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Methane emissions from residential biomass combustion

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Summary

Small scale biomass combustion can be a major source of air pollutants like hydrocarbons and particulate matters. Methane is one of the hydrocarbons emitted when burning biomass fuels and recent studies show that methane emissions from different kinds of residential biomass systems can vary significantly depending on type of combustion system and type of fuel. On a yearly basis Sweden is obligated to report air emissions of several pollutants to different international bodies. In previous reporting only one emission factor for methane is accounted for, including all technologies and all fuel types. This study aims to improve the reporting of methane emissions from small scale combustion of biomass by revising both activity data and emission factors. Further, the times series 1990-2003 for methane emission will be updated. New methane emission factors from small scale combustion of wood log, pellets and wood chips/sawdust was determined and an improved method was then used to calculate the emissions. In order to match the activity data categories, the emission factors were grouped by heating system category and fuel type. The result showed that methane emissions from wood log combustion are significantly higher compared to pellets combustion. However, significant variations in emission factors occur for specific combustion appliances and operation conditions. The recalculated time series for 1990-2003 showed higher values of methane emissions due to desegregation of emission factors by combustion technology.

Contents

1 Introduction

1.1 Background

On a yearly basis Sweden is obligated to report air emissions of several pollutants to different international bodies. Emissions of Greenhouse Gases, including methane, are reported to UNFCCC according to the revised 1996 guidelines for National Greenhouse Gas Inventories (IPCC, 1997). The Emissions are calculated from emission factors and activity data. Current emission inventories on methane from residential biomass combustion are quite uncertain due to uncertainties in both activity and emission factor. One of the difficulties is that emissions from stoves and domestic boilers very much depend on combustion technologies fuel quality and operation conditions. Thus, to increase the quality of the emission estimates these factors need to be considered.

Statistics Sweden (ref.) publishes activity data for biomass combustion in the official statistics. Statistics Sweden performs annual surveys on energy consumption in one- and two dwelling buildings, multi-dwelling buildings, agricultural residences and holiday cottages. The survey description has been relatively similar over the years and using more or less the same questionnaire design for all surveys. Respondents have been asked to fill in what type of heating system the house has and the consumption of biomass (in 1991-1997, only biomass in terms of wood logs were asked for). From 1998 wood pellets/briquettes and wood chips/sawdust were included in the survey.

In Sweden the most commonly used biomass fuel for residential combustion is dry wood log fuels. However, in recent years the use of upgraded fuels such as pellets and briquettes have increased its share in the use of biomass in the residential sector. Wood chips or sawdust are also used, although they are mainly used in agricultural residences and in multi-dwelling buildings. In the residential sector different kinds of boilers, stoves and fireplaces are used with a variety of models and designs. Residential wood boiler systems are most common for water-based heating and hot water production. To increase the combustion efficiency the boiler may also be connected to a heat storage tank (a water tank for storage of heat). Different types of stoves and fireplaces are also used, mainly as secondary heating source.

Systems that are used for pellets combustion are pellets boilers, special burners, adapted to wood or oil boilers and pellets stoves used as primary heating replacing heating with electricity. Wood chips and sawdust are usually combusted in small grate boilers with a continuous feeding or in special pre-furnaces connected to a boiler.

Small scale biomass combustion can be a major source of air pollutants like hydrocarbons and particulate matters (Boman, 2005). Methane is one of the hydrocarbons emitted when burning biomass fuels and recent studies show that methane emissions from different kinds of residential biomass systems can vary significantly depending on type of combustion system, type of fuel and operation conditions (Boman et al. 1995, Jonsson, et al. 2005, Johansson at al. 2004). As methane is a greenhouse gas it is important to consider the potentially high emissions from different biomass appliances. In Sweden's reporting of Greenhouse Gases emissions to UNFCCC in 2005, the methane emissions from residential biomass combustion were approximately 50 percent of the total amount of methane emissions in the energy sector.

In Sweden a national research program financed by the Swedish Energy Agency, Emissions and air quality with the sub-program “Biofuels, Health and environment” has been in progress during the years of 2001-2004. The overall objective of this program was to describe the influence of small scale combustion on emissions, air quality and health effects. In this program extensive quantification and characterisation of gases and particulate emissions was performed for a wide range of residential biomass combustion appliances during different fuel and operation conditions (Boman et al. 1995, Jonsson, et al. 2005, Johansson at al. 2004).

1.2 Aim of the project

This study aims to improve the reporting of methane emissions from small scale combustion of biomass by revising both activity data and emission factors. Further, the times series 1990-2003 for methane emission will be updated.

The revision of emission factors, foremost, data from the aforementioned research program “Biofuels, Health and environment will be used. New methane emissions factors from small scale combustion of wood log, pellets and wood chips/sawdust will be determined and an improved method will then be used to calculate the emissions. In order to match the activity data categories, the emission factors will be grouped by heating system category and fuel type. The activity data includes one- and two-dwelling buildings, multi-dwelling buildings, agricultural residences and holiday cottages.

