollution problems in other geographical areas than small-scale combustion devices, it is difficult to make a direct comparison of these abatement options.

Finally, it should be taken into account that the case study corresponds to a situation where an old functioning wood boiler is replaced, and the investment cost is calculated only for the pellet boiler. In the case where old boilers have to be replaced anyway, pellet heating is often a competitive option when compared to *e.g.* new oil boilers (Helynen et al. 2002). It should be noted though, that a new pellet boiler in most cases would lead to higher emissions of PM in comparison with a reasonably well functioning oil boiler.

6.4 Uncertainty

Major uncertainties in input data of the case study are found in the estimates of log boiler emission factors and country-level emission reduction potentials. The heating costs of an old boiler (and the unit costs) are sensitive to the choice of many calculation parameters, e.g. heating value and price of self-collected logs, labour and maintenance costs, interest rate and lifetime of appliance. It is often difficult to define such values for small privately owned installations. The estimates of heat production efficiencies and pellet combustion appliance and fuel prices can be considered relatively reliable.

The results of this case study should only be considered as order of magnitude estimates.

7. RAINS

The Particulate Matter Emission and Costs Module (PM EMCO) is part of the Regional Air Pollution Information and Simulation Model (RAINS), which has been developed at the International Institute for Applied Systems Analysis (IIASA) in Laxenburg, Austria. The RAINS Model represents a simulation model developed for scenario analyses. It includes a comparable data aggregation level for all countries and thus no detailed country-specific emission modeling or emission inventories.

This chapter summarises the status of the PM Module development as documented in a report by Klimont et al. (2002). The report includes the extensions and updates made from summer 2001 (see the previous report by Lükewille et al., 2001).

The summary in this chapter is based on the PM EMCO PC version 8.0 provided by IIASA, Transboundary Air Pollution Project (TAP) in April 2003. It concentrates on wood fuel burning in the residential sector, the topic of this report.

7.1 Sectors

The 2001 version of the RAINS PM EMCO Module contained only one aggregation in the residential sector: DOM for domestic stoves (Lükewille et al., 2001). The updated version 8.0 distinguishes between four sectors. They include medium sized boilers (DOM_MB), which are not part of the residential sector analyzed in this study. The other three sectors are:

- Fireplaces (DOM_FPLACE)
- Stoves (DOM_STOVE)
- Single-family house boilers, < 50 kW (DOM_SHB_)
    - Manual fuel loading (DOM_SHB_M)
    - Automatic fuel loading (DOM_SHB_A)

The main sector aggregation in the RAINS PM Module is comparable to the one used in this report. However, there is no sub-division of conventional stoves in RAINS. Low-emission fireplaces and stoves can be obtained by linking the DOM_FPLACE or DOM_STOVE sectors to respective control options (see chapter 7.4). The module version 8.0 does not include control options for single-family house boilers.

7.2 Activities

Economic activities in RAINS are expressed in Joule fuel consumed. Table 16 summarises the activity data for Denmark, Finland, Norway and Sweden included in the 8.0 version of the PM Module.

Table 16. Activities in the residential sector included in the updated 8.0 version of the RAINS PM EMCO Module for year 2000.

Sectors / Activities (TJ)				
Domestic sector	*Denmark*	*Finland*	*Norway*	*Sweden*
Fireplaces	1 030	2 270	1 090	1 280
Stoves	4 110	4 550	4 370	5 120
Single-family house boilers; manual fuel loading	4 110	9 100	4 370	5 120
Single-family house boilers; automatic fuel loading	3 080	11 370	3 280	3 840
Sum domestic	**12 330**	**27 290**	**13 110**	**15 360**

The information gathered in Table 16 (year 2000) shows only first country estimates and will be discussed, updated and changed by IIASA, Transboundary Air Pollution Project, in cooperation with respective national experts within the EU CAFÉ (Clean Air For Europe) programme. The following comparison with the activity numbers used in this report can be seen as a contribution to such a discussion

Denmark

In this study no activity numbers for fireplaces in Denmark were considered, while RAINS includes an activity of 1 030 TJ. The numbers for stoves are almost the same (4 300 TJ in this study; 4 110 TJ in RAINS). The activity for manually fed single-family house boilers (with and without accumulator tank) is higher in this study (6 570 TJ) than in RAINS (4 110 TJ). However, RAINS assumes an activity of 3 080 TJ for automatically fed single-house boilers (no number for Denmark in this study). RAINS does not include activities for low-emission pellet boilers (1 100 TJ in this study).

