Importance of activity data for improving the residential wood combustion emission inventory at regional level

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Abstract

The contribution of residential wood combustion (RWC) to emission inventory at local level was estimated using a bottom up approach for the Lombardy Region of North Italy. A survey, based on the CATI (Computer Assisted Telephone Interviewing) method, has been undertaken through 18,000 interviews. The interviews had the objective to characterize the RWC use in this region, in term of both total and municipal wood consumption. Details on the type of appliances used in RWC were also gathered.

The results of the survey were then statistically analyzed in order to allow an estimate of RWC with high spatial resolution (i.e. at municipal level) in relation to the size and altitude of the territory.

The work provides new evidence of the importance of wood combustion as a key source for PM and NMVOC emissions at local level, and thus highlights the importance of technological improvements and new policies aimed at emission reduction in this sector.

Considering the great differences in average PM emission factors between low efficiency appliances (fireplaces, old stoves) and high efficiency ones (new stoves, pellet burners), this work

emphasizes the importance of obtaining more detailed information on the types of wood appliances used for arriving at a reliable PM emission inventory for RWC.

Keywords: wood smoke; particulate matter; residential wood combustion; air pollution; stove; fireplace.

1. Introduction

Residential wood combustion (RWC) is widespread in many countries of Europe and its usage is increasing because biomass combustion represents a renewable source of energy. GHGs (greenhouse gases) emissions savings are expected when biomass substitutes fossil fuels and thus RWC is currently promoted in the framework of climate change mitigation policies.

The “Biomass Action Plan” of the European Commission set increasing targets of biomass use, because biomass has many advantages over conventional energy sources, as well as over some other renewable energies, such as “low costs, less dependence on short-term weather changes, promotion of regional economic structures and provision of alternative sources of income for farmers” (EC, 2005).

Nevertheless it has to be considered that RWC is an important source of both particulate matter (PM) and toxic air pollution around Europe (EEA, 2009; Hellén et al., 2008; Nussbaumer et al., 2008). In fact, in addition to a high level of primary PM emissions, RWC produces volatile organic compounds (VOC) with a high content of various toxic and carcinogenic compounds such as PAH and Dioxins (Lavric et al., 2004). Both PM and VOC have been proven to have important effects on human health (Zelikoff et al, 2002; Naeher et al., 2007).

The relevance of this emission source for air quality has been studied and confirmed in several European countries and with different methods using emission inventories, air quality data analysis, air quality modeling and source receptors modeling (Glasius et al., 2008; Favez et al., 2009).

Although numerous studies have highlighted the role of wood combustion in PM air concentration (Borrego et al., 2010; Caseiro et al., 2009; Glasius et al., 2006), only a few studies (i.e. Sternhufvud et al., 2004) use a bottom-up approach to calculate RWC emissions, due to the lack of information on activity data for this source (i.e. amount of wood and kind of appliances used at local scale).

Here, we investigate the contribution of RWC using a bottom up approach. This approach focused on obtaining an accurate estimation of the activity and its spatial distribution. In detail, the purpose of this work is to develop a reliable methodology to evaluate one of the fundamental inputs required for the estimation of the contribution of this sector to local and regional emission inventory: i.e. the amount of wood used. Information on the appliances used was also acquired. The focus area is the Lombardy region, a highly industrialized area in Northern Italy with 9 million inhabitants, where wood combustion has been identified as a key source for particulate emissions (ARPA Lombardia, 2009; Piazzalunga et al., 2010).

2. Material and methods

The CATI method (Computer Aided Telephone Interview) has been used in the survey, and was carried out at the end of the winter season 2007/2008. A sample of 18,085 families, resident in the 11 provinces of Lombardy, was built by randomly choosing names in the telephone book of all households with a telephone line.

A two-stage stratified sampling method was used. The primary statistical units (the first stage of sampling) are the Lombardy municipalities, while the secondary statistical units (second stage) are the resident families. The municipalities are aggregated in 50 homogeneous cells, for which non-proportional sampling is used to build the sample in order to maximize the efficiency of the estimates (Cochran, 1977).

The homogeneity of the cells is estimated on a series of variables that, in previous investigations (Caserini et al., 2007) have proved to be appropriate proxies for the analysis: the altitude, the municipal structure, consumption estimated by previous survey. In each unit sampled, families were then further stratified proportionally on the basis of the family members and settlement size.

Following the Italian National Institute of Statistics (ISTAT), the municipalities were divided into three categories (mountain, hill, plain) in relation to the amount of reliefs and the altitude (hills over 300 m and mountains over 600 m).

To estimate wood combustion use and to quantify the total wood consumption, only users that claim to “light the fire” at least five times a year were considered. Previous surveys on this subject have shown that occasional-user families have marginal impact on overall consumption and, moreover, they cannot provide precise estimates of their consumption.

The survey questionnaire requested the family to declare their use of wood for heating and cooking purposes, but it contained also control questions that allow the estimation of the actual wood consumption starting from the frequency and patterns of usage. In the subsequent data analysis particular attention has been paid to identifying and correcting any outliers, in term of absolute values (> 10 t y^{-1} per household) and total number of hours of usage in a year (> 2000 h y^{-1}). Outliers have been replaced with estimated values based on the average of available data of consumption for families with similar characteristic (using sampling cell, combustion device, domestic heated surface…).

Statistical errors (95% confidence interval) on the assessment of household using wood and wood consumption per household has been calculated through the usual formulas based on the number of interviews in the sample and the real variability of the estimated wood combustion (in terms of standard error, Cochran, 1977).

3. Results and discussion

3.1. Wood consumption

The survey has assessed the total domestic wood consumption in Lombardy to be about 1.57 million tons. The sampling methodology and the large number of interviews have resulted in low statistical errors, because the 95% confidence interval is between 1.42 and 1.72 Mt y^{-1}.

RWC is used by 598,000 households (16.4% out of the total in Lombardy region). Households where wood is burned at least five times per year are 71,4% of total households burning wood, with an average consumption of 3.68 (3.46 – 3.90 at 95% confidence) tons of wood per household per year; about 97% of these households use wood only in the primary residence, 1.7% only in a second home and 1.7% use it both in home residence and in a second house in Lombardy.