2 International emission reporting requirements and guidelines

2.1 General reporting requirements and guidelines

On a yearly basis Sweden is obligated to report national air emissions of greenhouse gases to:

- The European Union's Mechanism for Monitoring Community greenhouse gas emissions and for implementing the Kyoto Protocol and the UNFCCC (United Nations Framework Convention on Climate Change). Reporting follows revised 1996 IPCC (Intergovernmental Panel on Climate Change) Guidelines for National Greenhouse gas Inventories (IPCC Guidelines), IPCC Good Practice Guidance and Uncertainty Management in National Greenhouse gas inventories (IPCC Good Practice Guidance), and UNFCCC Reporting Guidelines on annual inventories (FCCC/CP/2002/8).

3 Scope of the project

- Revision of activity data on energy consumption in the residential sector.
- Revision of emission factors for methane from small scale combustion of biomass fuels.
- Recalculation of time series (1990-2003) for methane emissions in the residential sector.
- Estimates of uncertainty

4 Methods

The general method for calculating emissions from a certain source is to multiply relevant activity data with an emission factor, according to the equation:

$$E=AD*EF$$

Where E=emission, AD=activity data and EF= emission factor

In order to compile time series of methane emissions, several research studies and national official statistics were used.

4.1 Revision of activity data

Statistics Sweden performs annual surveys on energy consumption in one- and two dwelling buildings, multi-dwelling buildings, agricultural residences and holiday cottages. Respondents have been asked to fill in what type of heating system the house has, type of fuel and the consumption of fuel.

Energy consumption in agricultural residences is surveyed intermittent, whereas holiday cottages have been surveyed only in 1976 and 2001.

Results from all before mentioned surveys have been compiled in yearly publications for the whole residential sector (Statistics Sweden, 1991-2004).

During the review process, it was discovered that the enumeration method for biomass consumption in one- and two-dwelling building and agricultural residences had been altered between 1995 and 1996, resulting in inconsistent time series. Data for 1990-1995 has been recalculated using the same method as for later years.

4.1.1 One- and two-dwelling buildings

Consumption of wood logs has been surveyed annually since 1990 for three heating systems, boilers, stoves and open fireplaces (between 1991-1997, only biomass in terms of wood logs were asked for). From 1998 wood pellets and briquettes were also included in the survey. The consumption of pellets/briquettes 1990-1997 has been estimated by interpolation, assuming that no consumption existed in 1990.

Wood chips/saw dusts were asked for in the 1990 survey, but left out until the 1998 survey. The consumption for 1991-1997 has been estimated through interpolation. In addition, small amounts of unspecified biomass consumption have been reported. In this study, these amounts were assigned to the category boilers and the biomass was distributed proportionally on wood chips/saw dust and wood pellets/briquettes (Munkhammar, 2005).

4.1.2 Multi-dwelling buildings

Statistics on biomass and peat in other heating system have been investigated for multi-dwelling buildings only for 2001-2003 (Statistics Sweden, 2004). Since peat use is very limited and the use of wood logs does not exist in multi-dwelling buildings, it was assumed that the sum of biomass consumption could be distributed on wood chips/saw dust and wood pellets/ briquettes using the same proportion as for one- and two-dwelling buildings. (Munkhammar, 2005). The average consumption for the years 2001-2003 (237 GWh) was assigned as the annual consumption for 1990-2000.

4.1.3 Agricultural residences

Biomass consumption in agricultural residences has been surveyed intermittently - 1990, 1993, 1996, 1999, 2002, and 2003. However, in 1993 and 1996, only consumption of wood logs was asked for and it was assumed that there was no consumption of wood pellets/briquettes before 1999. In submission 2005, the biomass consumption for missing years was assigned the same value as the previous year, whereas in this study, missing years were estimated by interpolation. Table 1 summaries biomass consumption included in all surveys except for holiday cottages.

Table 1. Biomass consumption included in the residential sector surveys, except for holiday cottages.

	One- and two dwelling buildings		
Fuel	Heating system	Included in survey	Comment
Wood logs	All (boiler, stoves, open fireplaces)	1990-2003	
Wood chips/saw dust	All (boiler, stoves, open fireplaces)	1990,1998-2003	Consumption for the missing years 1991-1997 is estimated by interpolation.
Wood pellets/ briquettes	All (boiler, stoves, open fireplaces)	1998-2003	Consumption for 1990-1997 is estimated by interpolation, assuming that no consumption existed in 1990.
	Multi-dwelling buildings		
Fuel	Heating system	Included in survey	Comment
Biomass	Other heating system	2001-2003	For 1990-2000, consumption is estimated using the average for 2001-2003.
	Agricultural residences		
Fuel	Heating system	Included in survey	Comment
Wood logs	All (boiler, stoves, open fireplaces)	1990, 1993, 1996, 1999,2002, 2003	Data for the missing years is estimated by interpolation.
Wood chips/saw dust	All (boiler, stoves, open fireplaces)	1990,1999,2002, 2003	Data for the missing years is estimated by interpolation.
Wood pellets/ briquettes	All (boiler, stoves, open fireplaces)	1999, 2002, 2003	No consumption before 1999. Data for the missing years 1999-2003 years is estimated by interpolation.