Finland

The activity for fireplaces is much higher in RAINS (2 270 TJ) compared to the number given in this study (660 TJ). On the other hand the activity for stoves documented in this report is much higher than the number in RAINS (26 500 and 4 600 TJ respectively). The numbers for manually fed single-family boilers are similar, 8 300 TJ in this report. The activities for automatically fed single-family boilers are much higher in RAINS: 11 370 TJ compared to 2 900 TJ in this study. In Finland, activities for low-emission single-family house boilers in year 2 000 were relatively high (100 TJ for pellet boilers plus 2 900 TJ for automatically fed boilers other than pellets). Since there are no control options for single-family house boilers in RAINS PM EMCO 8.0, no emission factors for low-emission boilers can be calculated.

Norway

Activities for fireplaces are similar in RAINS (1 090 TJ) and in this study (860 TJ). The numbers given for stoves in this report are much higher: 19 100 TJ for conventional iron stoves plus 1 500 TJ for low emission stoves. RAINS includes only 4 370 TJ. In RAINS there are activities for manually fed (4 370 TJ) and automatically fed (3 280 TJ) single-house boilers, which were apparently of no basic importance in Norway in year 2000 (no activities considered in this study).

Sweden

For most categories the activities in RAINS are considerably lower than those estimated in this study. For fireplaces this study suggests 3 400 TJ while the corresponding value in RAINS is 1 280 TJ. Stoves, both conventional and low emitting, from this study add up to 14 500 TJ, in comparison with 5 120 TJ in RAINS. The activity for manually fed boilers in RAINS is estimated to only 5 120 TJ while the result in this study is considerably higher, 20 500 TJ for the sum of boilers with and without accumulator tank. For automatically fed boilers, on the other hand, data in RAINS are 3 840 TJ while the estimates in this study are somewhat lower, 2 800 TJ, if low-emission boilers and automatically fed boilers are added together. The total activity in RAINS, 15 360 TJ, is considerably lower that the presently reported activity of approximately 40 000 TJ.

7.3 Emission factors

In the 8.0 version of the RAINS PM EMCO Module emission factors for biomass combustion are no longer estimated within the module but derived directly from the literature (model input). The main reason is certainly the fact that ash contents of wooden fuels are low (usually below 1%). The main reason is that PM emission rates of small installations such as stoves or single-family house boilers depend much more on the type of installation and combustion conditions than on fuel properties (e.g., ash content).

In summary, reasons for taking emission factors directly from the literature are differences in:

- Wood burning devices in use;
- Operation of wood burning devices (e.g., burn rate, burn duration, damper setting);
- Tree species used for fuel wood;
- Practices of storing and seasoning fuel wood (affecting wood moisture and thus the heat value of the fuel);
- Chimney conditions;
- Household altitude.

Klimont et al. (2002) give an updated table with sources and emission factor ranges. Due to differences in operating practices, age of installations, etc. it was decided to use different factors for western and eastern European countries. The emission factors included for the Nordic countries are listed in Table 17.

Table 17: $PM_{2.5}$ Emission factors for Denmark, Finland, Norway and Sweden used in RAINS PM EMCO 8.0 .

Sectors / Unabated $PM_{2.5}$ Emission Factors (mg/MJ)				
Domestic sector	*Denmark*	*Finland*	*Norway*	*Sweden*
Fireplaces	279	279	279	279
Stoves	186	326	186	186
Single-family house boilers; manual fuel loading	167	326	167	167
Single-family house boilers; automatic fuel loading	93	186	93	93

The size fractions for biomass burning have been differentiated according to the new sector split. The size fractions for stoves and boilers in the residential/domestic sectors are given in Table 18.

Table 18. Size fractions used in RAINS PM EMCO 8.0 for biomass combustion in the residential sectors [%].

Biomass fuel	**$PM_{2.5}$**	**PM_{10}**	**TSP**
Stoves and boilers, domestic sector	93%	96%	100%

An in depth comparison of emission factors used in this report and included in the RAINS PM EMCO Module would go beyond the scope of this study since it should comprise a discussion of all sources considered, assumptions on control option made etc. Thus, the following discussion is only a first step.

