An extensive survey on wood use for domestic heating in Lombardy: implication for PM emission inventory

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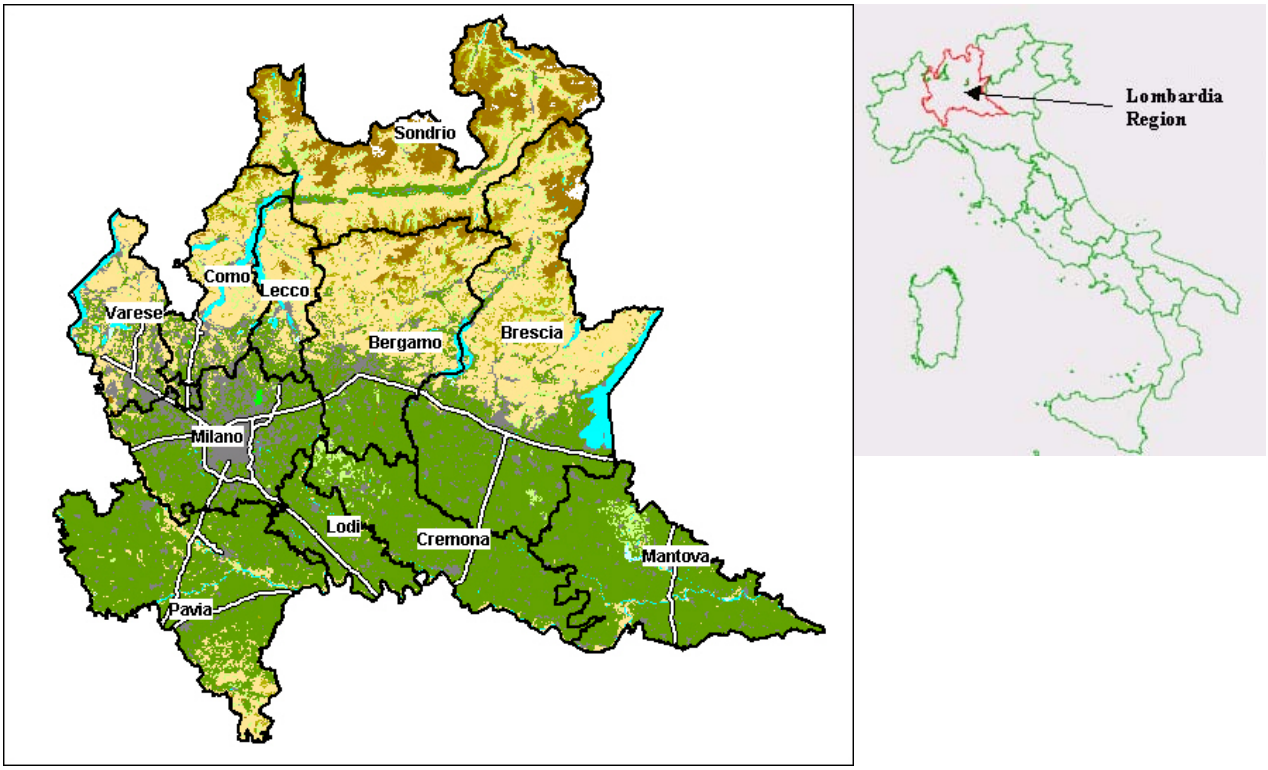
ABSTRACT

Given the lack of reliable data on wood combustion for residential heating in Lombardy (Italy), a specific survey has been undertaken: 98.061 questionnaires have been sent by mail to students of 386 secondary schools; 32.993 students (33,6%) of 236 schools filled the questionnaires. Data concerning quantity and quality of wood use, type of combustion systems and temporal split of wood use during the 2003-2004 winter season have been analyzed in order to produce an estimate of wood combustion and the consequent PM10 emissions, through the application of emission factors available in literature. The results allowed to define a large entity and a pattern of wood use for domestic heating in Lombardy, in particular in the sub-alpine area: 25% of the families of the sample use wood, with an average consumption of 4.0 t/y per family. The most reliable estimate of wood use in Lombardy is 1,9 Mt/y (210 kg/inhab/y), calculated through the creation of different clusters of towns according to population and altitude. PM10 emissions assessment made through emission factors available in literature confirm the role of wood as the most relevant source of primary PM in the domestic sector, a source with a significant importance in the total PM10 emission inventory in Lombardy. Further investigations are ongoing in order to assess specific emissions estimates of PM10 from different wood combustion systems commonly used in the region.

