

“An extensive survey on wood use for domestic heating in Lombardy: implication for PM emission inventories”

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Dr. Luca Marazzi

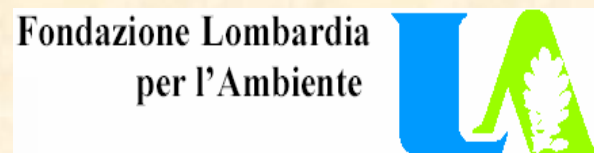
Lombardy Foundation for the Environment

www.flanet.org

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The survey has been conducted in the framework of the Kyoto Project – *research on climate change and greenhouse gases monitoring and control*

Research lines:

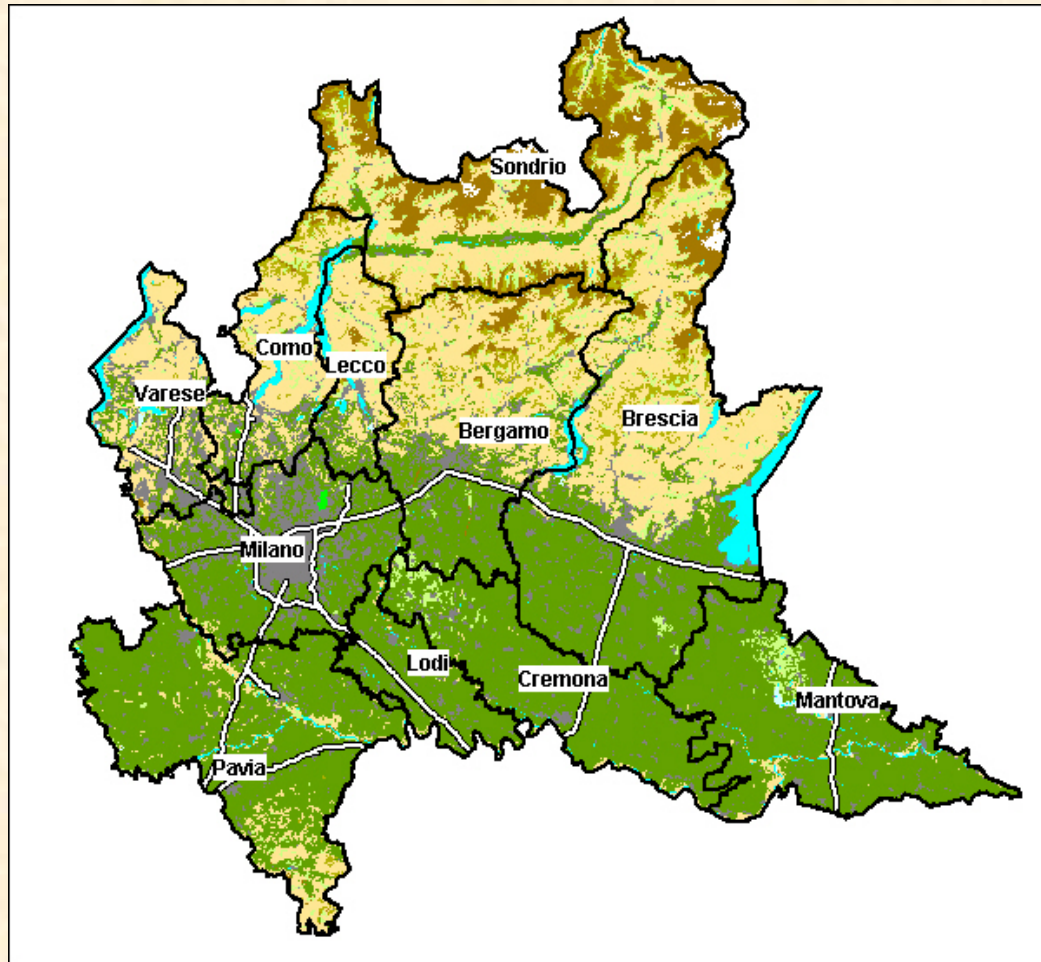
- 1) Climate study;
- 2) **Emissions**;
- 3) Terrestrial cycles of carbon and other greenhouse gases;
- 4) Impacts, damages and externalities;
- 5) Scenarios, policies and measures;
- 6) Communication



Overview

- 1) Air pollution in Lombardy region;
- 2) Wood combustion survey:
methodology,
results and discussion,
PM10 emissions estimate;
- 3) Conclusions and further investigations.