For conventional manually fed single-family house boilers the emission factors used for all countries in this study are much higher than those in RAINS (700 mg/MJ, Table 4; compared with the RAINS numbers in Table 17). However, RAINS does not distinguish between "conventional" and "low emission", and the RAINS emission factors are closer to those for modern/low-emission manually fed boilers given in this study (80 mg/MJ). For automatically fed boilers the emission factors are similar: 100 mg/MJ for Finish boilers in this report compared to 93 mg/MJ in RAINS.

For conventional stoves the average calculated emission factors for Finland and Sweden (170 and 340 mg/MJ, Table 4) used in this study are similar to the numbers in RAINS (see Table 17). The Norwegian emission factor in RAINS is much lower than in this study, 186 mg/MJ compared to 2 000 mg/MJ.

This study includes two emission factors for low emission stoves: 300 mg/MJ for Norway and 20 mg/MJ for Sweden for two different technologies. Those numbers can be compared to the values obtained after applying control options in RAINS (new stoves; see chapter 7.4). The resulting "abated" emission factor is about 70 mg/MJ.

7.4. Control options

Based on the new sector split introduced in the 8.0 version of the RAINS PM Module, the control options for fireplaces and stoves have been extended. The options and removal efficiencies are summarised in Table 19. The removal efficiency is assumed to be the same for all size classes.

Table 19. Removal efficiencies for abatement options included in RAINS PM EMCO 8.0

	Efficiency (%)
Fireplaces, non-catalytic insert	44
Fireplaces, catalytic insert	47
New domestic stoves, non-catalytic	63
New domestic stoves, catalytic	65

For domestic sources the most effective option is certainly the change to a newer type of installation rather than a modernisation of the existing device. Another modernisation option for existing devices is the installation of primary and secondary air deflectors.

The estimated unit costs for low-emission stoves and fireplaces included in RAINS PM EMCO 8.0 are higher than those for low-emission pellet boilers given in the case study presented in this report. However, the numbers are not directly comparable. Unit costs are, e.g., highly sensitive to assumptions about annual operating hours, fuel savings, and achieved PM reduction efficiency. Wood burning stoves are usually used for supplementary heat production, i.e., in RAINS it has been assumed that they on average operate 400 hours per year. Single-family house boilers are typically used for heating and for producing hot water required in a household. Assuming 2200 operating hours per year for stoves would result, in RAINS unit cost calculation, in costs in the range of those calculated in this report.

8. Conclusions

This study concentrates on the fine particulate matter emissions from the residential wood combustion in the Nordic countries. The burning of other biofuel and burning in larger boilers and installations was not considered. Both official existing emission inventories and the more detailed revised emission estimates made in this project highlights the importance of this sector in the total $PM_{2.5}$ emissions. For the revised emission calculations, activity data and emission factors were compared and harmonised within the countries in a common detailed technology-based classification. The contents of the official statistics covering the relevant activities for residential wood burning varied greatly between the countries. Only few measurements were available for emission factors in this sector. Both activities and emission factors were allocated to the common detailed sector classification to calculate the revised fine PM emissions. The abatement costs were explored by listing non-technical measures in the countries and with a case study on a technical control option of boiler replacement. Comprehensive cost curves were not compiled due to un-existing data on the large-scale application of control techniques. There are large uncertainties concerning the sectoral classification and calculation parameter values, however, the consistent presentation of existing knowledge greatly facilitates further assessment. The different aspects of the study are presented in more detail below.

Activity data

We have been able to compare activity data, as the main sectors were comparable in all the countries. In three countries, Denmark, Finland, and Norway, official statistics only give bulk numbers for residential wood use. It has been divided into combustion device specific sub-sectors using other studies, surrogate indicators and expert judgement (also outside this study group). In Sweden more detailed input statistics data were available from official statistics concerning amount and type of wooden fuels. Thus, official statistics give a reasonably reliable frame for total wooden fuel use in the residential sector in all countires. A few special studies referred in chapter 4, provided further information to refine estimates on the consumption of wooden fuel in the technology-dependent classification. These studies, however, do not systematically cover all the aspects of activity data that need to be known to achieve high quality estimates on particle emissions. The state and number of different technologial combustion devices are difficult to estimate, and especially the habits of firing and to what extent the devices are used. Concerning these issues a large proportion of expert estimate had to be used. The data uncertainty for activity data was deemed to be relatively smaller than for the emission factors.