INTRODUCTION

The present survey has been undertaken to evaluate wood consumption for household heating in Lombardy, a highly industrialized and populated region in northern Italy (9 million inhabitants) (Fig. 1). Although wood is a biological, renewable and carbon-neutral source of energy, its combustion has an environmental cost because of the emissions of pollutants dangerous for human health such as Carbon Monoxide (CO), Nitrous Dioxide (NO_2), Volatile Organic Compounds (VOC), Dioxins/Furans (PCDD/Fs) and most of all particulate matter (PM10 and PM2,5). As throughout the Pianura Padana area, PM10 concentrations in air are particularly high: for instance, the 2003 annual average of an urban background station in Milan reaches 59 µg/m^3, with 137 days above the limit value of 50 µg/m^3.
The detailed atmospheric emissions inventory managed by the Air Sector of ARPA, Regional Environmental Protection Agency (Caserini et al., 2004; Regione Lombardia, 2005) identify wood combustion from residential fireplaces and stoves as an important source of primary PM2.5 and PM10 emissions in Lombardy (17 % on yearly basis, 30 % in the winter period).
To increase the reliability of data on wood consumption in different territorial context in Lombardy, a research work has been developed in the framework of the Kyoto Project, a research on climate change and greenhouse gases monitoring and reduction promoted by Lombardy Foundation for the Environment, Lombardy Region and ARPA-Lombardia. At the national level, two surveys conducted through phone interviews in 1997 and 1999 by ENEA (the Italian Agency for Energy, New technologies and environment) show that a considerable part of Italian families (20-30%) uses wood for domestic heating, and the pattern of wood use is influenced by altitude, degree of urbanization and type of combustion system. Looking at the territory of Lombardy these studies suggest that more than 500.000 families use wood as a domestic fuel, even if the majority of them uses a small amount of it. The total amount of wood burned for domestic heating in Lombardy has been assessed by ENEA in 1 Mt/y, roughly 110 kg/inhab./y (Gerardi and Perrella, 2001).

Figure 1. Area of study - Lombardy region, northern Italy.



METHODOLOGY

A questionnaire was elaborated to collect information concerning the amount and modalities of wood consumption for domestic heating in Lombardy during the 2003-2004 winter season. This questionnaire (see *Attachment 1*) was reproduced in 98.061 copies and sent to 386 secondary schools all over the region, with an attachment containing explanations for its compilation; in a letter for each student and one for every school master, students were asked to collaborate with the help of their teachers and parents. Most of the schools have been involved because sensitive to environmental education initiatives proposed in last years by Lombardy Foundation for the Environment. On average, the percentage of Lombardy population interviewed was 1.1%, considering one questionnaire per person, but, more correctly, 3.0% of Lombardy families have been selected and contacted to collect home-related data (Tab. 1). Families were thus chosen as statystical units of the sample.
236 schools (61%) participated in the survey collecting questionnaires filled by their students, for a total amount of 32.993 questionnaires gathered, 33.6 % of those ones distributed. 10.544 questionnaires declared an use of wood, corresponding to 10.397 different families, because questionnaires compiled twice in the same family have been excluded during the phase of data-cleaning and coherence control; on the contrary in 22.449 (66.4%) stated no use of wood. The provinces with the largest share of families burning wood are in the alpine and sub-alpine area (Sondrio 67% and Brescia 44%): on average 32% of the students wrote that their families used wood for household heating during last winter (Fig. 2).

Figure 2. Distribution of questionnaires sent and compiled.