Lombardy is one of the four most productive regions in Europe

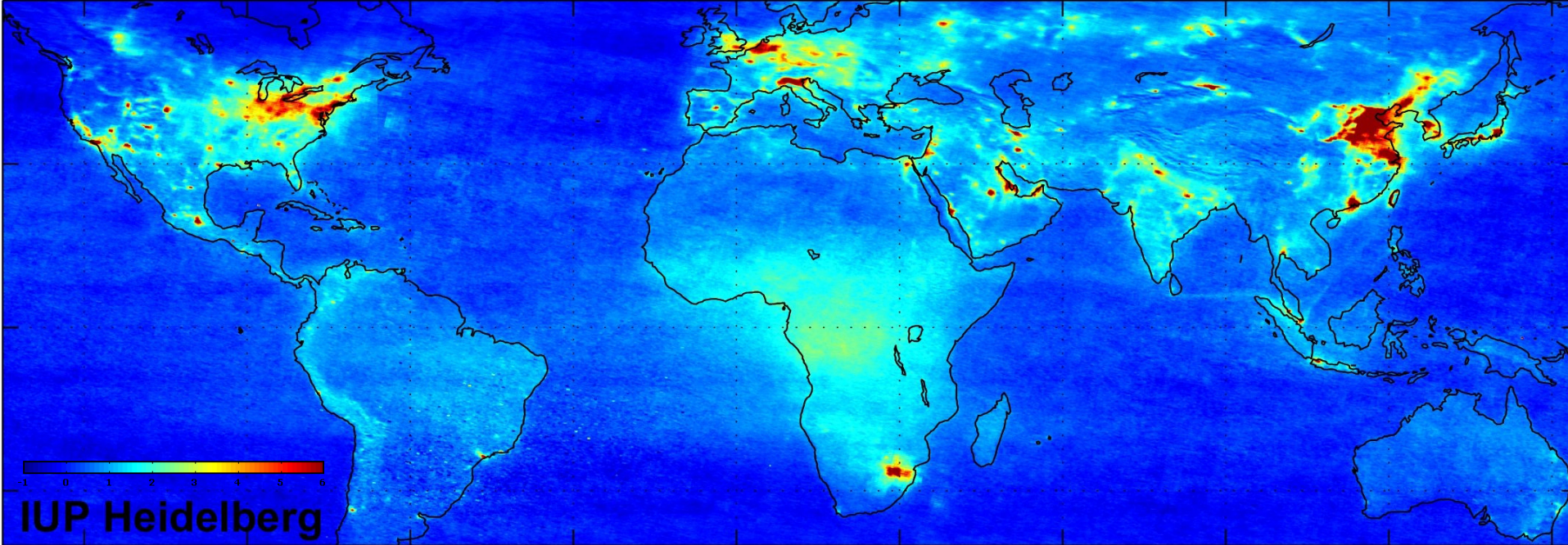


- 9 million inhabitants
- high density of industrial activities and very high use of motor vehicles
- 30 million of animals

Area of study: Lombardy Region – northern Italy:

1. Padana Plain 2. Prealpine area 3. Alps

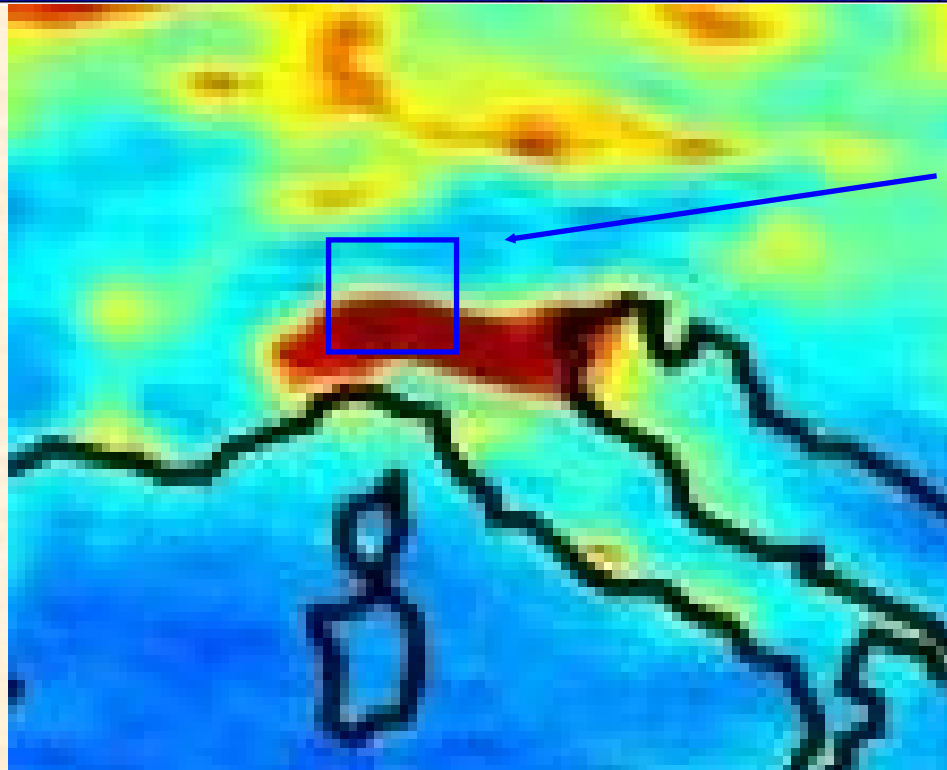




Global mean tropospheric
nitrogen dioxide (NO₂) vertical
column density
-January 2003 - June 2004
(SCIAMACHY instrument on ESA's
Envisat)