The pattern of wood use shows significant differences over the territory of the region. As expected, wood use is higher in the mountain area where 34% [1]of households use regularly a RWC appliance for heating purposes. This percentage decreases in the hill and plain areas, respectively to 14.3% and 7.1%.

The amount of wood consumed in each province and its confidence intervals, is presented in Table 1. Greater RWC use (in terms of number of appliances) is observed in the mountain provinces, such as Sondrio (45.2%), Brescia (20.7%), Lecco (18.4%) and Bergamo (17.1%). Not surprisingly, the highly urbanized province of Milan is a lower wood consumer, with only 3.2% RWC penetration percentage, whereas the consumption for those households which use wood for heating is only slightly lower than the regional average.

As regards average consumption per household, higher values are observed in smaller settlements (Fig. 1).

Table 1 – Wood usage in the Lombardy provinces.

PROVINCE	User [%]	**Wood consumption** [t y^{-1} $household^{-1}$]	95% c.i. average consumption [t y^{-1} $household^{-1}$]	**Wood consumption** Total [kt y^{-1}]	95% c.i. total consumption [kt y^{-1}]
Bergamo – BG	17.1	3.66	3.12 - 4.21	242	186 - 299
Brescia – BS	20.7	4.12	3.52 - 4.73	386	283 - 489

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Como – CO	15.4	2.86	2.31 - 3.40	92	72 - 112
Cremona - CR	17.3	3.75	3.11 - 4.39	88	75 - 101
Lecco – LC	18.4	3.26	2.43 - 4.09	79	60 - 97
Lodi – LO	14.6	3.79	2.30 - 5.29	43	29 - 57
Mantova - MN	13.7	4.91	3.63 - 6.20	98	61 - 135
Pavia – PV	10.3	4.68	3.48 - 5.88	102	65 - 139
Sondrio – SO	45.2	4.77	3.90 - 5.65	159	130 - 188
Varese – VA	16.5	3.09	2.61 - 3.58	164	127 - 201
Milano - MI	3.2	2.45	2.04 - 2.87	117	88 - 145
Totale	11.5	3.68	3.46 - 3.90	1,570	1,420 - 1,720

Figure 1 – Total consumption (black dot, right axis) and average consumption per household (gray bars, left axis) for 3 altitude class (mountain, hill and plain) and settlement size

In general RWC is mostly used for domestic heating rather than for cooking in Lombardy: 56.4 % of the household use it only for heating, 3.2% only for cooking and 38.4% both for cooking and heating purposes.

About a quarter (23.3%) of the interviewees declared that they intend to use RWC system more frequently in the coming years. There were three main reasons given for using RWC: it is considered economic (60%), it “heats better” (28%), and for aesthetic reasons (27.5%).

3.2. Appliances

In the 427.000 houses in which wood is more frequently used, there are 683.000 appliances, including wood-fired ovens and barbecues. The result is an average of 1.60 appliances burning wood per house (1.54 mountain areas, 1.71 hill areas and 1.58 plain areas).

Since the emission factor significantly depends on the type of wood appliance used, the results of the survey in terms of the different appliance types is of great interest. The breakdown of the number of appliances per type is shown in Table 2.

Traditional devices (open fireplaces, traditional stoves and closed fireplaces) are almost three-quarters of the total number of appliances at regional level (Table 2), whereas the percentage penetration for pellet stoves and innovative stoves is very low (about 5 % each). Almost one quarter (24.4%) of households own and use a barbecue while only 5.2% use a wood oven.

With reference to the altitude and the wood consumption for the different appliances (Fig. 2), higher consumption rates are reported in mountain areas especially for closed fireplaces, whereas in plain and hill areas, reported wood consumption is smaller.

Table 2 - Breakdown of the wood appliances in Lombardy region.

	Number of wood appliances [thousand]	Percentage distribution [%]	Wood consumption [kt $year^{-1}$]
Traditional open fireplace	162	23.7	309
Traditional stove	177	25.9	382
Closed fireplace	149	21.9	687
Automatic stove Pellets or chips	32.5	4.8	122
Stove innovative or advanced	34.2	5.0	47.0
Wood oven	22.6	3.3	8.0
Barbecue	106	15.5	16.5
TOTAL	**683**	**100**	**1,570**

Figure 2 - Wood consumption for type of appliance in different areas in Lombardy

3.3. Emission assessment

Emissions from RWC depend on several parameters such as the quality of the wood, the appliance type, the air supply system, the appliance lining, the humidity of the wood, and, most important, the operating condition (Nussbaumer, 2003). For these reasons the RWC emissions estimate is accompanied by a high level of uncertainty (Nussbaumer et al., 2008; EEA, 2009), which also depends on the variability of the fuels and the appliances used in a large domain such as the Lombardy region.

For a reliable estimate of emissions, striking a balance between the key input factors is therefore important: the quantity of wood burned, the types of appliances used and their associated emission factor. For example, using an average emission factor rather than specific values for each type of device can have consequences on emissions estimate due to the implicit assumptions on the relative weight of each type of equipment.

Since this study has achieved a great detail in the assessment of number of appliances and their wood use, a comparison of RWC emissions estimates obtained applying two different methodologies was made:

- use of an average emission factor for the whole residential sector (Tier 1);
- use of a different emission factor for every appliance (Tier 2).

In the Tier 1 approach, the average NOx, PM10, CO and NMVOC emission factors proposed by the EMEP/EEA Air pollutant Emission Inventory Guidebook (AEIG) (EEA, 2009) for the RWC sector were used.

In the Tier 2 approach, the emissions per appliance type are calculated, including estimation using the minimum and the maximum of wood consumption and of emission factors. Average, minimum and maximum emission factors have been taken from the AEIG (proposed value, lower and upper 95% confidence interval limits, respectively), except for closed fireplaces. This last category is not - with the exception of innovative closed fireplaces - specifically treated in the AEIG. In this case, the emission factors used are obtained comparing values suggested in the AEIG with other sources (Nussbaumer, 2008, Angelino et al., 2008).