Emission factors

In the official reports of PM emissions only one emission factor is used for each country. The emission factors used in official reports differs considerably between the countries from 150 mg/MJ for Denmark to 1932 mg/MJ for Norway (TSP). The lowest emission factor (Denmark) is the lower range of default emission factors of TNO (who has compiled a European emission inventory in the CEPMEIP project). The highest emission factor (Norway) is based on measurements on stoves.

The use of different emission factors highly affects the national inventories of total contribution of $PM_{2.5}$ emissions from the residential combustion sector. For instance, in Denmark the $PM_{2.5}$ emission from this sector is estimated to be 19%, while the corresponding number for Norway is estimated to 69%. If the PM emission contributions from different sectors are either under- or overestimated this can be very misleading and entail wrong decisions, such as an implementation of regulation measures in the countries.

The emission factors are strongly technology dependent. The official emission factor should preferably be a weighted average of the emission factors from different boilers and stoves. However, there are gaps of knowledge and measurements on technology dependent emission factors from different boilers and stoves in all the countries. The appliance type specific emission factors used in this study are based on only a few measurements. Another problem is that even if estimates of emission factors for different technologies were available, data on the use of different technologies are largely lacking in all countries. In Sweden, there have been some attempts to use the chimney sweepers register to receive more information, but this has only been carried out in a pilot study and the chimney register has to be improved to give trustful information.

An important additional detail affecting the emission factor is the existence of accumulator tanks, whether optimally sized or not. The pilot study carried out in Sweden pointed out that even if accumulator tanks are used together with old wood boilers, only a few of these tanks have the optimal size, which results in much higher emissions than necessary.

In the estimates of emission factors the firing habits and fuel quality has not been assessed. They might cause greater uncertainty on emission factors than the use of different technologies.

Emissions

In this study the revised total $PM_{2.5}$ emissions were calculated by using a common technology-dependent sector classification and harmonised emission factors. Country specific activity data were allocated to these technological subcategories using additional information from other studies and expert estimates. Emission factors were harmonised by taking into account available national and international measurement data and assigning appropriate values for each technological subcategory with expert judgement.

For Norway and Sweden revised total $PM_{2.5}$ emissions from residential combustion of wood are comparable with the official inventory data (Norway 40 000 contra 38 500 ton and Sweden 20 000 contra 17 500 ton). The estimated number for Finland is 7 900 ton which is much lower than the official number that is 15 000 ton. For Denmark it is the opposite: the estimated amount of $PM_{2.5}$ from the residential sector has in this report been estimated to 13 000 ton, while the official number is only about 2 000 ton.

The emission factors used in this study are based on only three Nordic measurement studies. Furthermore, emission factors based on measurements carried out in one country are applied to all Nordic countries without evaluation whether the appliances are similar in terms of emissions in all countries. E.g. using Norwegian high emission factor estimate on conventional iron stoves in all countries has considerable effect on emission in

Denmark. Therefore the emission estimates carried out in this study should be considered as first estimates using alternative estimation method, rather than proposals for true numbers.

Abatement techniques and estimated costs

An investigation of different technical and non-technical measures available in the Nordic countries has been carried out in this project. Economic instruments, regulations and information campaigns related to domestic wood use promotion and emission reducing behaviour, implemented by the governments and other organisations, are moderately in use in all the four countries. The EU standards and Nordic ecolabelling are used to a certain extent.

Due to the lack of available information it has been difficult to estimate the applicability of different measures and the effect of the regulations and information campaigns in use. However, since it seems that the manner in which wood is combusted has a substantial effect on PM emissions, it could be interpreted that information campaigns about efficient and low-emission ways of wood combustion may be a feasible instrument to reduce emissions.

There are no adequate data available from experiences of technically controlling PM emissions in residential wood burning. Therefore, the magnitude of costs for technical control was approached through a case study on a specific measure: replacement of old wood-boilers to modern pellet boilers and also installation of new pellets burners in old wood boilers. Based on the case study, $PM_{2.5}$ emission reduction efficiency by the replacement of manually fed boilers without accumulator tanks with modern pellet boilers is higher than 90%. The total effect on emission reductions was estimated to be approximately 18 000 tons per year in the Nordic countries. However, the uncertainties in these estimates are high.