Scale = 10^{15} molecules/cm⁻²

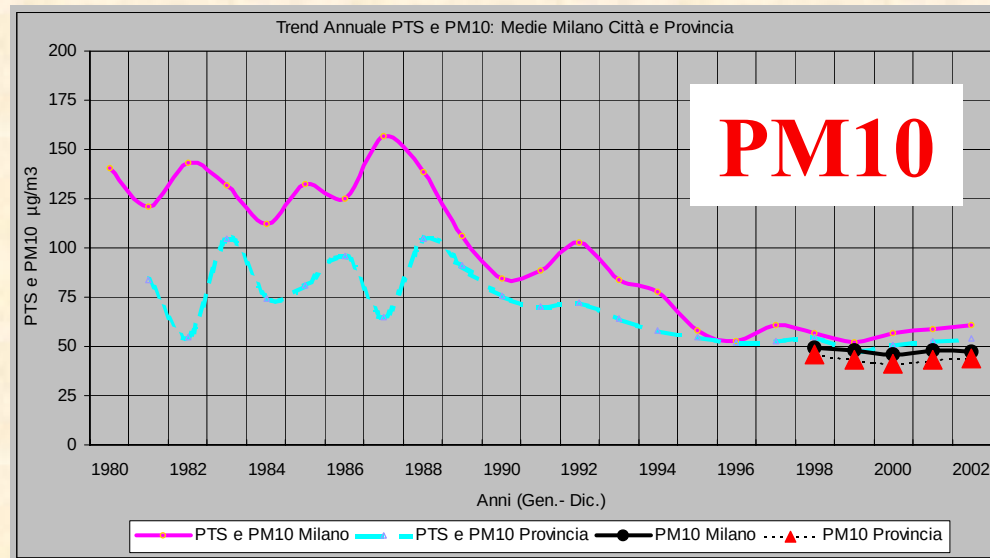
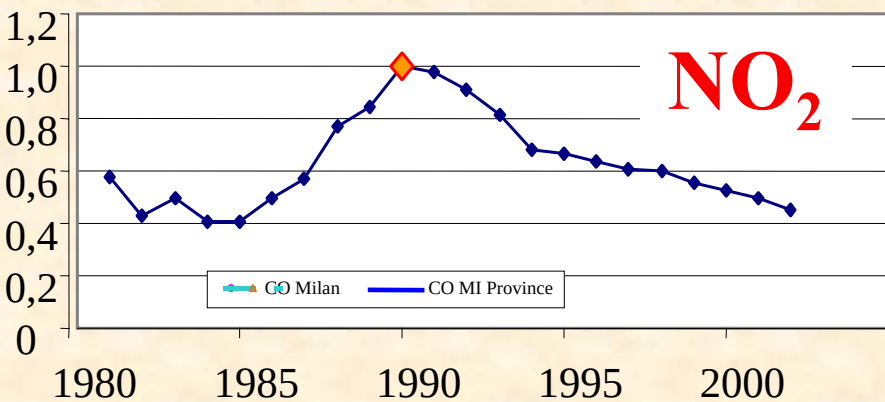
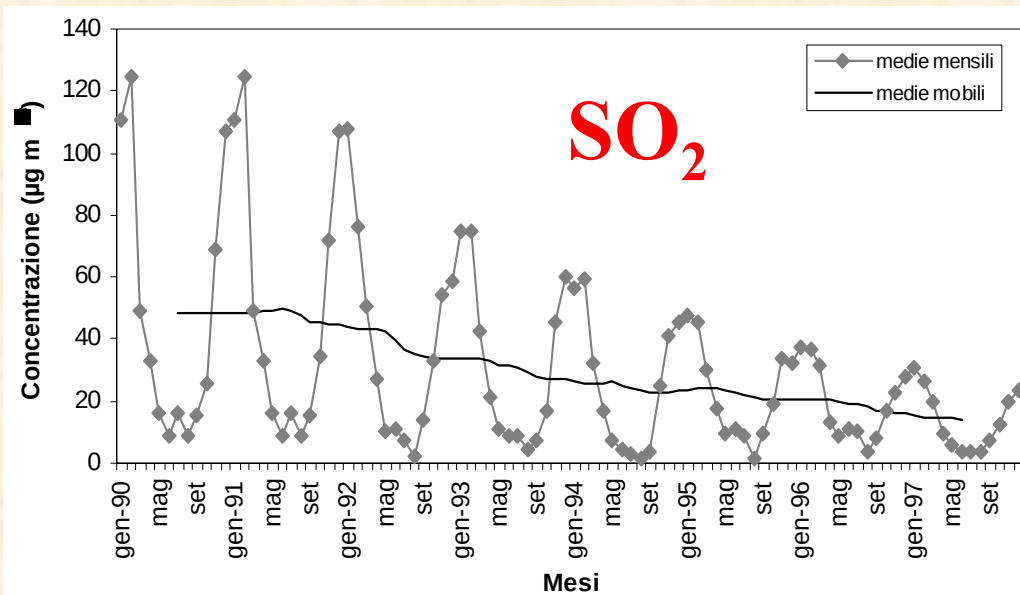
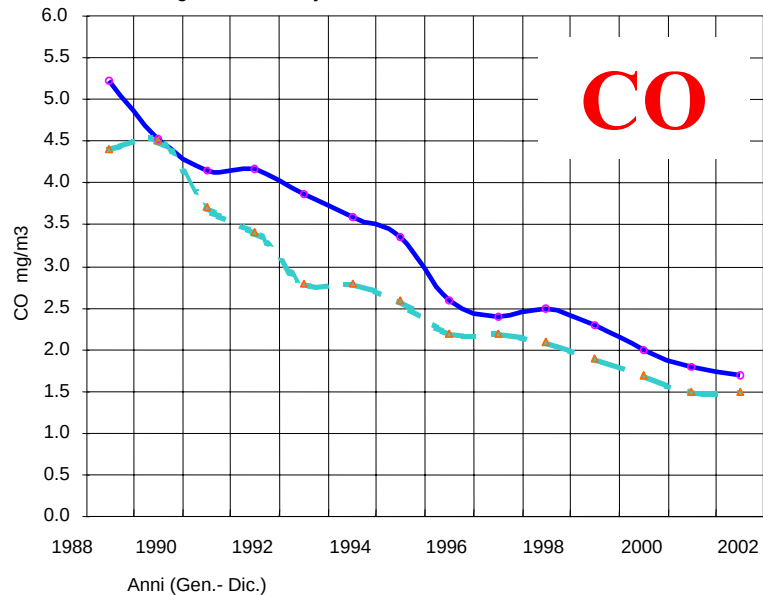
[http://www.esa.int/esaCP/SEM340N
KPZD_index_1.html](http://www.esa.int/esaCP/SEM340NKPZD_index_1.html)