4.1.4 Holiday cottages

Energy consumption in holiday cottages has only been investigated two times in the last thirty years, 1976 and 2001 (Statistics Sweden, 1978, 2001). Though, in the 1976 survey, biomass consumption was not quantified. However, information on numbers of different heating systems (i.e. direct electricity, stoves and open fireplace) was included.

Looking at the average number of each heating system, it is obvious that there has been a transition in the way people warm their cottages, from mostly using biomass in stoves and open fireplaces in 1976 to using direct electricity in 2001. Applying the proportional changes for each parameter from the two studies, it has been possible to calibrate an approximative (declining) times series for consumption of biomass per house.

However, due to the increased numbers of holiday cottages between 1976 and 2001, the total biomass consumption in 1976 was estimated to the same level as in 2001. Hence, the biomass consumption was assumed to be constant for the whole time series 1990-2003. It is also assumed that all consumption consists of wood logs.

Note that in submission 2005, estimated biomass consumption from holiday cottages was included in the residential sector only in 2001-2003.

4.2 Revision of emission factors

Until submission 2005 covering data for 1990-2003 only one emission factor was used when reporting methane emissions from residential biomass combustion. The results from a closer examination by Statistics Sweden of existing national energy statistics for residential heating has enabled a desegregation of the fuel consumption of biomass by fuel type (wood logs, pellets, wood chips), as well as by technology (boiler, stoves, and open firing places) (ref). These are also the categories that are used for the revised emission factors.

In the present work the revised emissions factors are to a large extent based on results from the research program “Biofuel, Health and Environment”. The method used was to summarise methane emissions from several combustion experiments of wood log and pellets using different boilers and stoves. Data from mainly five different research studies have been used (Boman et al. 1995, Jonsson, et al. 2005, Johansson at al. 2004). In table 2 it can be seen what type of fuel, type of combustion appliances and operational conditions that was used in these studies. Some experiments and measurement were done in a laboratory and some measurements were done in the field (see appendix).

The wood boilers that were used in the studies were modern boilers with a storage tank and old-type boilers fired both with and without storage tank. The boilers without a storage tank were divided into two firing habits. In some of the experiments with wood log the moisture content and wood log size was varied.

The pellets stove experiments were performed with systematic variations of chimney draught, fuel load and pellets diameter. For the pellets boilers and pellets burners the fuel load was varied.

Table 2. A summary of the combustion technology and operational conditions used for emission quantification and characterisation within the sub-program “Biofuels, Health and Environment”.

Fuel	Technology	Operational conditions (firing habits)
Wood logs	Boiler with storage tank Boiler without storage tank Stoves	Fuel quality (moisture content) Percentage air supply Batch size
Wood pellets	Pellets burners Pellets stoves	Fuel quality (pellets diameter) Fuel load Chimney draught

4.2.1 Methane emissions from wood log boilers

The emission factor for wood log boilers is estimated according to the following assumptions (request from Swedish EPA); Since there is no activity data on firing habits it was assumed that ten percentages of the wood log boilers are operated under a decreased air supply. Further, the emissions data from wood log boilers (decreased air supply) are presented as a median value due to an outlier in data.

4.2.2 Methane emissions from open fire places

There was no information on methane emissions from open fire places, the emission factor for methane for wood logs in open fireplaces was therefore recalculated from the emissions ratio of CO, TCH and PM (Karlsson, 1992) from reference (Boman, 2005).

4.2.3 Methane emissions from wood chips/saw dust combustion

In the present study emissions factors for wood chips/saw dust is also included. However, since no relevant data could be found this data is estimated. According to the activity data, agricultural residences and multi-dwelling buildings mainly uses this type of fuel and several of the used boilers are probably old types. Wood chips and sawdust is mainly used in a boiler with continuous fuel feeding which is more like a pellets burner with continuous operation than a boiler used for wood logs. However, wood chips and saw dust is not a uniform fuel and may have high moisture content. It was assumed that the methane emission factor is 20 % lower than the methane emission factor from wood log combustion. It should be considered that the variations might be large.

5 Results and Discussion

5.1 Revision of activity data

Figure 1 shows the time series 1990-2003 of biomass use in the household sector, both total amounts before revision and biomass by fuel category after revision. Overall, the two time series show good comparison. As can be seen in figure 1, wood log is the most commonly used fuel but pellets have lately expanded into the residential heating market. In 2003 approximately 13 % was used as pellets in the residential sector. However, the use of pellets will probably continuo to increase, especially in one and two-dwelling buildings. Wood chips/saw dust accounts for a minor part of the total biomass consumption and has decreased slightly in magnitude from the mid 90's until 2003.