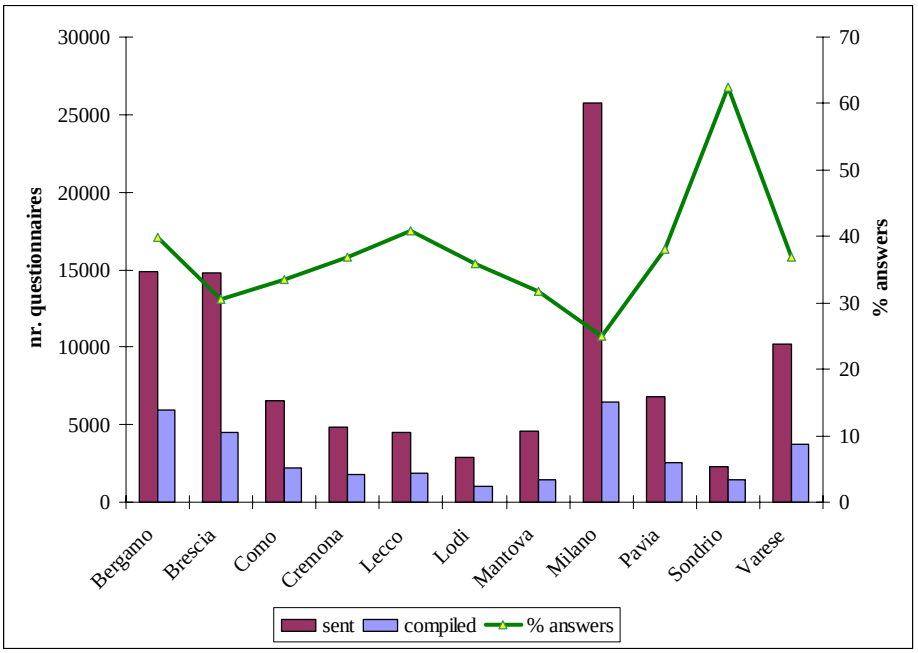


Table 1. Distribution and compilation of questionnaires by province.

Provinces	Nr. questionn. distributed	% questionn. distr. by Province	Nr. questionn. compiled	% questionn. compiled	Lombardy Population	% population distr. by Province	Sample interviewed (% of pop.)	Nr. families in Lombardy	% families by Province	% families reached by the survey
	a	b=a/∑a	c	d	e	f=e/∑e	g=a/e*100	h	i=h/∑h	l=c/h*100
Bergamo	14,890	15.3	5,941	39.9	973,129	10.7	1.5	373,832	11.3	1.59
Brescia	14,808	15.2	4,530	30.6	1,108,776	12.3	1.3	434,061	13.1	1.04
Como	6,577	7.2	2,199	33.4	537,500	6.0	1.2	210,701	6.4	1.04
Cremona	4,803	4.6	1,768	36.8	335,939	3.7	1.4	134,607	4.1	1.31
Lecco	4,515	3.7	1,843	40.8	311,452	3.5	1.5	121,102	3.7	1.52
Lodi	2,898	2.5	1,039	35.9	197,672	2.2	1.5	77,436	2.3	1.34
Mantova	4,555	5.2	1,449	31.8	377,790	4.2	1.2	144,961	4.4	1.00
Milano	25,725	2.,9	6,433	25.0	3,707,210	40.1	0.7	1,498,029	45.2	0.43
Pavia	6,795	6.5	2,581	38.0	493,753	5.4	1.4	208,979	6.3	1.24
Sondrio	2,305	3.2	1,441	62.5	176,856	2.0	1.3	69,717	2.1	2.07
Varese	10,190	9.6	3,755	36.8	812,477	9.0	1.3	322,053	9.7	1.17
Lombardy	**98,061**	**100.0**	**32,847**	**33.6**	**9,032,554**	**100.0**	**1.1**	**3,316,782**	**100.0**	**0.99**

RESULTS

Amount of wood used

The most important datum resulted by the compilation of questionnaires is the use of wood for household heating during the 2003-2004 winter season: 8.201 families (79 %) of the 10,397 using wood quantified the amount of wood used. The study of the answers took into account the wrong perception of unit of measure like quintals or cubic meter from students and their parents, so that out of range data have been excluded after comparing data with average energetic needs for household heating, calculated as shown in the Equation below (1).

Equation (1) $WD = HD \cdot H / HV$

where

WD = specific wood demand for domestic heating [kg/h/m^2]
HD = average specific heating demand [kJ/m^3/h]
H = height of a flat [m]
HV = lower heating value [kJ/kg]

Considering an average specific heating demand of 85 kJ/m^3/h, a lower heating value of 12,000 kJ/kg and an average height of 3 m, equation (1) brings to a specific wood demand of 0.21 kg/h/m^2 , quite similar to the average value calculated from wood consumptions declared by families, 0.25 kg/h/m^2. 48 data of consumption, exceeding 1 kg/m^2/h, i.e. 4 times the average mean wood demand, have been considered out of scale. The average use of wood is thus referred to 8.201 families, for a total amount of wood for the sample of questionnaires analyzed of 33.2 kt. The average wood consumption relative to the families that use wood (4.0 t/fam/y) is very diversified among the Lombardy Provinces (Tab. 2).

Table 2. Use of wood in families questioned through the survey.