We are
here

Air quality trend in Milano area

CO Annual average : Milano City and Milan Province



Objectives of the research

- 1) Assessment of wood use for domestic heating
- 2) Characterization of patterns of wood use in families living in Lombardy
- 3) Estimate of PM10 emissions from wood combustion



Previous studies

1999 survey by phone interviews by ENEA – Italian Agency for Energy, New technologies and Environment (Gerardi and Perrella, 2001)

Wood use for household heating:

22.3% of Italian families (sample: 6,000 phone interviews)

and

18.3% of families in Lombardy (sample: 957 phone interviews)



Activities undertaken

- 98.061 questionnaires sent to 386 schools
- April-June 2004: school directors and teachers have been contacted by phone
- 32.847 questionnaires filled and collected from 246 schools all over Lombardy territory
- 33.6% of the students answered



Questionnaire - 23 questions:

a) Student's family: class, nr. of family members

b) House: geographic position, type, surface, fuels for heating

c) Wood:

- surface heated;
- amount of wood burnt;
- system of combustion (fireplaces, stoves, etc.);
- nr. days of use per week;
- nr. hours of use per day;
- type of wood

d) Satisfaction, reasons for wood use



Questionnaire - part 1/3

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:.....m²

8)Type of house:

☐	Apartment	☐	☐	House in row	☐	Single house
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9)House location

☐	Center of the country/city	☐	Nearby the center	☐	Suburb	☐	Rural
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10)Fuel/s used for domestic heating (mark one or more boxes):

☐	Gas	☐	☐	☐	Gas oil/Kerosene	☐	☐	☐	G.P.L.	☐	☐	☐	Wood	☐	☐	I don't know
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Other (specify):.....

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

11)Surface of the house heated with wood:.....m²

Questionnaire - part 2/3

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

☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐
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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):

☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐
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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):

☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐
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<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):

☐	<u>Saturday</u>	☐	☐	<u>Sunday</u>	☐	☐	<u>Saturday and Sunday</u>	☐	<u>neither Saturday nor Sunday</u>
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16) Average number of days of wood use during the weekend (Saturday and/or Sunday):

☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐
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<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
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Questionnaire -part 3/3

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

	Economic (money saving)			Ecologic			Practical		Aesthetic
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23) Did another member of the family receive the questionnaire? ☐ Yes ☐ No

Provinces	Nr. question. distr.	% questionn. distr.	Lombardy Population	% population distr.
	a	b=a/∑a	e	f=e/∑e
Bergamo	14,890	15.3	973,129	10.7
Brescia	14,810	15.2	1,108,776	12.3
Como	6,577	7.2	537,500	6.0
Cremona	4,803	4.6	335,939	3.7
Lecco	4,515	3.7	311,452	3.5
Lodi	2,898	2.5	197,672	2.2
Mantova	4,555	5.2	377,790	4.2
Milano	25,725	29.0	3,707,210	40.1
Pavia	6,795	6.5	493,753	5.4
Sondrio	2,305	3.2	176,856	2.0
Varese	10,190	9.6	812,477	9.0
Lombardy	98,061	100.0	9,032,554	100.0