When comparing the total biomass consumption of all fuels before and after the revision (figure 1), it can be seen that the previous compilation in general resulted in lower consumption. This is a result of the various activity data revisions described in chapter 4.1. It can also be seen that the consumption for 2003 has increased, which is due to overestimation of the consumption in multi-dwelling buildings in the previous compilation.

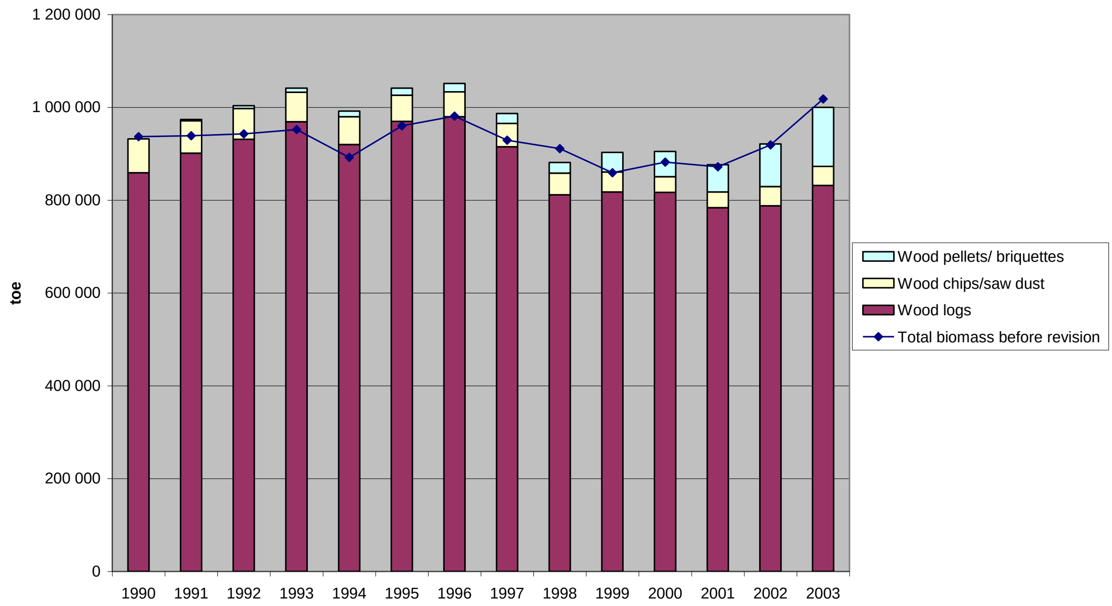

Figure 1. Biomass activity data 1990-2003; total amounts (toe) before revision and amounts (toe) by fuel after revision.

Figure 2 shows the revised biomass consumption in the residential sector 1990-2003 divided on heating systems. It also illustrates the time series for the total consumption regardless of heating system before the revision. The majority (about 80 %) of the biomass is consumed in boilers, whereas consumption in stoves and open fire places accounts for minor contributions (17% and 3% respectively).