Although more up-to-date literature exists currently, EFs proposed by the EEA-AEIG were initially based on a wide literature survey and a calculation methodology of mean values for a variety of European appliances and typical uses. The possibility to define a specific average and range of emission factors for this case study is limited by the difficulty to define a coherent set of emission factor due to the great variability of measurement conditions found in literature, in terms of load cycle (real cycle load or full load), monitoring system (with or without dilution tunnel) and appliances tested.

For barbecues a specific emission factor was not available, and therefore they were considered as open fireplaces. The assumption was considered acceptable because of their low contribution (about 1%) to total RWC use.

An average lower heating value of 12.5 GJ t^{-1} wood was used for wood and 16.4 GJ t^{-1} for pellets (van Loo and Koppejan, 2007). For wood consumption, uncertainty values corresponding to 95% confidence intervals obtained in the investigation were used. For emission factors, the 95% confidence intervals are given by the AEIG separately for each pollutant, although the maximum values are not expected to occur simultaneously for all pollutants.

The maximum emission factor indicated by AEIG for pellet stoves seems to be high, in comparison with other values currently available in literature. This is a result of recent advances in pellet stove technology which should be addressed in a newer version of the AEIG chapter. Nevertheless for our test case AEIG values were used to ensure coherence by using – whenever possible - the same source for all emission factors. A detailed analysis of emission factors for pellet stoves in Lombardy is not in the scope of this study, also because of the relatively small share of those type of stoves.

RWC consumption and emission factors used are listed in Table 3.

Table 3 - Emission factors used in this study for wood combustion appliances

		Wood Use	**PM10**	**NO_X**	**NMVOC**	**CO**
		kt $year^{-1}$	**g GJ^{-1}**			

Tier 1	Average	**1570**	**695**	**74.5**	**925**	**5,300**
	Open fireplace	309	860	50	1,300	6,000
	Traditional stove	382	810	50	1,200	6,000
	Closed fireplace	687	450	70	750	5,100
Tier 2 – average	Innovative stove	47	240	90	250	3,000
	Pellets stove	122	76	90	20	500
	Wood oven	8	810	50	1,200	6,000
	Barbecue	16	860	50	1,300	6,000
	Open fireplace	259	516	30	780	4,000
	Traditional stove	327	486	30	720	4,000
	Closed fireplace	594	230	40	300	1,780
Tier 2 - minimum	Innovative stove	35	66	50	20	300
	Pellets stove	94	66	50	10	300
	Wood oven	5	486	30	720	4,000
	Barbecue	11	516	30	780	4,000
	Open fireplace	358	1,200	70	1,500	6,500
	Traditional stove	436	1,130	150	1,500	6,500
	Closed fireplace	779	600	150	900	5,600
Tier 2 - maximum	Innovative stove	59	250	150	500	5,000
	Pellets stove	149	240	150	500	5,000
	Wood oven	11	1,130	150	1,500	6,500
	Barbecue	22	1,200	70	1,500	6,500

The comparison between total emissions from RWC assessed with Tier 1 and Tier 2 is shown in Fig. 3. The low difference between the two values means that the appliance mix assumed by the AEIG for Europe (Tier 1 value) is similar to the one found in Lombardy. The RWC emissions are generally lower in the Tier 2 approach (almost 15 % for PM10 and NOx, whereas the difference is not so pronounced for NMVOC and CO). The range between higher and lower values (deriving from the 95% confidence interval for wood consumption and emission factors) is nevertheless very high.

Annual Tier 2 emissions for each appliance type are shown in Fig. 4. Fireplaces and traditional stoves contribute more than 95% to the total emission of PM10, NMVOC and CO. The contribution of innovative stoves and pellet stoves (11% of the used wood) is less than 4% for these pollutants, whereas this increases to 15% for NOx.

Figure 3 – RWC emission in Lombardy from Tier 1 and Tier 2.

Figure 4 – RWC emissions per appliance type

Comparing these results with the emissions of other sources in Lombardy region (ARPA Lombardia, 2009), wood combustion appears to be the most important source for PM10 (75% of emissions from all other sources), and one of the most important for CO and NMVOC (45 % and 8% respectively); of secondary importance are NOx emissions (< 1%). It's worth noting that RWC activity occurs mainly during the colder months while the other PM10 and NMVOC key sources (transport or industrial processes) have more homogeneous temporal distribution; this leads to an increase of the percentage contribution of RWC to total emission during the colder months.

Thanks to the high detail on wood consumption data provided by the survey, it is therefore possible to estimate the total annual emission from RWC sector for each municipality and province. The emissions of different areas (mountain, hill and plain) are reported in Table 4, in terms of total emissions and emissions per capita. Due to the larger use of wood (in particular in closed fireplaces, see Fig. 3), emissions are higher in mountain area both in absolute terms and on a per capita basis.

Table 4 - Total emissions and per capita emissions for three area types in Lombardy.

	Emissions [t year^{-1}]				Per capita emissions [kg person^{-1}]		
	Mountain	Hill	Plain	TOTAL	Mountain	Hill	Plain
NOx	581	265	434	1,280	0.58	0.14	0.07
NMVOC	7,420	3,638	6,692	17,750	7.4	2.0	1.1

CO	43,728	19,885	36,518	100,131	43.8	10.7	5.9
PM10	4,771	2,423	4,400	11,594	4.8	1.3	0.71

3.4. Comparison with previous estimate

A previous estimation of RWC activity in Lombardy region has been carried out for the winter 2005/2006 on the basis of a national survey of a total of 5000 (of which 900 in Lombardy) interviews (Caserini et al., 2007).

Fig. 5 shows the comparison of the type of appliances estimated by the present work and previous assessment. The main difference concerns the share of closed fireplaces, which appears higher in the 2005/2006 survey.