Provinces	**Nr. of families using wood**	**% of families using wood**	**Wood consumption in the sample (kt/y)**	**Wood consumption per family using wood (t/fam./y)**
	m	**n = 100 · m/c** **("c" in Tab.1)**	**o**	**p = o/m**
Bergamo	1,641	35.2	7.0	4.3
Brescia	1,548	44.2	6.2	4.0
Como	662	38.0	2.8	4.2
Cremona	505	29.1	1.5	3.0
Lecco	475	33.3	2.0	4.2
Lodi	220	26.3	0.8	3.6
Mantova	367	14.4	2.0	5.4
Milano	662	39.5	1.9	2.9
Pavia	385	21.5	1.7	4.4
Sondrio	800	66.8	3.5	4.4
Varese	936	30.7	3.7	4.0
Lombardy	**8,201**	**31.9**	**33.2**	**4.0**

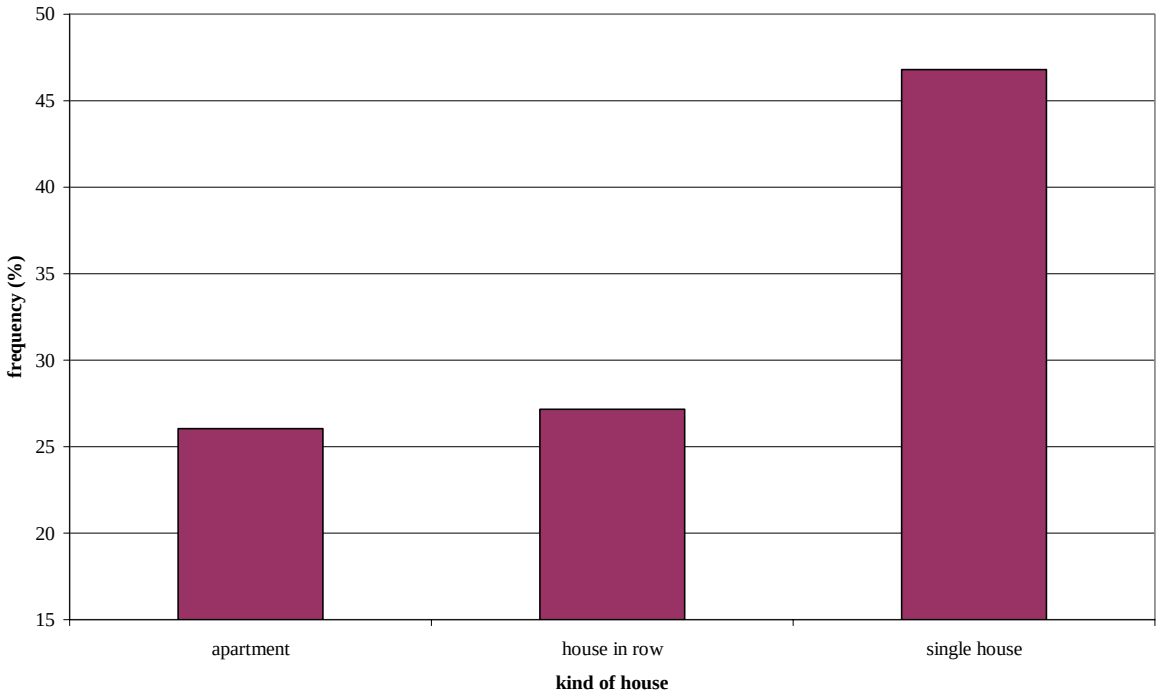
Families and houses

The questionnaire has been sent to students of secondary schools aged between 11 and 13 years old. 54% of families is composed by four people, 16% by three members, 21% by five, and 8% by more than five people. Comparing these data with statistical official data about Italian population (ISTAT, 2001) is possible to recognize an under-representation of families with one or two members (34% of Lombardy population) due to the nature of the population sample reached by the survey. Data concerning the surfaces of houses and apartments show that, on an average basis, houses of the families contacted have a surface of 140 m^2: about a half of this surface (73 m^2) is warmed with wood combustion.

Type and location of the house

According to different type of houses, wood is, on average, mostly used in single houses or villas (47%) while 26% are apartments and 27% houses in row (Fig. 3). 17% of houses is located in the city centre, 35% nearby the centre of the town/city, the 32% are in the suburb and the 16% in the country. Further investigation is needed in order to understand patterns of distribution of wood use compared to the type of house and its location.

Figure 3. Type of house with use of wood in the sample.