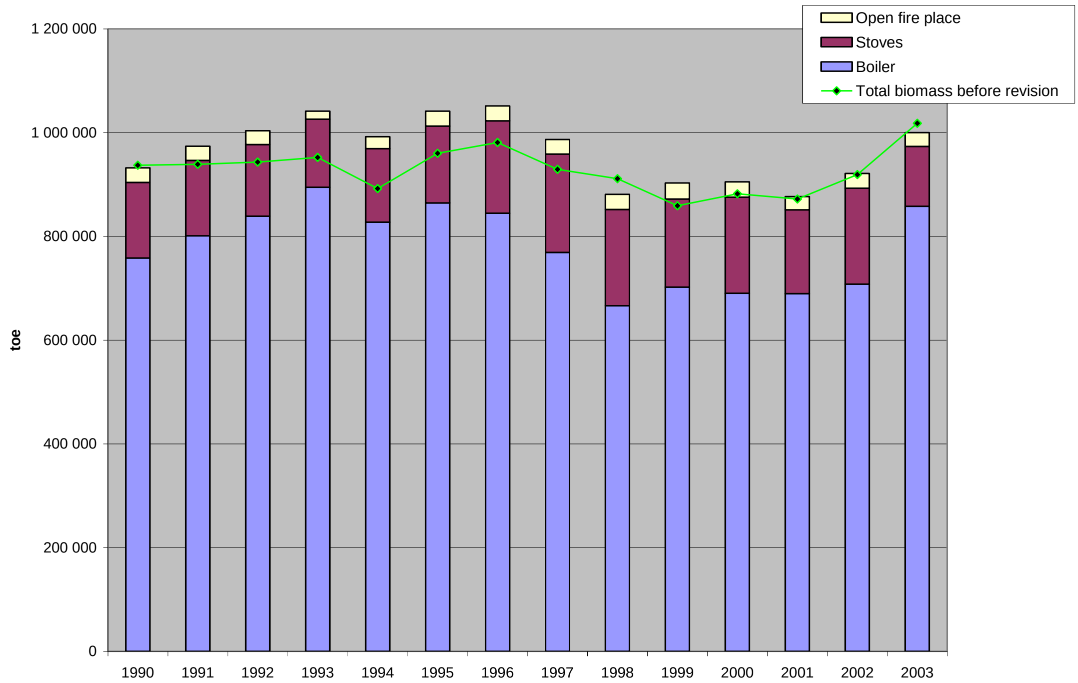

Figure 2. Biomass activity data 1990-2003; total amounts (toe) before revision and amounts (toe) by heating system after revision.

Figure 3 show the revised time series for biomass consumption in the residential sector divided on consumer category (i.e. holiday cottages, multi-dwelling buildings, agricultural residences and one- and two-dwelling buildings). Most consumption occurs in one- and two-dwelling buildings followed by agricultural residences. Consumption in both holiday cottages and multi-dwelling building only stand for about 8 % of the total biomass consumption.

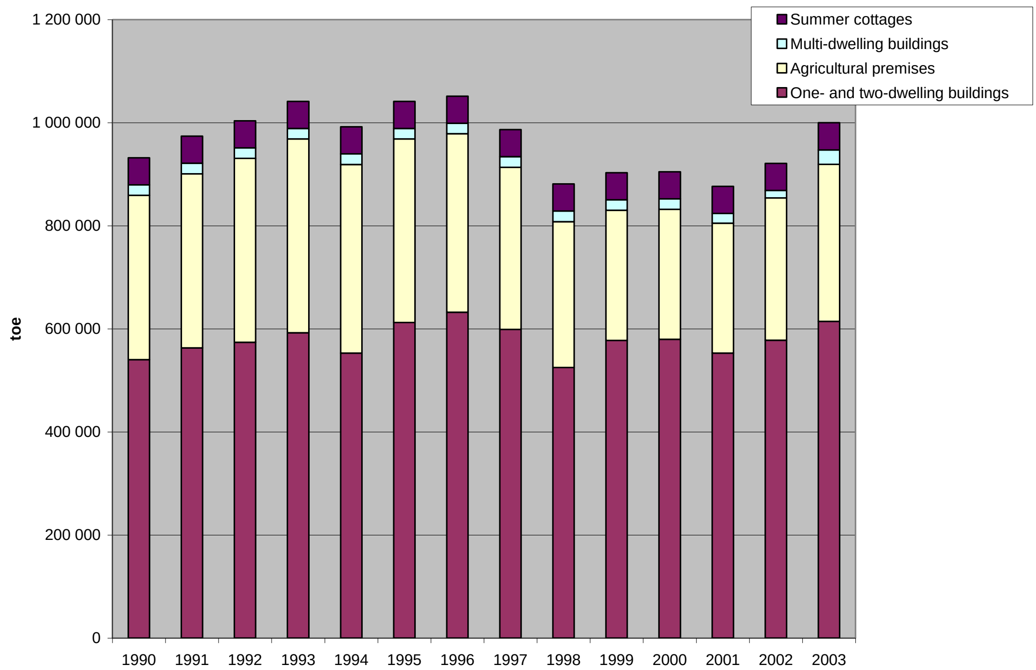

Figure 3. Revised biomass activity data (toe) 1990-2003 by consumer category (holiday cottages, multi-dwelling buildings, agricultural premises and one- and two-dwelling buildings).

5.2 Revision of emission factors

Based on extensive characterisation and quantification work within several projects, the revised emissions factors for calculation of methane emissions are presented in table 3. The previously used single emission factor is also shown.

In table 4 the median value and range including all used data, (appendix 1) is shown. In addition the emission factors for the wood log boiler are presented separately, as discussed later in the text.

In general emissions from boilers with a storage tank are significantly lower since this boiler usually is more modern and the firing habits are more appropriate. The boilers without a storage tank can be divided into two firing habits. The first represent the house owner who is home during daytime and charges small batches of wood. The second firing habit represents the user that charges as large batches of wood as possible and then decreases the air supply, which often leads to high levels of methane emissions (126-4800 mg/MJ). Since there is no activity data available differentiating between boilers with or without storage tank, these emissions could not be calculated separately.

The methane emissions from wood log combustion are significantly higher compared to pellets combustion. However, significant variations in emission factors are determined for specific combustion appliances and operation conditions. The emissions of methane varied in the range of 0.8-4800 mg/MJ for the wood log boilers, 10-1700 mg/MJ for the wood log stoves, 0.5-14 Mg/MJ for the pellets burners and 0.7-18 mg/MJ for the pellets stoves.