Differences are observed in the estimation of the total amount of wood consumed (2,048 kt in the 2005/2006 survey and 1,570 kt in the present) and in its spatial distribution in the region. This difference could be explained in three different ways. First, the meteorological differences for the two periods considered: 2007/08 was warmer than 2005/06, with a 13% lower consumption of fossil fuel in the domestic sector (Regione Lombardia, 2010). Second, the methodology used was much more detailed in the 2007/08 survey (18.000 interviews against 900 in 2005/06). Finally the difference could be the effect of a regional law which introduced restrictions on the use of wood biomass for residential heating starting in the year 2007 in Lombardy (ban for traditional fireplaces, traditional stoves and closed fireplaces, if the efficiency is lower than 63 % or CO concentration in flue gas is higher than 0,5 %, Regione Lombardia, 2007).

In order to compare the spatial distributions obtained in the two studies and to avoid possible misunderstandings caused by the difference in total consumption, the percentage spatial distribution obtained in the 2005/2006 survey was applied to the total consumption for winter 2007/2008. The comparison of the spatial distribution among provinces is shown in Fig. 6. The absolute value represents the difference between the total amount of wood calculated at provincial level using the 2005/2006 and the 2007/2008 spatial distributions. The percentage is calculated dividing the above mentioned difference for the total amount of wood calculated in the last survey.

The comparison underlines that the spatial distribution can vary considerably on the basis of the chosen approach and this could importantly affect not only the spatial distribution of the emission inventory but also the results of the air quality models that use this emission inventory as input. The difference in some cases could be higher than 100% (Como province – CO), meaning that the improved methodology has halved the reported amount of RWC used in the province, which greatly influences the PM and NMVOC emission inventory in this area.

Figure 5 - Share in the number of appliances for RWC in Lombardy estimated by the previous assessment (year 2006/2007, Caserini et al., 2007) and this work (2007/2008)

Figure 6 – Difference in wood consumption assessment at provincial level between the 2005/2006 assessment (normalized to 2007/2008, see text) and the 2007/2008, in absolute value (bars) and in percentage (lines). The letters in the X-axis correspond to the provinces of the Lombardy region.

3.5. Uncertainty estimate at local scale

The accuracy level of an emission inventory is determined by uncertainties associated to the input parameters, in this case activity data and emission factors. The uncertainty in activity was estimated and used to calculate the regional emission inventory and its effect is reflected in the final result. The uncertainty in emission factors was not considered since the paper focus mainly on the estimation of activity data.

As already mentioned in the methodological chapter, based on a statistical analysis of the overall wood consumption, an uncertainty range of 1420-1720 ktons per year was estimated for a 95% confidence interval. Ignoring the uncertainty of emission factors (which would be the same for all areas) it is possible to approximate the emission uncertainty for each province of the region solely on the basis of the wood consumption uncertainty. Taking those uncertainties into account, the percentage contribution of wood combustion to total PM10 emission may reach particularly high values for the provinces that lie in the mountain areas, like Sondrio (80%), Lecco (60%), Como (48%) and Bergamo (47%). The same effect is seen for NMVOC emissions, which taking the uncertainty into account, can reach 12% of the total for the Sondrio province, while for the others provinces, the NMVOC wood emission contribution is in the range of 2-11%.

4. Conclusions

An RWC activity survey was undertaken in order to obtain information useful for the development of high quality emission inventory at the local and regional scale and to provide input data to air quality modeling and planning.

A CATI survey based on 18,000 interviews was carried out at a local level in the Lombardy region, allowing a better insight into the pattern of wood consumption activity and its spatial distribution in the region and at provincial and municipal level. 55 areas, differentiated by altitude, settlement size and wood demand, allowed the assessment of wood consumption at a local level, also identifying the uncertainty range.

The total amount of wood consumed in Lombardy in year 2007 is 1.57 (+/- 0.15) Mt for both heating and cooking purposes. Higher consumption is observed in mountain areas, followed by hill and plain areas; biomass is utilized commonly in houses, in small settlements below 5,000 inhabitants, and in single buildings.

Wood is typically the most used fuel, mainly for domestic heating and hardly ever for cooking. The main reasons that lead to a preference for wood as a fuel are the economic savings and the “aesthetic” quality of a wood fire.

Among appliances for heating purposes, traditional combustion systems (open fireplace, traditional stove) are 61% of the total appliances in the region; 27% are closed fireplaces and the remaining 12% are innovative devices (or automatic stoves). Information on the use of different appliances is of great importance because wood as a fuel has a big impact in terms of PM and NMVOC emissions, which is directly affected by combustion technology and is higher for old stoves and fireplaces. Wood is used differently in different appliances: closed fireplaces burn the majority of the wood (44%), traditional appliances use 45% and the remaining 11% is used in innovative stoves.

RWC could be considered a very important source for PM and NMVOC, at regional level but also for many provinces and municipalities. Its role is even greater during winter, because its use occurs mainly during the colder months while the other PM and NMVOC key sources (transport or industrial processes) have more homogeneous temporal distribution.

On the basis of the uncertainty of the activity data and the range in the emission factors available, an estimate of the uncertainty of emissions was made. The relevant variation in the emission assessment due to different assumption in the average emission factors suggest that efforts to better assess RWC activity data and emission factors are of particular importance in order to decrease the overall uncertainty of PM, NMVOC and CO emission inventory at the local scale.

The regular update of the bottom-up approach in RWC emission assessment proposed by this paper will allow obtaining a much more robust monitoring of this emission source evolution over time**.**

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***Research Highlights**

- CATI method allow a detailed assessment of domestic wood use at the local level
- Old appliances (open fireplace, traditional stove) are still widespread and used.
- Details on the type of appliances used are very important for PM emission assessment
- Large variability of PM emission factors limits the reliability of local inventory
- A great potential of PM emission reduction through appliance renewal is identified