Statistical analysis

Families = statistical units of the survey

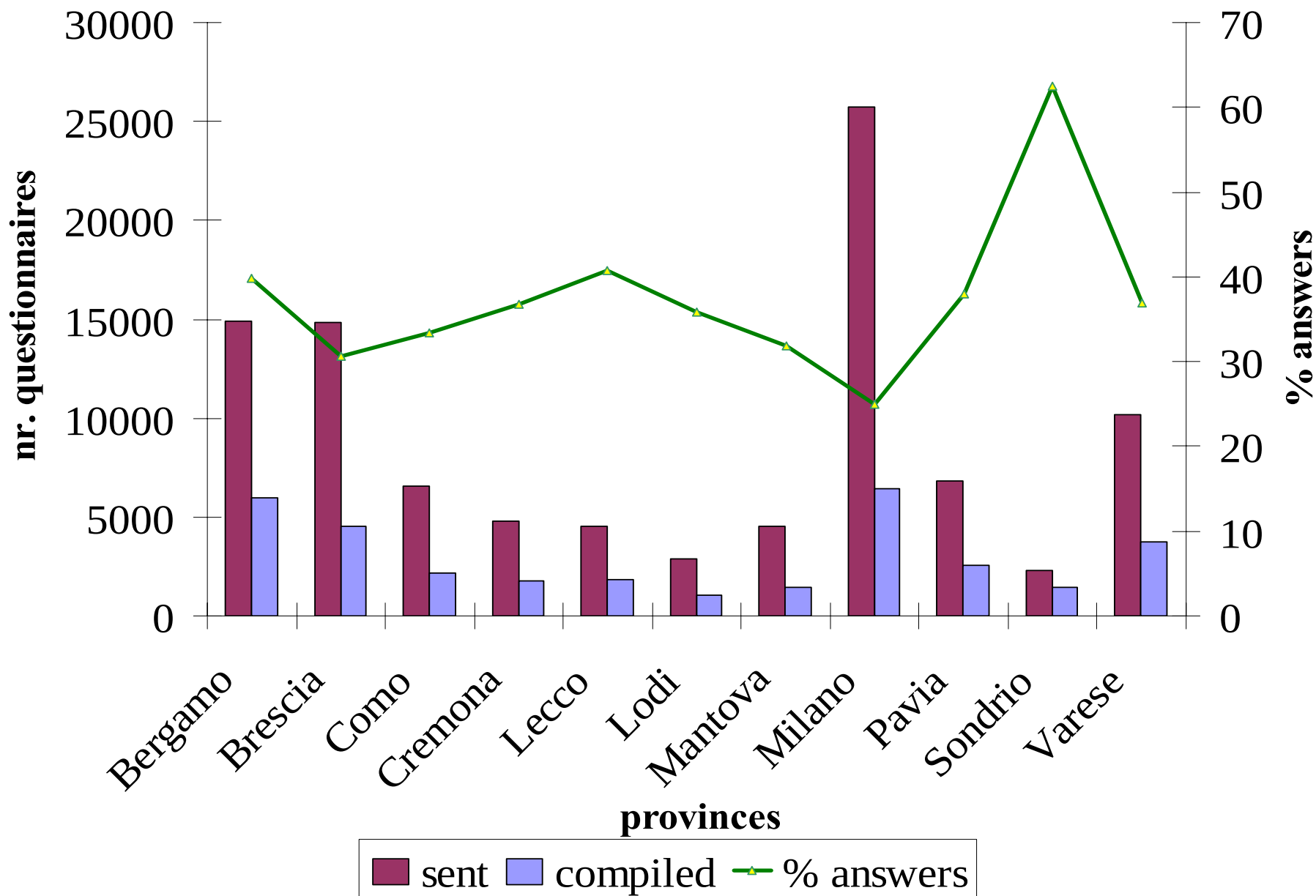
Information have been collected from families (students and parents) in order to have reliable data about home-related data



Representativeness of the sample

Provinces	Population (ISTAT, 2001)	% families reached	Nr. Families (ISTAT, 2001)	% families answering
	e	g= nr. quest. /e*100	h	l=nr. quest. filled/h*100
Bergamo	973,129	1.5	373,832	1.59
Brescia	1,108,776	1.3	434,061	1.04
Como	537,500	1.2	210,701	1.04
Cremona	335,939	1.4	134,607	1.31
Lecco	311,452	1.5	121,102	1.52
Lodi	197,672	1.5	77,436	1.34
Mantova	377,790	1.2	144,961	1.00
Milano	3,707,210	0.7	1,498,029	0.43
Pavia	493,753	1.4	208,979	1.24
Sondrio	176,856	1.3	69,717	2.07
Varese	812,477	1.3	322,053	1.17
Lombardy	9,032,554	1.1	3,316,782	0.99

Answers to questionnaire



Results - wood combustion

- 8,201 families gave the information of quintals of wood burnt
- 31.9% of 32,993 families interviewed use wood
- Total amount of wood used = 33.2 kt
- Average consumption per family. = **4.0 t/y**
(among the one that use it)



Wood use in the sample

Provinces	Nr. families	% of families	Wood cons. (kt/y)	Wood cons. (t/fam./y)
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

Data controlling – some data have not been used household heating demand

$$WD = HD \cdot H / HV$$

where

WD = specific wood demand for domestic heating
[kg/h/m²]

HD = average specific heating demand [85 kJ/m³/h]

H = height of a flat [3 m]

HV = lower heating value [12,000 kJ/kg]