Use of other fuels

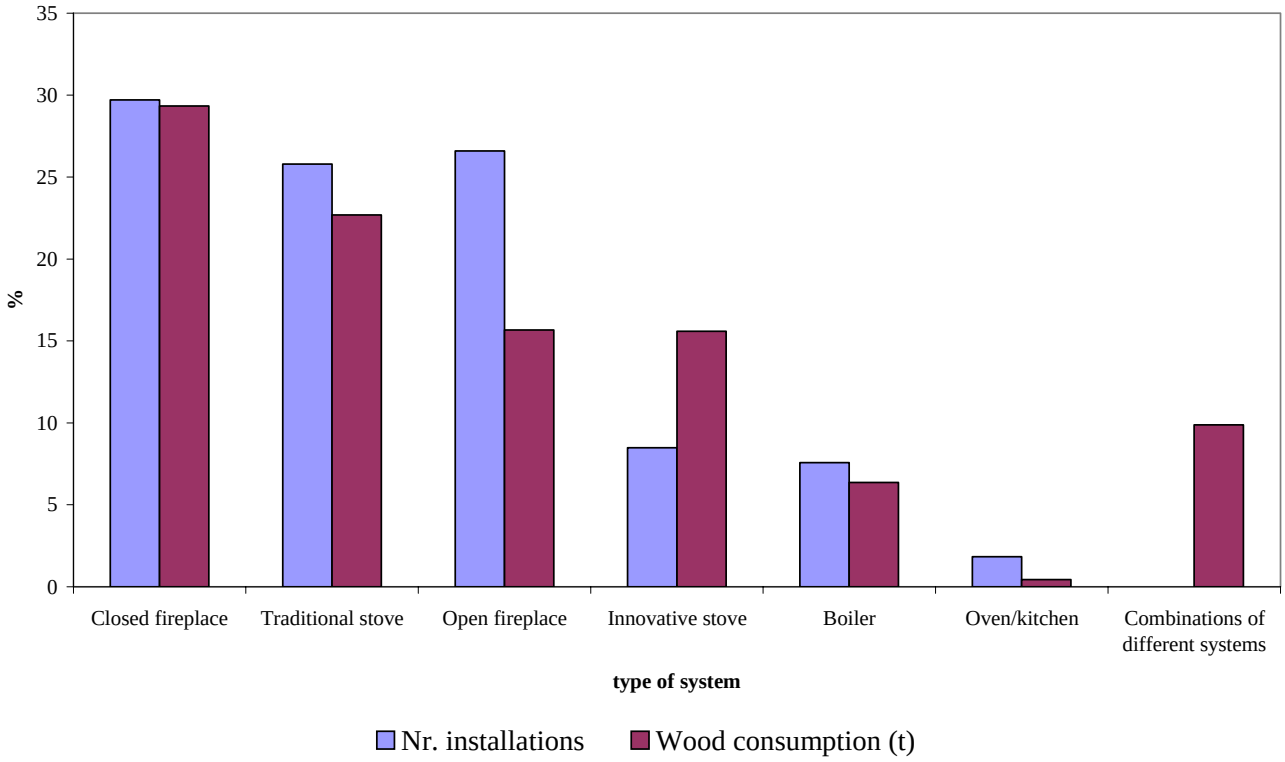
Among the families that use wood the overwhelming majority (84%) use another fuel for the same purpose (67% gas, 11% gas oil and 6% GPL), while 16 % heat their house only with wood.

Type of system used for wood combustion

Concerning the type of combustion systems (Fig. 4), answers show, among fireplaces, a prevalence of the closed ones (30% face to the 27% of open fireplaces). Data regarding stoves show that the use of

traditional ones is larger (26% face to 9%) than innovative stoves; new technological devices, mostly represented by closed fireplaces, are in Lombardy more spread than catalytic stoves. Regarding wood consumption in the different systems, about 30% of wood is burnt in closed fireplaces, 23 % in traditional stoves, 16% in open fireplaces, 16% in innovative stoves and 7% in boilers.

Figure 4. Type of wood combustion systems used in the sample.



Daily pattern of wood use

Among families that burn wood for domestic heating, there is a prevalence of a frequent exploitation of this energetic resource. 58% of families use wood all the 5 working days of the week, while 84 % use wood both on Saturday and Sunday. 50 % of the families use wood everyday. Daily consumption shows the prevalence of classes of higher use: 66% of families use wood from 4 to 10 or more hours a day while, on average, the remaining 33% employ it for less than four hours a day.

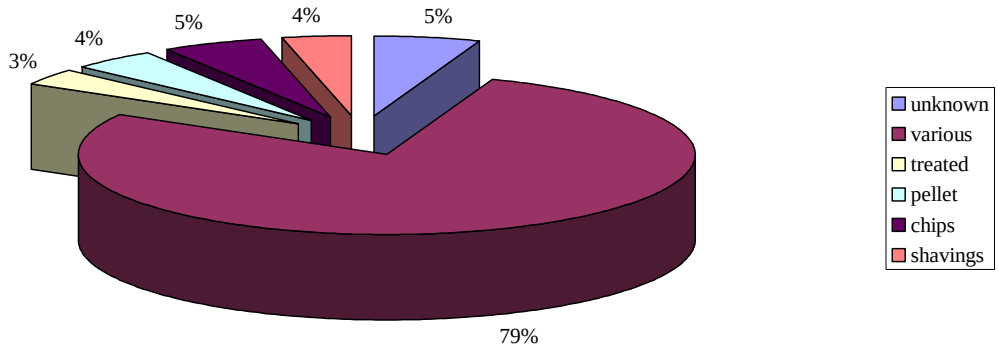
Use of wood in second houses and by grandparents

Among the families that use wood in the first house the 12% declare to burn wood in a second house in Lombardy. More than 50% of students interviewed declare that grandparents use wood at their home in Lombardy. These data suggest that also families with 1-2 members, not reached by the survey, could have a significant use of wood.