The abatement unit costs of replacing old functioning log boilers with new pellet boilers were estimated to vary between 5 000-16 000 euro/ton reduced $PM_{2.5}$ for a new boiler and between 3 000-13 000 for replacing only the burner. Unit cost estimates are sensitive to the assumptions of many calculation parameters, especially the emission factor and fuel price of wood logs. The emission factors of log boilers vary greatly depending on e.g. boiler size, fuel quality and firing habits. Due to lack of available measurement data it was difficult to estimate reliable emission factors. The use of purchased or self-collected wood also affects the unit costs considerably and if all wood is assumed to be purchased the unit costs decrease to 3 000-11.000 euro/ton reduced $PM_{2.5}$ (7 000-16 000 euro/ton reduced $PM_{2.5}$ for purchased logs). The true number is probably somewhere in between as some wood is purchased and others self-collected.

The abatement costs of PM reduction estimated in the case study are on one hand high in comparison to typical unit costs in small industrial or district heating plants. On the other hand they are lower than in the traffic sector. In the Swedish BHM project (Hansson et. al., 2003) it was estimated, based on heath effects and premature deaths caused by PM-emissions, that a sufficient exchange of old boilers with new boilers would amount to a cost of 30-70 million euro. Measures to reduce emissions from road traffic would, as a comparison, amount to more than 100 million euro annually (Hansson et.al., 2003).

One reason for the high unit costs in this study is that all old wood boilers are assumed to be changed at once. In practice, most boilers are replaced when they are broken and it is necessary to buy a new one. In that case only the differences in investment and not total investment would be included in the cost calculations.

Rains comments

The RAINS PM Module, version 8.0, includes already first estimates of investment and unit costs for fireplaces with non-catalytic and catalytic inserts as well as for non-catalytic and catalytic new domestic stoves. This draft economic data will have to be discussed with national experts. In the near future the RAINS model of IIASA will be used to calculate PM cost curves. Those curves will be important in the revision of the 1999 Gothenburg protocol of CLRTAP and the national emission ceilings directive of EU.

This study on the situation in the Nordic countries has shown that single-family house boilers are already widely used in these countries and that they have a large future potential. This applies to log and pellet boilers with and without accumulator tanks. RAINS include so far only control options for fireplaces and stoves (and medium-sized boilers). The case study presented in this report show the importance of including options such as a shift to low-emission pellet boilers for single-family houses into the RAINS PM Module.

Directions for further research

We have compiled available data relevant to PM emissions from residential wood burning in the Nordic countries. The data have been compared, hamonised and used to calculate revised fine particulate matter emissions from this sector. We also pointed out the obvious needs for further studies in many aspects of the residential wood combustion. There are gaps of information and lack of adequate measurement data in activity data, emission factors and cost calculations. In particular, the following issues are suggested to be subject for further analyses to improve the reliability of estimated emissions:

- Statistics of the use of different boilers, stoves and accumulator tanks in the countries.
- More precise statistics on wood fuel consumption are needed, including the estimated amounts of purchased and collected firewood.
- PM emission factors of different wood burning technologies, with and without accumulator tanks or catalytic converters, are needed. It is also important to have more real emission measurements in situ, as the firing habits have also a very high influence on the PM emission factors.
- The estimates for control potential and abatement costs are in general difficult to estimate for the residential wood burning sector, which benefits little from end-of-the-pipe control techniques conventionally used to compile cost curves for economically ranked abatement options for the countries. Replacement of old equipment and non-technical measures, such as campaigns on fuel quality and firing techniques, can be valuated to some extent when enough large-scale data become available.

References

BACCSF, 2003. www.baccsf.org

BAXI, 2003. www.baxi.se

Boström, C.-Å. Swedish Environmental Research Institute, personal communication, december 2003.

Boverket, 2002. Boverkets Byggregler, BBR 2002:19.

CEPMEIP (Co-ordinated European Programme on Particulate Matter Emission Inventories, Projections and Guidance) (2002) Database presented on the Internet: http//www.air.sk/tno/cepmeip/.

COM, 2001, 245 final. Communication from the Commission,. The Clean Air for Europe (CAFE) Programme: Towards a Thematic Strategy for Air Quality.

Denmark's Road Safety and Transport Agency et al., 2001. Partikelfiltre på tunge køretøjer – rapport fra arbejdsgruppentil belysning af mulighederna for fremme udbredelsen af partikelfiltre til lastbiler og busser i Danmark. Copenhagen.

Dk-Teknik and Danish Energy Agency. Firewood Statistics, December 2000.

EC (European Commission) (1999a) European Union Energy Outlook to 2020. Energy in Europe - Special Issue. Directorate-General for Energy, November, 1999.