Figure 1

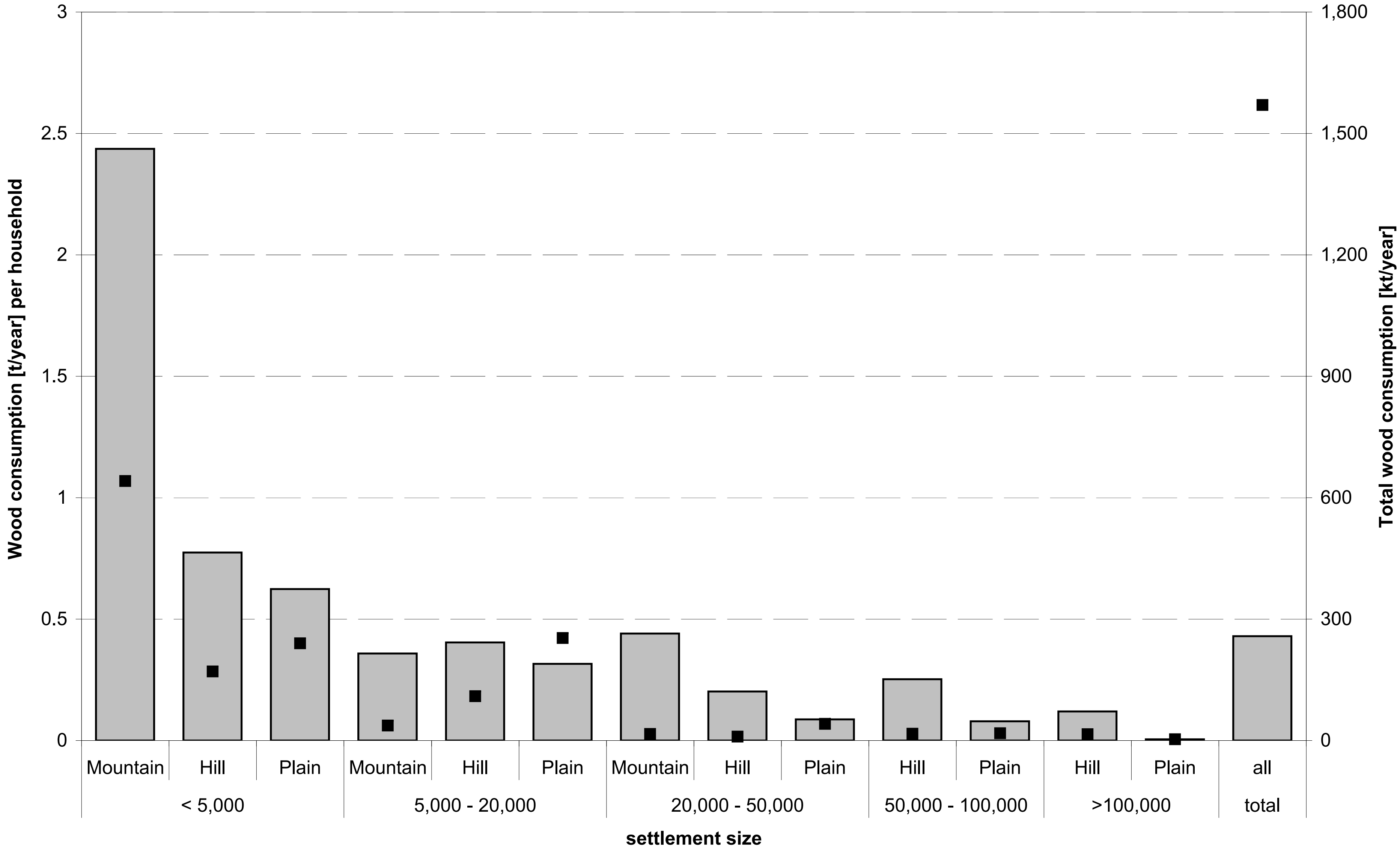