Type of wood

Large majority of families (78%) uses various wood obtained by clearing of trees (Fig. 5). Although the 9% that use treated wood could influence pollutant emission, particularly for what concern micro-pollutants (IPA, dioxin, etc.), this aspect has not been taken into account due to scarce availability of reliable emission factors.

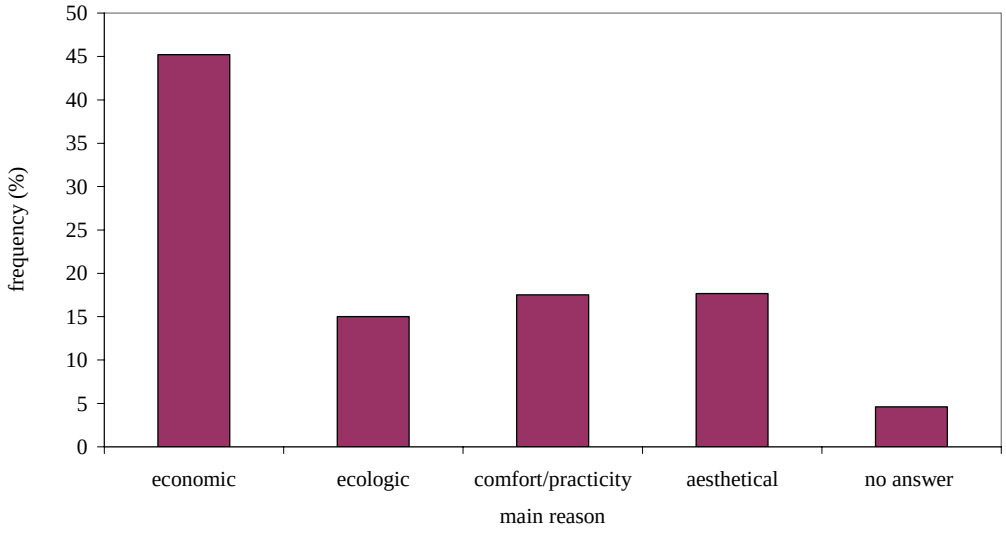
Figure 5. Type of wood used in the sample.



Satisfaction degree and reasons for wood use

94% of the families appreciate wood as an energetic resource for domestic heating. The most important factor making families use wood is economic saving (45%), while other reasons are comparable (Fig. 6).

Figure 6. Main reason for using wood according to the families questioned.



DISCUSSION

Estimate of wood combustion in Lombardy

The first estimate of total wood consumption in Lombardy has been made considering the representativeness of the number of families reached by the survey in Lombardy and in every Province. With this approach, basing on a consumption for the sample of 33.2 kt/y and considering that the sample is related to 0.99 % of the total number of families in Lombardy (see Table 1, last column), about 3.3

Mt/y are used every year in Lombardy. Making the calculation by Province, this approach leads to an assessment of 2.8 Mt/y of wood used in Lombardy.
A more precise analysis has been done taking into account 18 classes of cities, defined for population size and altitude (Tab. 3). The estimate of wood consumption has been made with this approach through the extrapolation of the amount of wood used in every class of the sample to the entire number of families in the region, in every class, in Lombardy (Tab. 4). An average size of 4 person per family has been considered, as calculated from the sample of families available in the survey. Only 11 classes are represented in the sample; for the classes not covered by the sample, the assessment rely on the average wood use per family found in the sample, 0.85 t/fam/y. The result of this approach, that considers differences in towns according to their dimension and geographic position, gives a total consumption of wood for Lombardy of 1.9 Mt/y (Tab.4), significantly lower than the one obtained through the simple extrapolation of the total amount of wood declared by the families questioned. This large amount of wood use, corresponding to 210 kg/inhab./y, is higher than the previous assessment made by ENEA in 1999. This could be explained both by the increase in wood consumption in last years and by the difference in the scale of the survey (32.847 questionnaires collected in the present work compared to the 900 phone interviews made in Lombardy by the ENEA survey).