$$WD = \mathbf{0.21} \text{ kg/m}^2$$

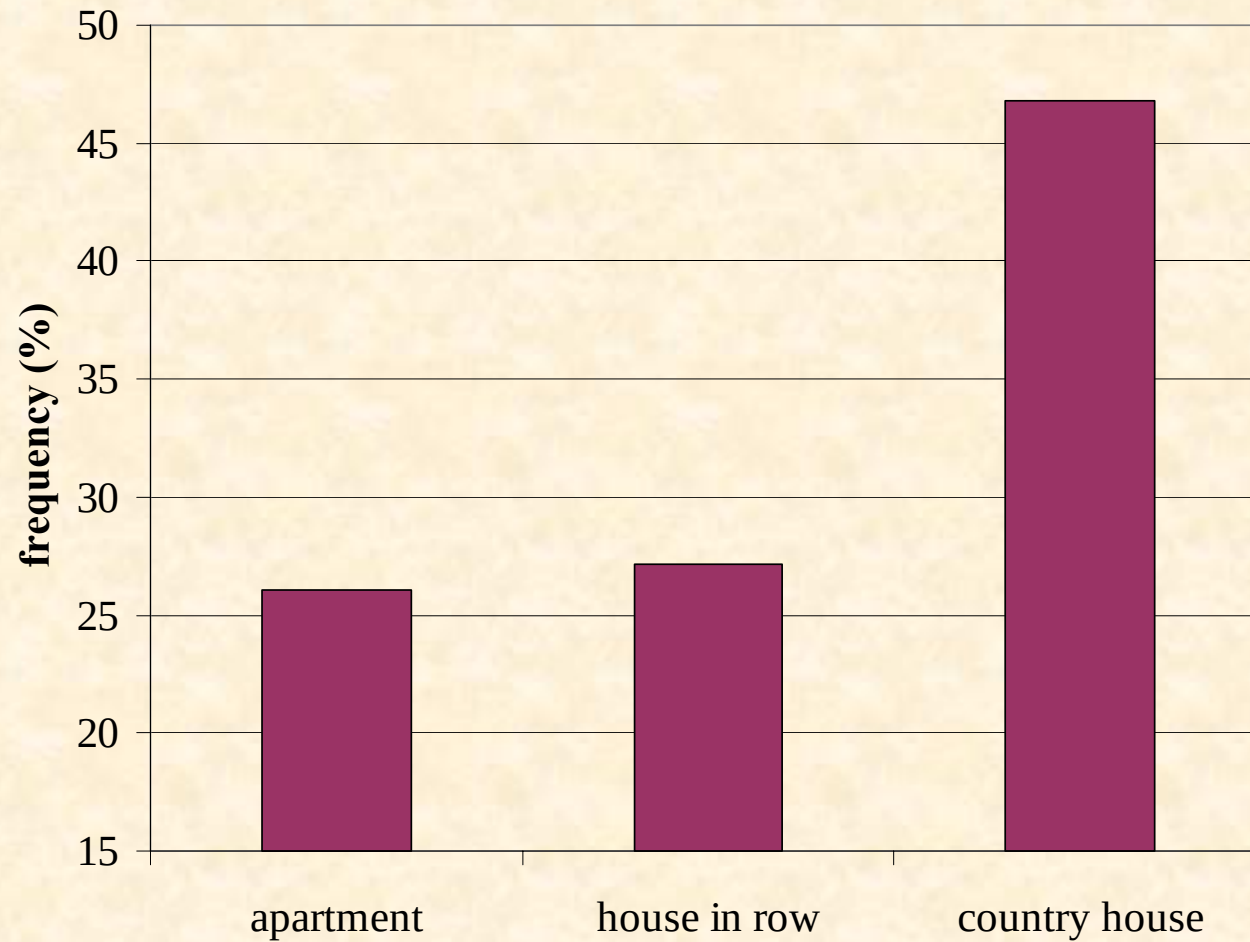
average WD from questionnaires = **0.25** kg/m²



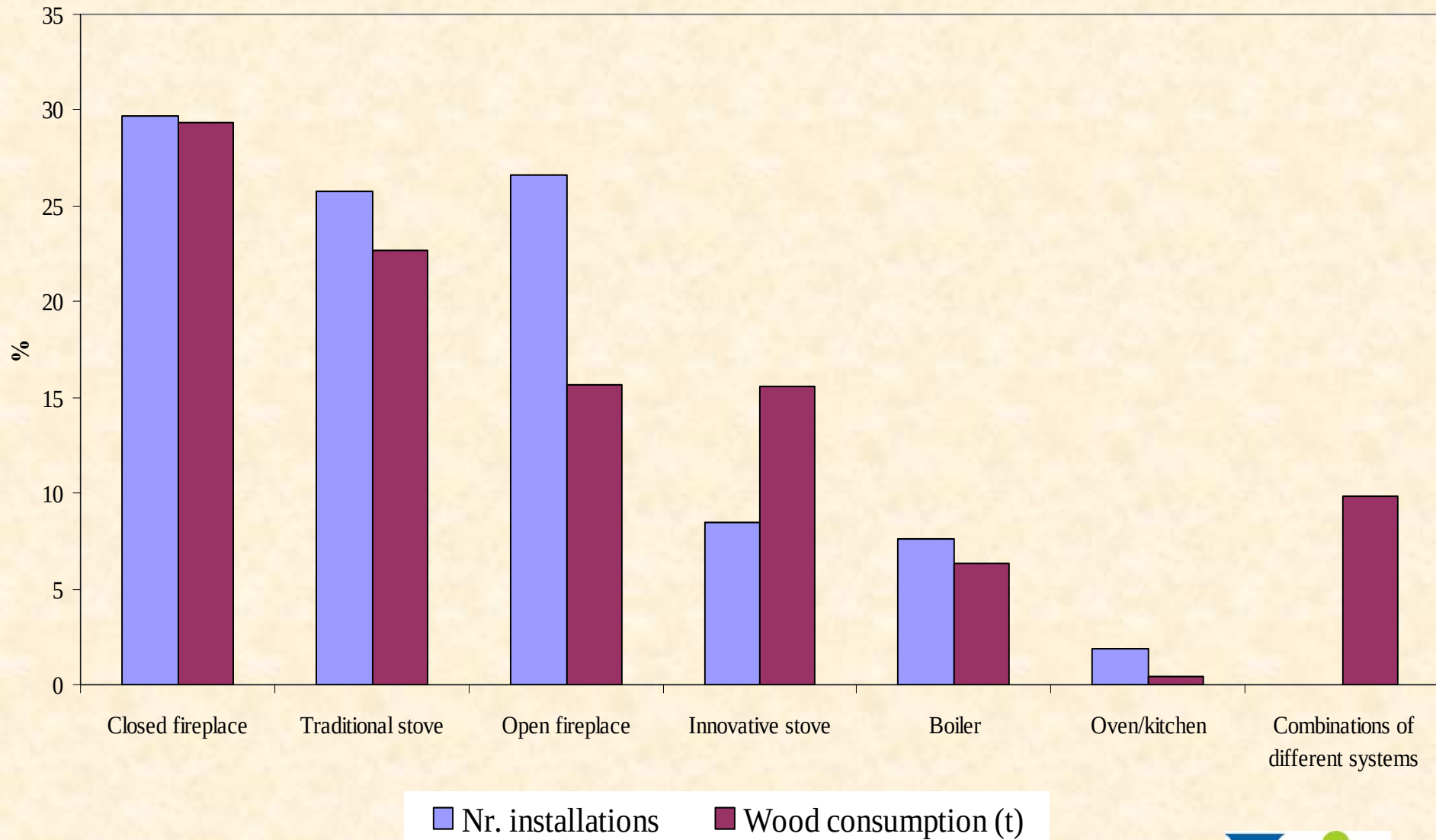
Data with $WD > 1 \text{ kg/m}^2$ have been excluded