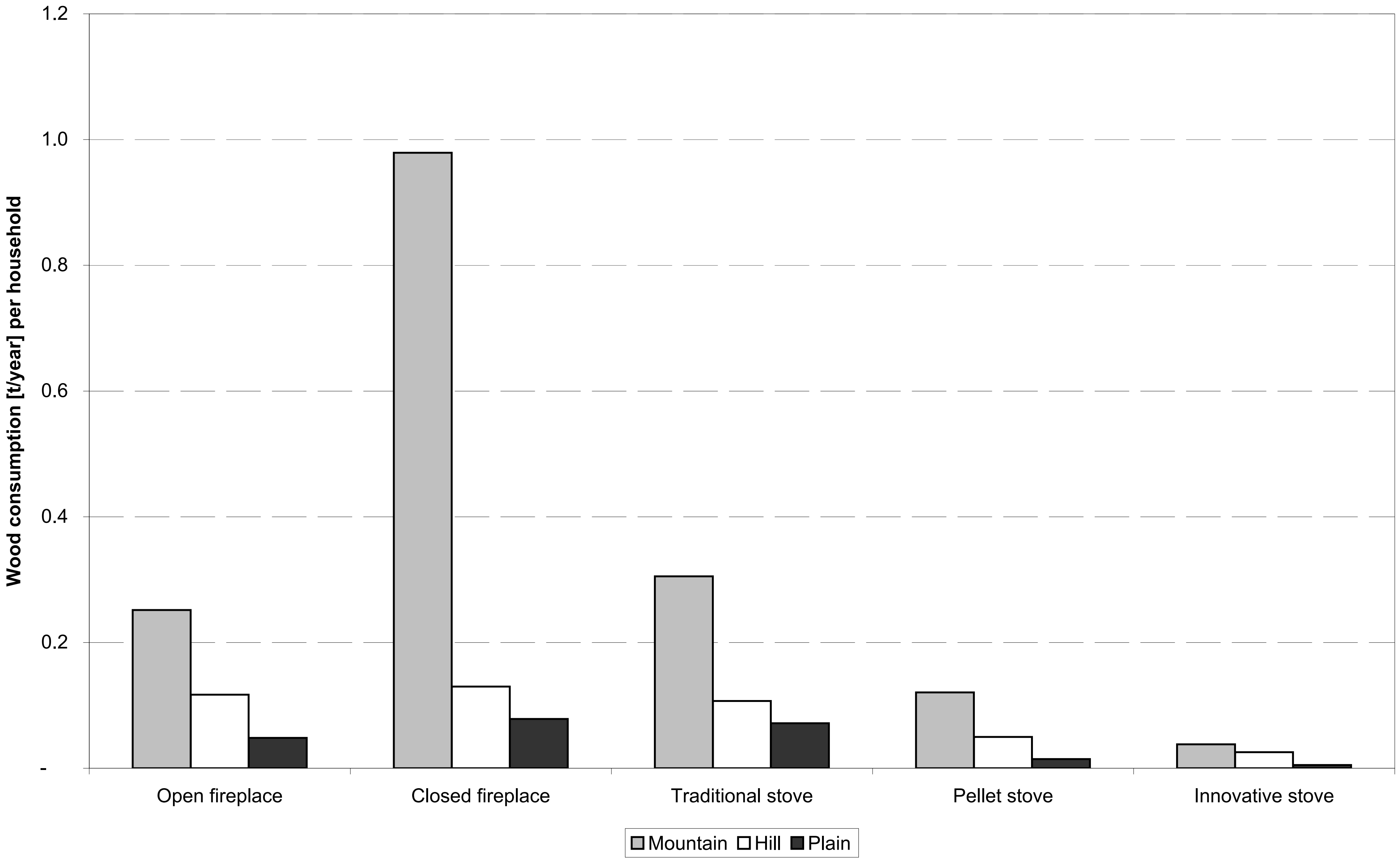
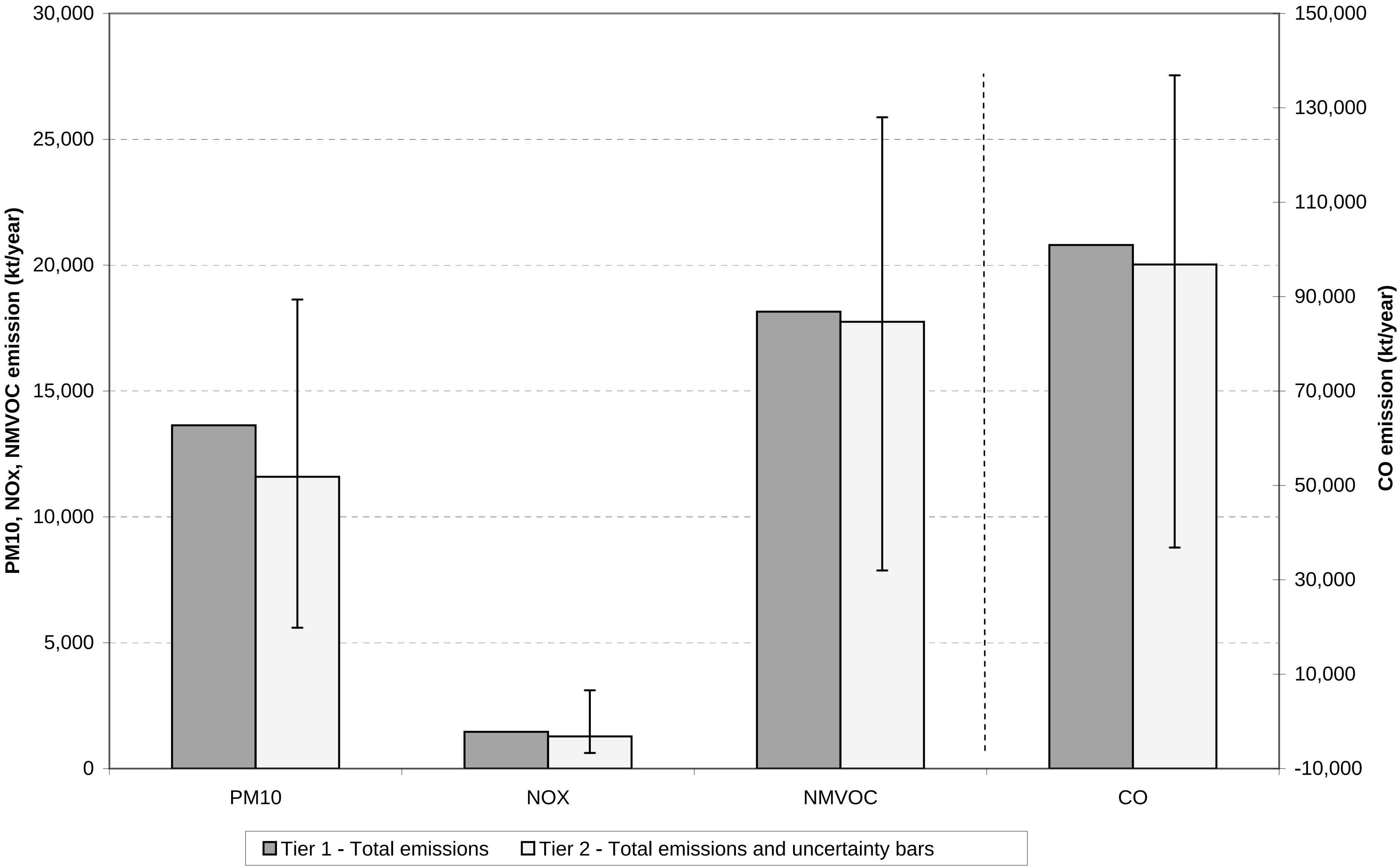