Table 3. Classes of towns according to population and altitude(Plain:0-250m, Hill:250-800m, Mountain:>800 m).

Classes	**Altitude**	**Population**	**Population of town reached by the sample (N. of towns)**	**Total population per class in Lombardy**	**% population**	**Total Nr. of families per class**
			q	**r**	**s = q/r · 100**	**t = r/4**
A	Plain	<1,000	-	-	-	-
B	Hill	<1,000	1,836 (2)	93,973	2.0	23,493
C	Mountain	<1,000	-	-	-	-
D	Plain	1,000-5,000	194,838 (61)	1,131,177	17.2	282,794
E	Hill	1,000-5,000	174,598 (54)	804,764	21.7	201,191
F	Mountain	1,000-5,000	22,162 (6)	73,929	30.0	18,482
G	Plain	5,000-20,000	677,196 (68)	2,299,895	29.4	574,973
H	Hill	5,000-20,000	256,817 (27)	653,637	39.3	163,409
I	Plain	20,000-50,000	444,263 (14)	1,249,721	35.5	312,430
L	Hill	20,000-50,000	42,880 (2)	123,134	34.8	30,783
M	Plain	20,000-50,000	326,100(5)	630,400	51.7	157,600
N	Hill	20,000-50,000	84,187 (1)	84,187	100.0	21,046
O	Plain	>100,000	1,610,945 (3)	1,729,873	93.1	432,468
P	Mountain	5,000-20,000	-	-	-	-
Q	Mountain	20,000-50,000	-	-	-	-
R	Mountain	50,000-100,000	-	-	-	-
S	Hill	>100,000	-	-	-	-
T	Mountain	>100,000	-	-	-	-
Total	-	-	**3,648,379 (243)**	**8,874,690**	**41.1**	**2,218,673**

Table 4. Assessment of wood use in Lombardy by classes of population and altitude.

Classes	Altitude	Population	Questionn. filled	Wood use in the classes (sample) (t/y)	Wood use per familiy in the sample (t/fam./y)	% of families reached by the survey	Wood use in Lombardy (t/y)
			u	v	z = v/u	z= u/t · 100 (see table 5)	x = v/z · 100
B	Hill	<1,000	382	122	0.32	1.63	7,503
D	Plain	1,000-5,000	3,443	4,279	1.24	1.22	351,460
E	Hill	1,000-5,000	3,307	6,152	1.86	1.64	374,275
G	Plain	5,000-20,000	8,629	5,999	0.70	1.50	399,730
F	Mountain	1,000-5,000	520	1,034	1.99	2.81	36,751
H	Hill	5,000-20,000	2,829	2,306	0.82	1.73	133,200
I	Plain	20,000-50,000	3,285	826	0.25	1.05	78,559
L	Hill	20,000-50,000	246	154	0.63	0.80	19,271
M	Plain	20,000-50,000	1,910	671	3.51	0.12	553,663
N	Hill	20,000-50,000	287	101	0.35	1.36	7,407
O	Plain	>100,000	844	134	0.16	0.20	68,662
Others	-	-	-	-	0.85	-	33,546
Total	-	-	**25,682**	**21,778**	**0.85**	**1.63**	**1,914,951**

PM10 emissions from wood combustion

PM10 emissions from wood combustion could be assessed by the use of emission factors given by literature as shown in Equation (2).

Equation (2) $E = W \cdot EF \cdot HV / 10^6$

where

E = PM10 emission [t/y]
W = wood amount [t/y]
EF = Emission Factor [g/GJ]
HV = Lower Heating value [GJ/t]

A review of available PM emission factors for residential wood combustion has been made (EEA, 2004; Houck et al., 2001; Gullet et al., 2003). Literature data show a large variability of PM emission factors for wood combustion, depending on type of wood, type of installation, etc. A first rough assessment of PM10 emission range has been done on the basis of 1.9 Mt/y of wood use assessed as previously

explained, a Lower Heating Value for wood of 16 GJ/t (EEA, 2004), and a range of emission factors from 190 g/GJ to 700 g/GJ. The first value, used for the 2001 inventory, has been proposed in review of PM emission factor collected by TNO-MEP within the CEPMEIP project (CEPMEIP, 2002); the latter is the default value proposed for a simple methodology for small combustion installations in the residential sector in the European Inventory Guidebook (EEA, 2004), and similar to the average value from a detailed review of wood heater and fireplace emission factor in US (Houck et al., 2001). The corresponding PM10 emission range is 5,800 – 21,000 t/y. These value are higher than what assessed by the Lombardy Region Emission Inventory, 3,977 t/y of PM10 for the year 2001 (Regione Lombardia 2005).