EC (European Commission) (1999b) Economic Foundations for Energy Policy. Energy in Europe - Special Issue. Directorate-General for Energy, December, 1999.

EMEP-Webdab, 2003. Official annual emission data of European countries available in http://webdab.emep.int/.

Energimagasinet, 2003. www.energimagasinet.com

EU, 2001. Directive 2001/81/EC of the European Parliament and of the Council of 23 October 2001 on national emission ceilings for certain atmospheric pollutants. European Communities, Brussels, Belgium, 2001. Official Journal, L 309, 27 November 2001, pp 22–30.

Färnlund J., Holman C., Kågesson P., 2001. Emission of ultrafine particles from different types of light duty vehicles. Swedish National Road Administration.

Gustavsson, L., 2002. Presentation, Swedish National Testing and Research Institute.

Haakonson G., 2003. Statistics Norway, personal communication.

Haakonson G. and Kvingedal E., 2001. Utslipp til luft fra vedfyring i Norge. Utslippsfaktorer, ildstedsbestand og fyringsvaner. Statistisk sentralbyrå - Statistics Norway, 2001/36.

Hahkala M., and Vesterinen R., 1986a. A study of emissions from small and medium-sized heating plants using domestic fuels.

Hahkala M., Jormanainen P., Puustinen H. and Pohjola V., 1986b. A study of emissions from small boilers using domestic fuels.

Hansson, H.-C. (co-ordinator), 2003. Biobränsle -Hälsa -Miljö. Draft final report, summary, 2003-07-16.

Helynen et al., 2002. The possibilities of bioenergy in reducing greenhouse gases. VTT Research Notes 2145.

IEA (International Energy Agency) (1998) Energy Statistics and Balances: 1960/1971-1996. 1998 Edition. IEA/OECD, Paris.

IFE, 2003. Institute for Energy Technology, http://www.ife.no/english/

IIASA, 2003.The particulate matter calculation method and data in the RAINS model of the International Institute for Applied Systems Analysis, Laxenburg, Austria. www.iiasa.ac.at

Jansson, T, 2002. Eldning med fasta biobränslen i småhus, Sweden.

Johansson L., Tullin C., Leckner B., and Sjövall P., 2003a. Particle emissions from biomass combustion in small combustors. Biomass and bioenergy 25:435-446.

Johansson L., Gustavsson L., Tullin C., and Cooper D., 2003b. Emissioner från småskalig biobränsleeldning - mätningar och preliminära mängdberäkningar. Swedish National Testing and Research Institute report, 2003:08.

Karvosenoja N., 2001. Primary particulate emissions from stationary combustion processes in Finland. Finnish Environment Institute Mimeograph 232, Helsinki, Finland, 34 pp.

Klimont Zbigniew, IIASA, 2003. Personal communication.

Klimont Z., Cofala J., Bertok I., Amann M., Heyes C. and Gyarfas F., 2002. Modelling Particulate Emissions in Europe A Framework to Estimate Reduction Potential and Control Costs. Interim Report IR-02-076.

Lammi K., Lehtonen E., and Timonen T., 1993. Technical and economic alternatives to reduce particulate emissions from energy production. Helsinki, Finland, Ministry of the Environment, Report 120. 64 pp.

Löfgren, B.E., 2002. Inventering av biobränsleanvändning i Lycksele, Götene och Växjö. Energimyndigheten/Äfab. Projektnr P12603-3.

Lükewille, A., Bertok, I., Amann, M., Cofala, J., Gyarfas, F., Heyes, C., Karvosenoja, N., Klimont, Z. and Schöpp, W., 2001. A Framework to Estimate the Potential and Costs for the Control of Fine Particulate Emissions in Europe. IIASA IR-01-023.

Malisius U., Jegg H., Schmidt H., Nilsson B., Rapp S., Strehler A., Hartmann H., Whitfield J., Kessler D., Giesselhofer A., and Hahn B., 2000. Woodpellets in Europe.

Naturvårdsverket 1998. Småskalig vedeldning – underlag samt förslag till "Förordning om åtgärder för att minska utsläppen från små anläggningar som eldas med fasta biobränslen". (Small-scale firewood combustion). Redovisning av regeringsuppdrag. NV rapport 4912.

Nikolaisen, L., 2003. Personal communication. Danish Technological Institute

Puuenergia, 2003. www.puuenergia.com

Schöllin, M. Statistics Sweden, 2003, personal communication.