3
2.5
2
1.5
1
0.5
0
1,800
1,500
1,200
900
600
300
0
Wood consumption [t/year] per household
Total wood consumption [kt/year]
Mountain
Hill
Plain
Mountain
Hill
Plain
Mountain
Hill
Plain
Hill
Plain
Hill
Plain
all
< 5,000
5,000 - 20,000
20,000 - 50,000
50,000 - 100,000
>100,000
total
settlement size

Figure 2



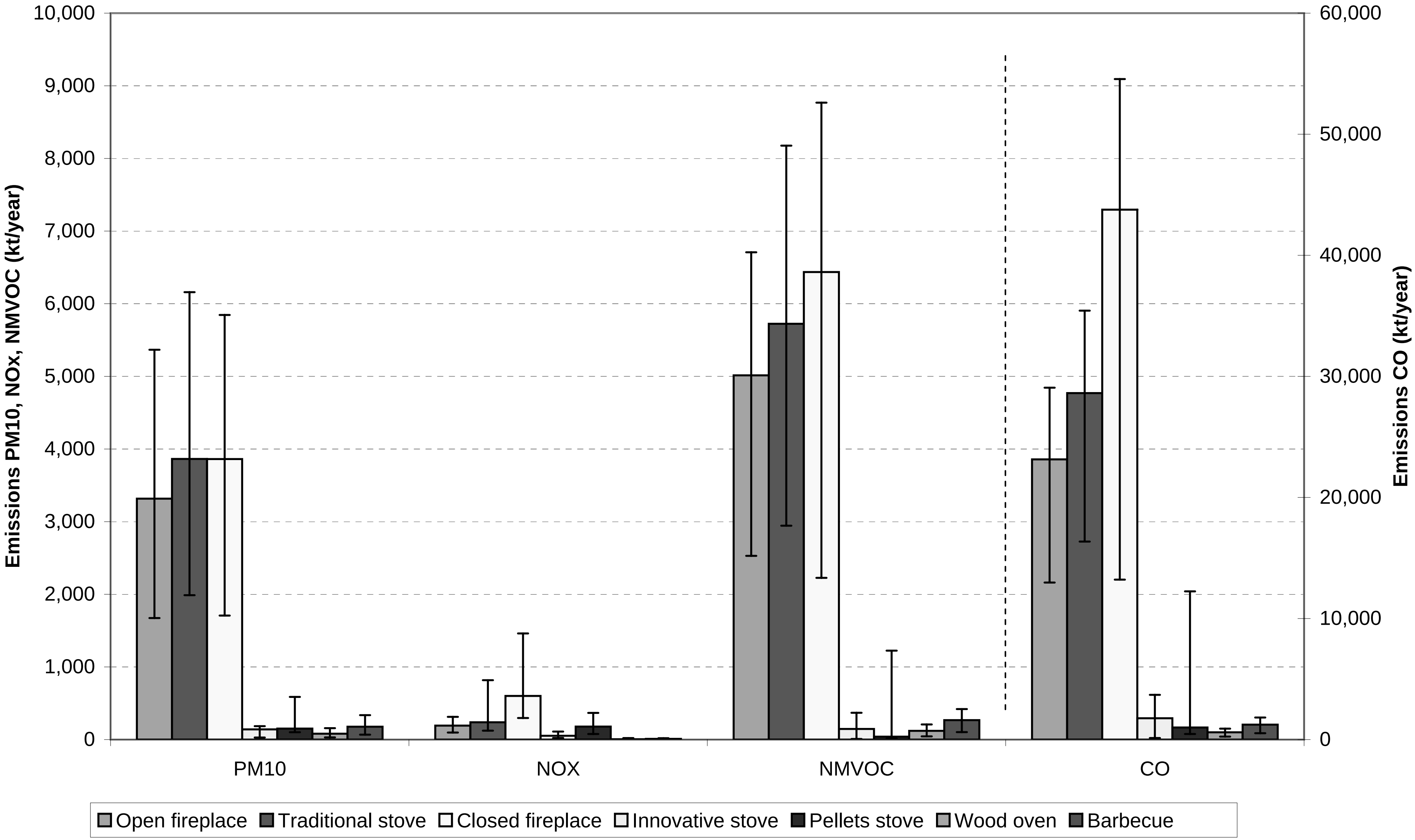
1.2
1.0
0.8
0.6
0.4
0.2
-
Wood consumption [t/year] per household
Open fireplace
Closed fireplace
Traditional stove
Pellet stove
Innovative stove
Mountain
Hill
Plain

Figure 3



PM10, NOx, NMVOC emission (kt/year)
30,000
25,000
20,000
15,000
10,000
5,000
0
CO emission (kt/year)
150,000
130,000
110,000
90,000
70,000
50,000
30,000
10,000
-10,000
PM10
NOX
NMVOC
CO
Tier 1 - Total emissions
Tier 2 - Total emissions and uncertainty bars

Figure 4



Emissions PM10, NOx, NMVOC (kt/year)
10,000
9,000
8,000
7,000
6,000
5,000
4,000
3,000
2,000
1,000
0
Emissions CO (kt/year)
60,000
50,000
40,000
30,000
20,000
10,000
0
PM10
NOX
NMVOC
CO
Open fireplace
Traditional stove
Closed fireplace
Innovative stove
Pellets stove
Wood oven
Barbecue