The lower emission factors for pellets are due to pellets are very different from firewood with regard to both moisture content and physical structure. Pellets are a uniform and dry fuel, further the fuel is combusted under continuous fuel feeding and controlled conditions (sufficient mixing of fuel and air). As is the case for the wood boiler, the influence of furnace design and operation conditions, especially high and low load affects the emissions during pellets combustion. A low load operation creates lower temperature and less stable combustion conditions with increased emissions of hydrocarbons like methane.

For log boilers good air supply and dry splitted wood is considered to favour the combustion with low emissions. However, Bomans study shows that full loads of extra dry and fine splitted logs may cause too high combustion intensity, causing insufficient air supply leading to higher emissions.

The results in table 4 illustrate the variability of methane emissions during different fuels, technologies and operational conditions in general. However it should be considered that the referred studies try to simulate different conditions in the field, and the variability may be even larger. Today there is little documented about firing habits, which probably is one of the factors that mostly affect the emission factor.

Table 3. Emission factors for methane determined from small scale combustion of wood logs, pellets and wood chip using different combustion technologies. All data presented as mg/MJ fuel.

Appliance type	Fuel	CH_4 mg/MJ (average)
Boilers	Wood logs	254*
	Wood chips	203*
	Pellets	3
Stoves	Wood logs	430
	Wood chips	344
	Pellets	7
Open fire places	Wood logs	318*
	Wood chips	not relevant
	Pellets	not relevant
All technologies	All biomass	250 (previous value)

* Estimated values (see methods page x)

Table 4. Emission factors for methane determined from small scale combustion of wood logs, pellets and wood chip using different combustion technologies. All data presented as Mg/MJ fuel.

Appliance type	Fuel	Average mg/MJ	Median mg/MJ	Range mg/MJ
Boiler with storage tank	Wood logs	211	117	0.8-1000
Boiler without storage tank	Wood logs	256	220	16-431
Boiler without storage tank (<air supply)	Wood logs	1313	486	126-4800
Boiler	Wood chips/saw dust	230[1]		
Pellets burner/boiler	Pellets	3	1.8	0.5-14
Stoves	Wood logs	430	100	10-1700
	Pellets	7	5.5	0.7-18
Fire places	Wood logs	318[1]		

[1] Estimated value (see methods page x)

5.3 Recalculated time series

Figure 4 shows the recalculated time series for methane emissions. Overall the new time series show higher values except for 2003. The explanation for the higher values are that emissions factors are divided by combustion technology and, as table 3 shows the emission factor for stoves (430 mg/MJ) is significantly higher compared to the previous value (250 mg/MJ) that was used for all technologies. In addition, activity data has been revised for most years 1990-2003, resulting generally in higher biomass consumption. For example, estimated consumption in holiday cottages 1990-2000 is included in this study. The decreased values for methane emission in 2002-2003 is explained by the increased use of pellets/briquettes that show significantly lower values for emission factors (table 3) and the previously overestimated consumption in multi-dwelling buildings in 2003.

To further improve the calculation of methane emissions it should be of interest to divide wood log boilers into two groups, boilers with or without storage tank. This is due to that firing habits affect this group, and it especially concerns boilers without a storage tank.

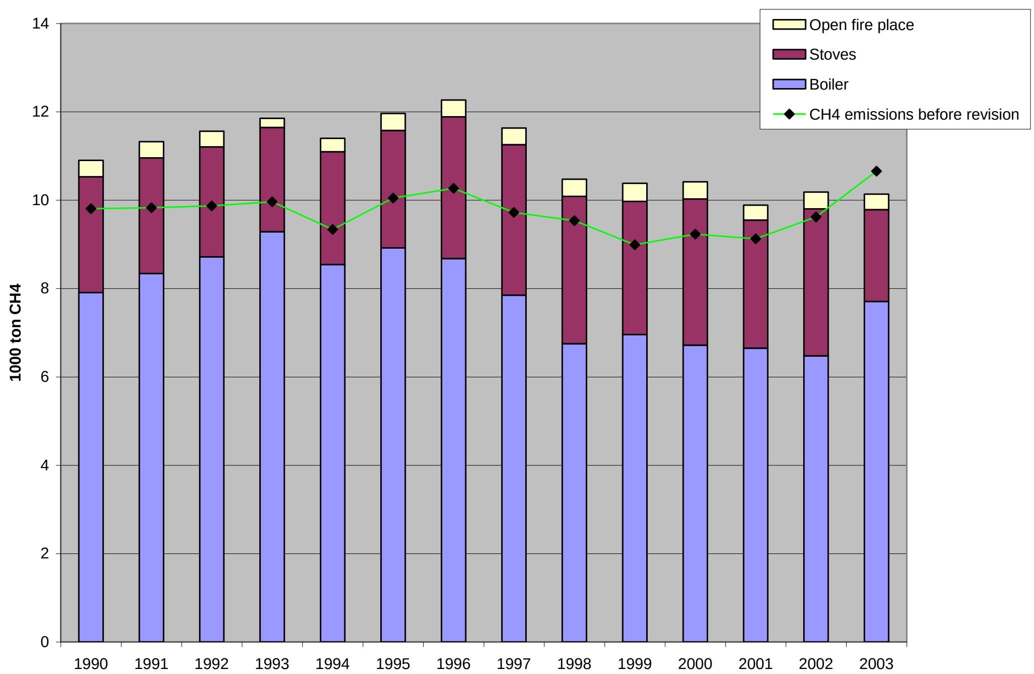

Figure 4. Recalculated methane emissions 1990-2003 in the residential sector; total methane emissions (1000 ton) before revision and methane emissions (1000 ton) by heating system after revision..