SSB, 2003. www.ssb.no/emner/01/04/10/klimagassn/tab-2003-04-01-02.html

Statistics Finland, 2001. Energy Statistics 2000. Statistics Finland, Helsinki, Finland, Energy 2001:2.

Statistics Norway, 2003. http://www.ssb.no/english/yearbook/ and personal communication

Statistics Sweden, 2002a. Energistatistik för småhus, flerbostadshus och lokaler. Sammanställning avseende år 2000 och 2001. (Summary of energy statistics for dwellings and non-residential premises for 2000 and 2001). EN 16 SM 0204.

Statistics Sweden, 2002b. Energiförsörjningne fjärde kvartalet samt åren 2000 och 2001, korrigerad version. (Energy supply the 4th quarter and the whole years 2000 and 2001, preliminary data, corrected version) EN 20 SM 0202, korrigerad version.

SIS, 2003a. www.sis.se

SIS, 2003b. Criteria document 14 December 2000 - 14 December 2004 Version 1.2. www.svanen.nu

SIS, 2003c. Criteria document 6 June 2001 - 5 June 2004 Version 1.0. www.svanen.nu

SNS, 2003. www.sns.dk

SP, 2003. Swedish National Testing and Research Institute. www.sp.se

TNO, 2003. www.air.sk/tno/cepmeip

Tuomi S., 1990. Kotimaisen polttoaineen tulisijat pientaloissa (Heating devices fired by indigenous fuels used in detached houses in Finland). Helsinki, Finland, TTS-Institute's Publications Series 312. 95 pp.

Tuomi S. and Mattila K., 1996. Ostopolttopuun käyttö pientaloissa (On the use of purchased fuelwood in detached houses in Finland). Helsinki, Finland, TTS-Institute's Publications Series 351. 54 pp.

UNECE, 1999. Protocol to the 1979 convention on long-range transboundary air pollution to abate acidification, eutrophication and ground-level ozone. United Nations, Economic Commission for Europe, Geneva, Switzerland, 1999. EB.AIR/1999/1.

UNECE, 2002. Draft Guidelines for Estimating and Reporting Emissions Data. EB.AIR/GE.1/2002/7.

US-EPA, 1998. Compilation of Air Pollution Emission Factors AP-42, Fifth Edition, Volume 1: Stationary Point and Area Sources. The U.S. Environmental Protection Agency.

WHO, 2003. Health aspects of air pollution with particulate matter, ozone and nitrogen dioxide. Report on a WHO working group, 13-15 Jan 2003, Bonn, Germany, 29 pp.

Appendix 1: Certificates

EU standards

To harmonise the goods produced in the European countries, the ministers of EU work out different directives, which the countries have to follow. Standardisation organisations thereafter create European standards, which specify the effects of the directives on health, security and environment. The countries are not forced to use the standards but the use of the standards facilitates for the countries to follow the directives.

In many cases (about 75%) the preparation of standards is not decided by EU but is due to the need from the market to have common solutions. The standards are prepared in co-operation between users and producers. Common European guiding principles for testing, certification and accreditation are available in the so-called EN 45.000–standards (SIS, 2003a).

Boiler standard: EN 303-5

EN 303-5 concerns boilers which use solid fuels and are either manually or automatically fed with a nominal heat output of up to 300 kW. The standard includes requirements for terminology, requirements, testing and marking. For instance are net heat production efficiency measures as well as temperature of the flue gas, and the size of the accumulator tank. They also provide threshold values for CO, OGC and particles (Jansson, 2002).

Table 20. EU boiler standard EN 303-5.

Feeding method	**Nominal heat output**	**CO (mg/m^3 (N) at 10% O_2)**			**OGC (mg/m^3 (N) at 10% O_2)**			**Particles (mg/m^3 (N) at 10% O_2)**		
	kW	*Class 1*	*Class 2*	*Class 3*	*Class 1*	*Class 2*	*Class 3*	*Class 1*	*Class 2*	*Class 3*
Manual	< 50	25 000	8000	5000	2000	300	150	200	180	150
	50-150	12 500	5000	2500	1500	200	100	200	180	150
	150-300	12 500	2000	1200	1500	200	100	200	180	150
Automatic	<50	1500	5000	3000	1750	200	100	200	180	150
	50-150	12 500	4500	2500	1250	150	80	200	180	150
	150-300	12 500	2000	1200	1250	150	80	200	180	150

Fireplace standards

There are also EU standards for fireplaces (see Table 21), but as for the boilers they are not binding for the member countries (Baccsf, 2003).