Figure 5

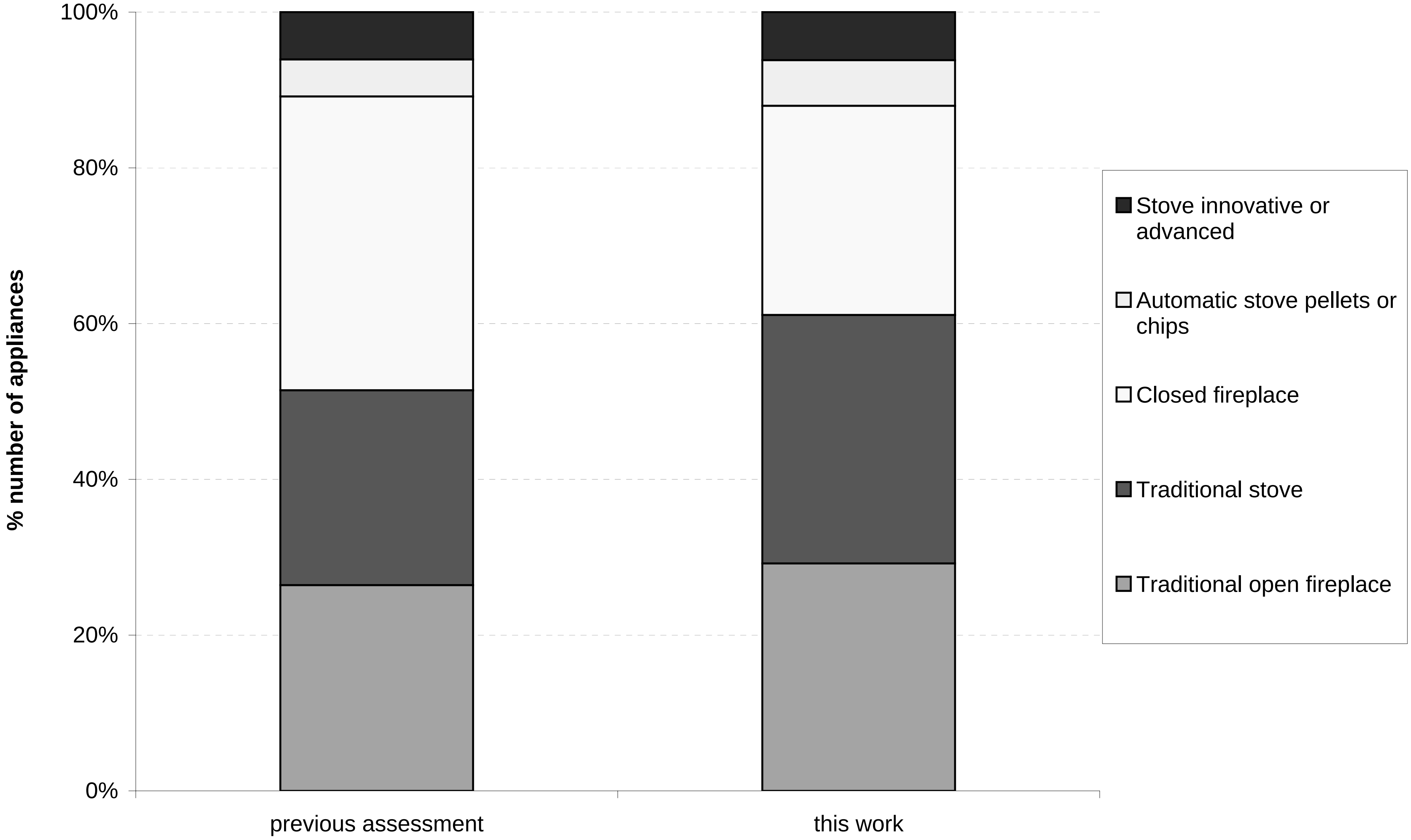
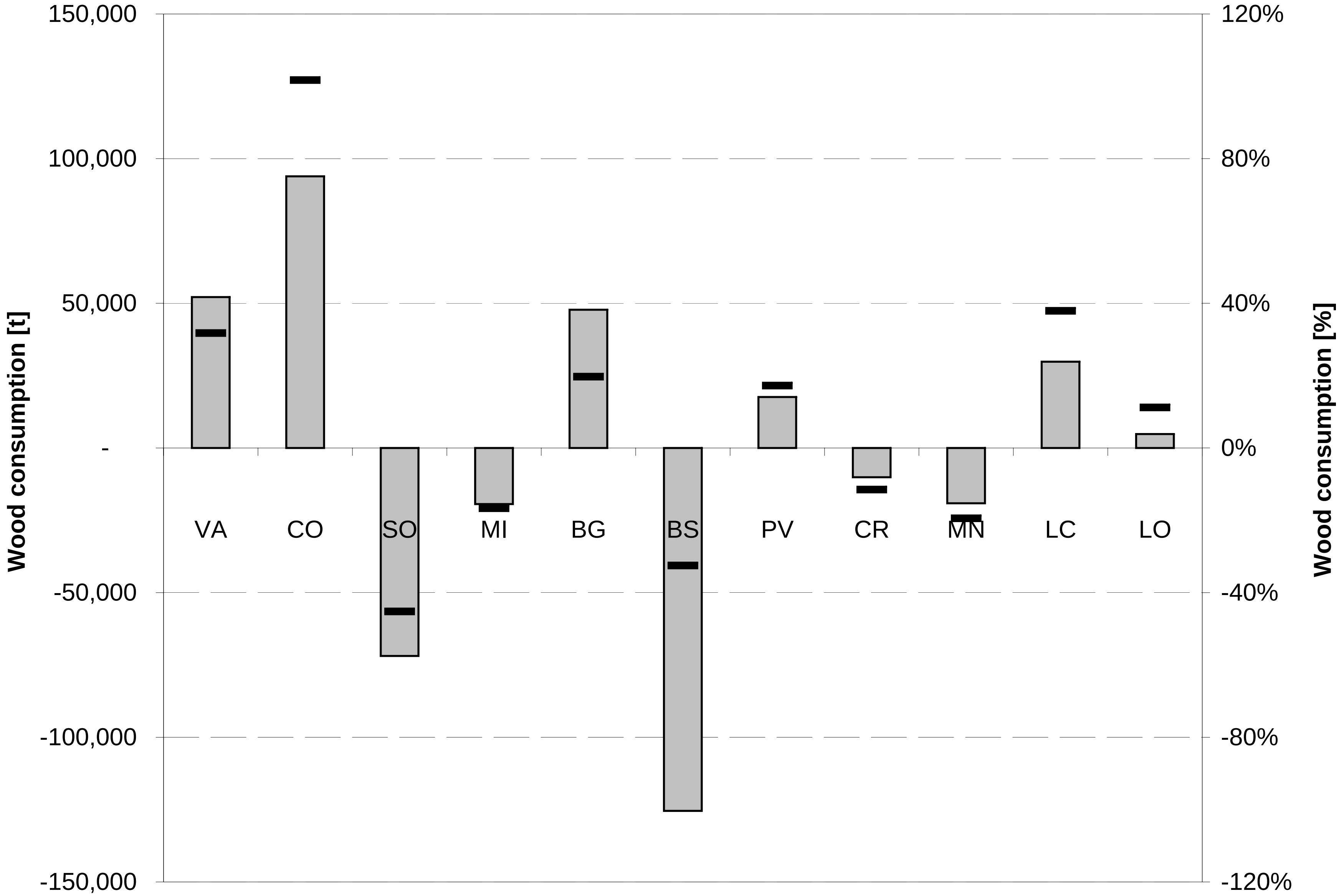

100%
80%
60%
40%
20%
0%
% number of appliances
previous assessment
this work
Stove innovative or advanced
Automatic stove pellets or chips
Closed fireplace
Traditional stove
Traditional open fireplace

Figure 6


150,000
100,000
50,000
-
-50,000
-100,000
-150,000
Wood consumption [t]
120%
80%
40%
0%
-40%
-80%
-120%
Wood consumption [%]
VA
CO
SO
MI
BG
BS
PV
CR
MN
LC
LO