6 Uncertainty estimates

6.1 Uncertainty estimates for activity data.

The overall uncertainty in biomass activity data in the residential sector is estimated by expert judgment to +- 10%. This is based on the assumption that the statistics on the main consumer category, i.e. one- and two- dwelling buildings are relatively good (+- 5%), but that the remaining categories at the same time are considerable more uncertain (+- 20% and above).

6.2 Uncertainty estimates for emission factors

Confidence intervals are intervals, which have a stated probability of containing the true population value. To estimate the uncertainty in emission factors the 95 % confidence interval was used. The confidence intervals for the mean are computed using a table of the students´s t- distribution. This table is entered to find critical values. The width of the confidence interval is a function of a critical value for t, the standard deviation of the data, and the sample size, see formula:

$m \pm s_m t0.05(f=n-1)$

m=mean value

S_m=standard deviation

t0.05= t-value

n=sample size

The distribution of the sample mean will be closely approximated by a normal distribution as sample sizes get larger, even though the data may not be normally distributed. For smaller sample sizes the data will not be normally distributed unless the data themselves are normally distributed. When data are skewed or contain outliers, the resulting interval will be so wide that most observations will be included in it. It may also extend below zero on the lower end. This was the case for the emission factor for wood stoves and pellets boiler due to small sample sizes (8 samples).

In table 5 the uncertainty for each emission factor is shown. The emission factors were no data were available (e.g. emission factors for wood chips) the uncertainty was estimated to 100 %. This was the uncertainty that was used for the previous used single emission factor.

To decrease the skew distribution for pellets boiler the emission factors for the boilers and stoves were combined. The explanation for this is that the ranges of the emission factors were similar and it was assumed that the uncertainty for the boilers is quite similar for stoves.

An unavoidable problem in statistical analysis of emission factors is dealing with outliers. For the wood log boilers one outlier has been identified, see figure 5. If no plausible explanation for an outlier can be found, the outlier might be excluded and using a simple outlier test can do this. In table 5 the uncertainty is presented when the oultlier is both included and excluded.

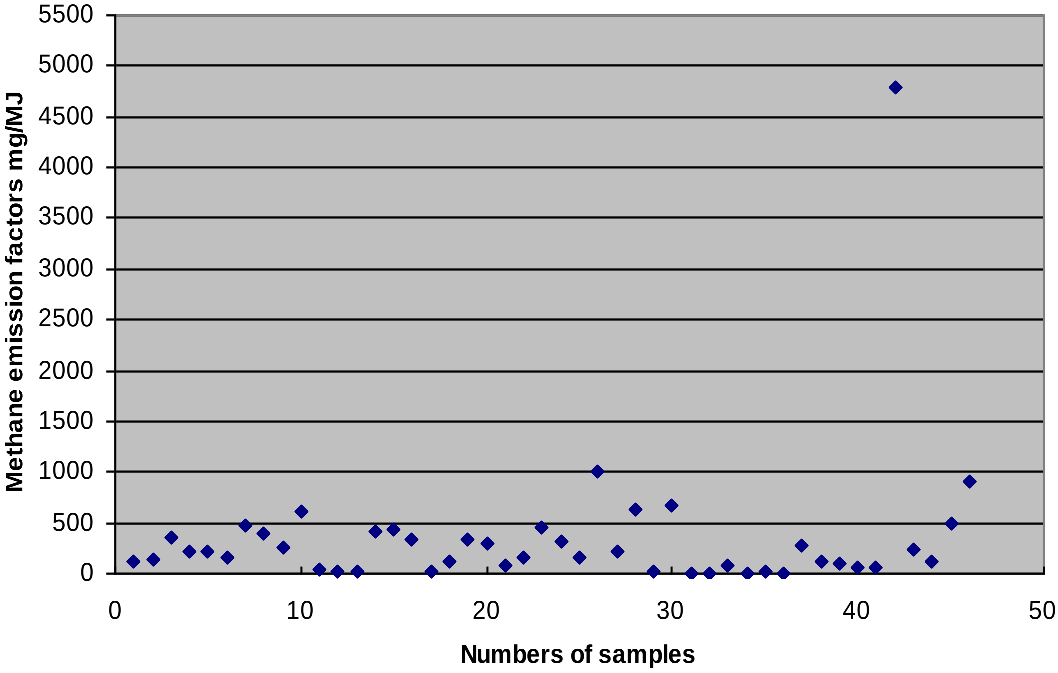

Figure 5. Show all emission factors for the wood log boiler.