Wood combustion from residential fireplaces and stoves represents a substantial share of primary PM10 emissions in Lombardy. The lower PM10 emissions calculated represent the 24 % of total PM emission in Lombardy (24.3 kt/y), as estimated by the Lombardy Region Emission Inventory INEMAR (Caserini et al., 2004; Regione Lombardia 2005). Further analysis are ongoing to achieve more detailed estimates of PM10 and other pollutants, in relationship to the different combustion systems and type of wood used.

CONCLUSIONS

Survey on wood use on students of secondary schools allowed to reach a high number of families on the territory of Lombardy: the straightforwardness of questionnaire, its capillary distribution on the territory and the direct contact maintained with schools has permitted to obtain the compilation and restitution of more than one third of the questionnaires. The survey confirm the wide amount of wood used in Lombardy for household heating (210 kg/inhab./y), as suggested in a previous study done at national level by ENEA, that identify the importance of non-invoiced and self-supplying wood amount. Results of the work are interesting and allow to identify the pattern of wood use for type and location of houses, type of combustion installation and for different territorial contexts in Lombardy. The importance of PM10 emissions in the overall PM10 emissions in Lombardy and the large variability of PM10 emission factors for wood combustion, suggest the importance of further investigation, already ongoing in the framework of PARFIL (Particulate Fine in Lombardy) project.

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KEY WORDS

Wood combustion
PM10
Fireplace
Stove
Emission Factor
Questionnaire

Attachment 1. Questionnaire elaborated for the survey.

Fondazione Lombardia per l'Ambiente

KYOTO PROJECT
Research on climate change and greenhouse gases monitoring and reduction

SURVEY ON THE USE OF WOOD IN LOMBARDY

1)Name of the school:……**2) Class**:……..……

3)Town of the school:…….....

4)Town of residence:…….……. **5)Province:**…….…….…….

6)Number of members of the family:……...…...….

7)Surface of the house:……m^2

8)Type of house:

☐ Apartment ☐ House in row ☐ Single house

9)House location

☐ Center of the country/city ☐ Nearby the center ☐ Suburb ☐ Rural

10)Fuel/s used for domestic heating (*mark one or more boxes*)**:**

☐ Gas ☐ Gas oil/Kerosene ☐ G.P.L. ☐ Wood ☐ I don't know

Other (*specify*):…….……...……

Continue the compilation only if you marked"Wood"; otherwise go to question 19

11)Surface of the house heated with wood:……..……m^2

12)Type of system used for wood combustion *(mark one or more boxes)***:**

☐ Traditional stove ☐ Innovative stove ☐ Open fireplace ☐ Closed fireplace ☐ Oven/Kitchen ☐ Boiler

Other (*specify*):……..……...……

13)Average number of days of wood use during the week (from Monday to Friday):

☐ 0 days ☐ 1 day ☐ 2 days ☐ 3 days….. ☐ 4 days ☐ 5 days

14)Average number of daily hours of wood use during the week (from Monday to Friday):

☐ <1 hour ☐ 1-2 hours ☐ 2-3 hours ☐ 3-4 hours ☐ 4-6 hours ☐ 6-8 hours ☐ 8-10 hours ☐ >10 hours

15)Days of wood use during the weekend (Saturday and/or Sunday):

☐ Saturday ☐ Sunday ☐ Saturday and Sunday ☐ neither Saturday nor Sunday

16)Average number of days of wood use during the weekend (Saturday and/or Sunday):

☐ <1 hour ☐ 1-2 hours ☐ 2-3 hours ☐ 3-4 hours ☐ 4-6 hours ☐ 6-8 hours ☐ 8-10 hours ☐ >10 hours

17)Total wood consumption during last winter season (from October to March - 1 quintal= 100 kg)**:**

…….quintals *or* ….cubic meters

18)Type of wood used *(mark one or more boxes indicating, approximately the percentage; see explanations in the attachment)***:**

☐ ….. % ☐ ….. % ☐ ….. % ☐ ….. % ☐ ….. % ☐ ….. %

I don't know Various wood Treated wood Pellet Wood chips Wood shavings

19)Do you use a burning wood heating system in a second house in Lombardy? ☐ Yes ☐ No

20)Do your grandparents use wood for household heating? ☐ Yes ☐ No ☐ I don't know

21)Are you satisfied in general by the wood burning system used?

☐ Very much ☐ A little ☐ Enough ☐ Not at all

22)Main reason to use a wood burning system for household heating *(mark one box)***:**

☐ Economic (money saving) ☐ Ecologic ☐ Practical ☐ Aesthetic

23)Did another member of the family receive the questionnaire? ☐ Yes ☐ No