Table 21. Other standards.

Standard	
EN 13 240	EU standards for roomheaters fired by solid fuel. Requirements and test methods.
EN 13 229	EU standards for residential cookers fired by solid fuel. Definitions, requirements, instructions, marking and testing.
EN 12 809	EU standards for residential independent boilers fired by solid fuel with a nominal heat output up to 50 kW. Requirements and test methods.
EN 12 815	EU standards for residential cookers fired by solid fuel. Requirements and test methods.

Nordic ecolabelling – "The Swan"

In 1989, the Nordic Council of Ministers adopted a measure to implement a voluntary, positive ecolabelling scheme in the Nordic countries. The objective of ecolabelling is to provide information to consumers to enable them to select products that are the least harmful to the environment. The criteria are updated regularly.

Solid biofuel boilers

Ecolabelling of solid biofuel boilers (main heat source) has the following air emission limit values, which may not be exceeded during tests of (SIS, 2003b):

1) nominal load for manually fed boilers installed with an accumulator tank.
2) nominal load and low load for automatically fed boilers. An average of the three low load tests should be taken. Particles are however only measured during testing against nominal load.

The requirements refer to both manually and automatically fed boilers and are listed in Table 22.

Table 22. Requirements for solid biofuel boilers

Boiler output	**OGC (mg/m^3 tg at 10% O_2)**	**CO (mg/m^3 tg at 10% O_2)**	**Particles (mg/m^3 tg at 10% O_2)**
x < 100 kW	70	1000*/2000**	70
100 < x < 300 kW	50	500*/1000**	70

** automatically fed boiler ** manually fed boilers*
Documentation requirements. The laboratory should certify accreditation to EN 303-5.

Closed fireplaces for biofuels

Ecolabelling of closed fireplaces for biofuels (supplementary heat source) has the following air emission limit values, which may not be exceeded during tests of (SIS, 2003c):

1) accumulating fireplaces with a nominal load for OGC, CO and particles.
2) other manually fed fireplaces with:
- a nominal load in terms of OGC and CO and
- a mean of the results at nominal load and the two low-load tests for particles.

3) other automatically fed fireplaces with:
- a nominal load and a mean of the two low-load tests for OGC,
- a nominal load in terms of CO and
- a mean of the results at nominal load and the two low-load tests for particles.

Table 23. Requirements for closed fireplaces for biofuels.

Accumulating fireplaces		**OGC (mg/m^3 tg at 13% O_2)**	**CO (mg/m^3 tg at 13% O_2)**	**Particles (g/kg fuel)**
(nominal load)		180	2500	3
Other fireplaces				
Manually fed	nominal load	180	2500	
	$\bar{x}$ (low1; low2; nominal)			<10 <20 (for each individual test)
Automatically fed	nominal load	55 also $\bar{x}$ (low1; low2)	1250	
	$\bar{x}$ (low1; low2; nominal)			<10 <20 (for each individual test)

Documentation requirements: Certification from the laboratory that is accredited for EN 13 240 or that the laboratory has recently applied for accreditation.

Appendix 2: Cost calculation equations

For a typical single-family house:

Annual fuel cost (FC) = Fuel price * Annual heat production / Heat production efficiency

Annual investment cost (IC) = Investment * Annualisation factor

(investment costs are calculated only for new (pellet) equipment)

Annual labour cost (LC) = Labour price * Labour need

Annual maintenance cost (MC) = 3% * Investment

Annual other variable cost (OC) = 2 euro/MWh * Annual heat production / Heat production efficiency

Annual total heating cost (TC) = FC + IC + LC + MC + OC

Heat production price (HP) = TC / Annual heat production

Annual PM emission (EM_{house}) = PM emission factor * Annual heat production / Heat production efficiency

Unit cost for PM reduction (UC) = (TC_{pellet}– TC_{old}) / (EM_{old}– EM_{pellet})

Replacement potential at country level:

PM emission in old boilers ($EM_{country,old}$) = PM emission factor * wood use in replaceable boilers

PM emission in pellet boilers ($EM_{country,pellet}$) = PM emission factor * wood use in replaceable boilers * EF_{pellet}/ EF_{old}

PM emission reduction potential ($RP_{country}$) = $EM_{country,old}$ - $EM_{country,pellet}$

PM emission reduction cost = UC * $RP_{country}$