Table 5. Show the uncertainty in ± percentage for the revised emission factors.

Appliance type	Fuel	CH_4 mg/MJ (average)	Uncertainty ± in percentage (%)
Boilers	Wood logs	254*	30
	Wood logs	254*	60 (outlier included)
	Wood chips	203*	100*
	Pellets	3	40
Stoves	Wood logs	430	130
	Wood chips	344	100*
	Pellets	7	40
Open fire places	Wood logs	318*	100*
	Wood chips	not relevant	
	Pellets	not relevant	
All technologies	All biomass	250 (previous value)	100 (previous)?

* Estimated values (see methods page x)

7 Conclusions and future work

The conclusions from this work are:

Time series of total amount of biomass in the residential sector before and after the revision showed good comparison.

Most consumption occurs in one- and two-dwelling buildings, and wood log is the most used fuel.

The use of pellets will probably continue to increase especially in one and two-dwelling buildings.

Recently in Sweden, grain crops have been explored as suitable solid biofuel mainly used by farmers. Today there are special boilers developed and it should be considered that this is a fuel that may increase in the category agricultural residences.

The methane emissions from wood log combustion are significantly higher compared to pellets combustion. However, significant variations in emission factors occur for specific combustion appliances and operation conditions.

In general methane emissions from boilers without a storage tank is higher. It should therefore be of interest to include the category boiler with or without storage tank in the activity data. Especially since boiler without storage tank often are old-type and in a longer perspective they may decrease in numbers.

Emission factors from combustion of pellets and chips/saw dust in multi-dwelling buildings and agricultural premises need to be further examined. In the present work the revised emissions factors are to a large extent based on results from experiments in boilers used in one- and two-dwelling buildings. Further, in activity data the consumption of biomass fuel should be divided into fuel type pellets/briquettes and wood chips/saw dust.

The recalculated time series showed higher values of methane emissions due to desegregation of emission factors by combustion technology.

The recalculated time series showed lower value for 2003 due to increased us of pellets and miscalculations in previous reporting.

Future work may involve improving emission factors such as PM, NMVOC, PAH and metals from small scale combustion.

The future potential for residential biomass combustion is probably on the use of up-graded wood fuels such as pellets, combusted in well adapted and optimised appliances. In addition, the on-going use and of new and improved wood log combustion technology is significant and will enable a continued share of wood log combustion in different residential heating sources.

Due to the increased residential installation of pellets burners, stoves and new wood boilers it is important to study the emissions of different compounds.

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9 Appendix

Table 1. Emission factors for methane determined from combustion of wood logs.

Experiment	CH4 mg/MJ	Fuel	appliances	Air supply	Field/lab
1	110	wood log	Boiler		F
2	130	"	"		F
3	360	"	"		F
4	210	"	"		F
5	220	"	"		F
6	150	"	"		F
7	480	"	"		F
8	400	"	"		F
9	260	"	"		F
10	610	"	"		L
11	30	"	"		F
12	4800	"	"	Decreased	L
13	242	"	"	Decreased	L
14	126	"	"	Decreased	L
15	486	"	"	Decreased	L
16	29	"	"		L
17	16	"	"		L
18	406	"	"		L
19	431	"	"		L
20	912	"	"	Decreased	L
21					
22					
23	330	"	Boiler (storage)		F
24	19	"	"		F
25	110	"	"		F
26	340	"	"		F

27	290	"	"	F
28	70	"	"	F
29	160	"	"	F
30	450	"	"	F
31	310	"	"	F
32	160	"	"	F
33	1000	"	"	F
34	210	"	"	F
35	640	"	"	F
36	11	"	"	F
37	670	"	"	L
38	1	"	"	L
39	0.8	"	"	L
40	73	"	"	L
41	6.8	"	"	L
42	14	"	"	L
43	9.2	"	"	L
44	280	"	"	L
45	124	"	"	L
46	90	"	"	L
47	68	"	"	L
48	62	"	"	L

Table 2. Emission factors for methane determined from combustion of wood log and pellets.

Experiment	CH4 mg/Mj	Fuel	Appliance	Load	Field/Lab
1-8	430 (average)	Wood Log	Stoves	All	L
1-6	73 (average)	"	"	High not included	L
1-8	3.1	Pellets	Stoves	High	L
1-8	10	"	"	Low	L
1	0.5	Pellets	Burner	High 11 kW	L
2	2.7	"	"	6 kW	L
3	14	"	"	Low 3 kW	L
4	0.5	"	"	High 22 kW	L
5	5.3	"	"	6 kW	L
6	0.8	"	"	Low 3 kW	L
7	1.8	"	"	-	F
8	1.8	"	"	6 kW	L