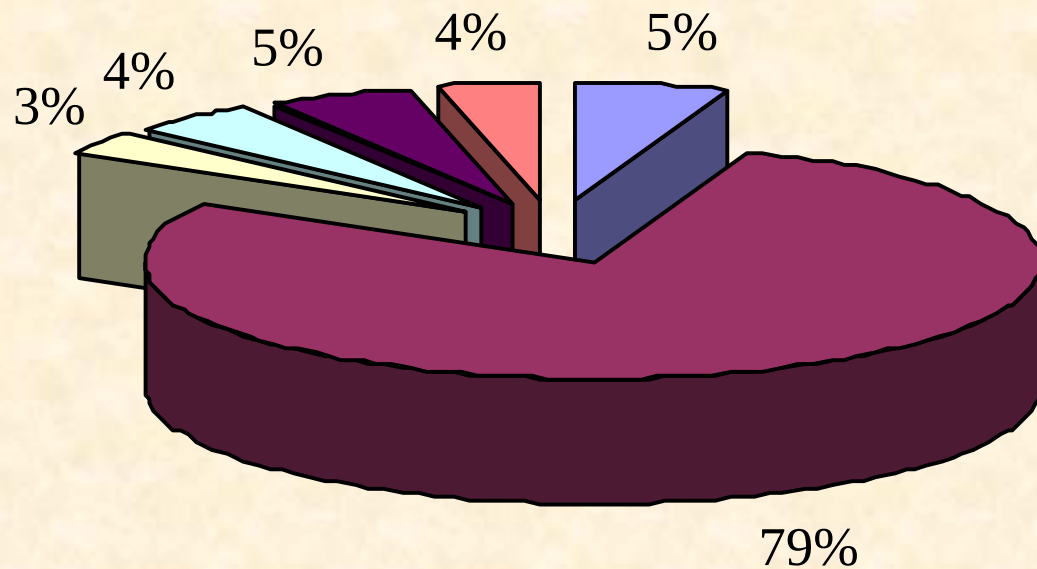
Results - Type of house



Results - Wood combustion systems



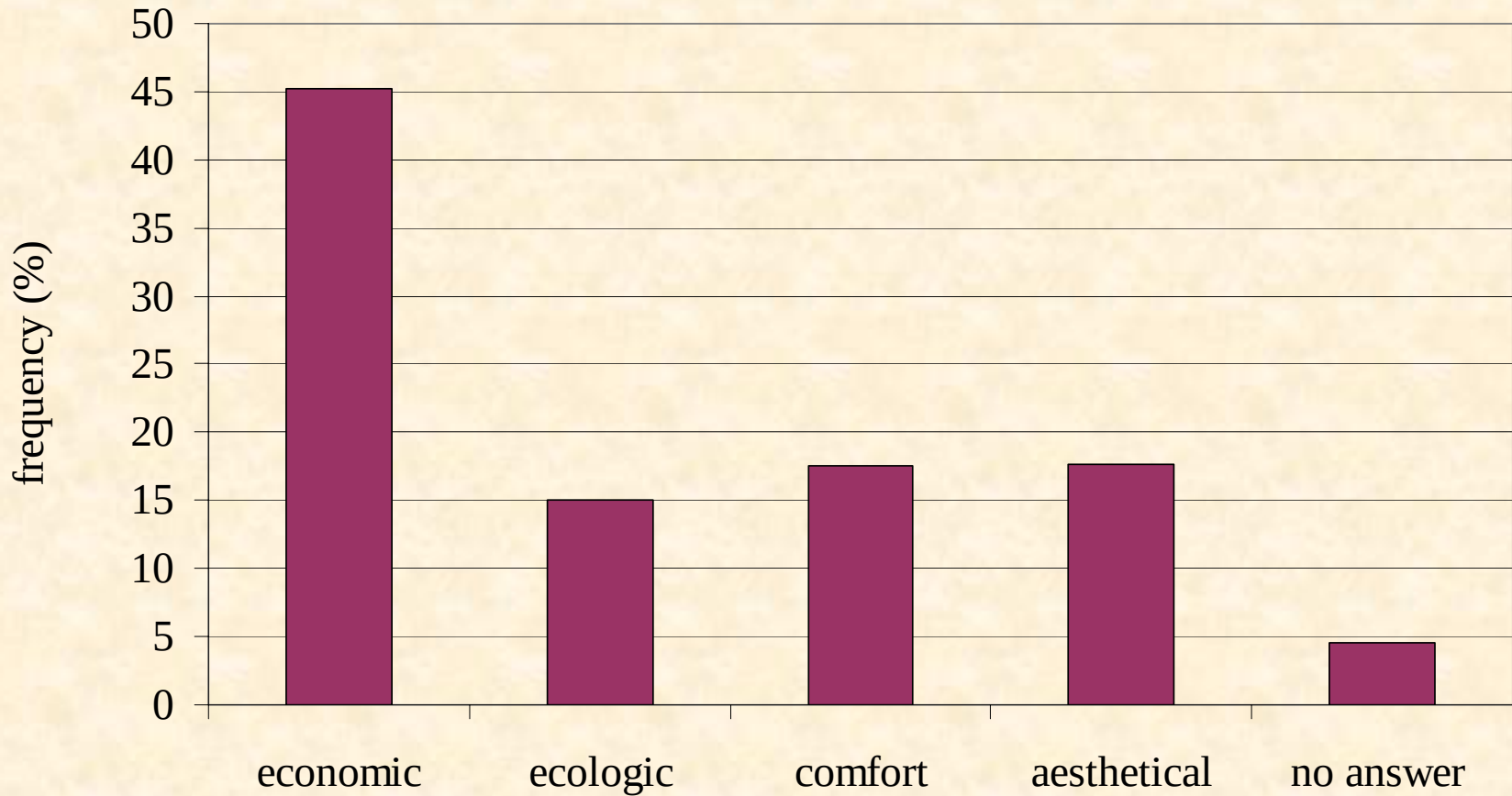
Results - Type of wood



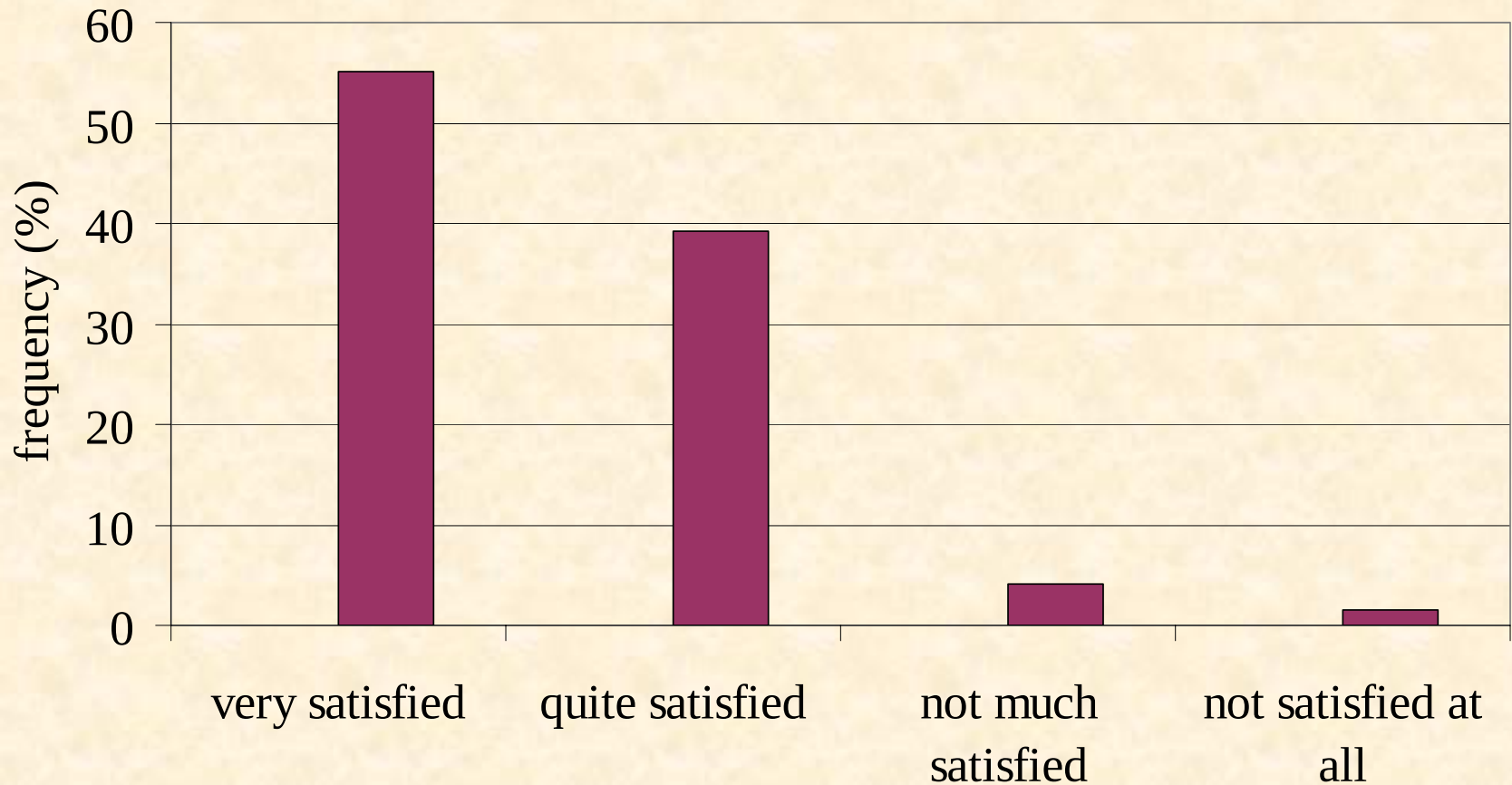
■ unknown ■ various ■ treated ■ pellet ■ chips ■ shavings



Results - Main reasons for wood use



Results - Degree of satisfaction for wood use



Wood combustion estimate in Lombardy / 1

- Simplified methodology :
- Total wood in the sample of families: **33.2 kt/y**
- Families interviewed = **1%** of Lombardy families



- Estimate of wood consumption: **3.3 Mt/y**



Wood combustion estimate in Lombardy / 2

- More detailed methodology :
- It is based on the classification of towns according to their population and altitude
- Data of wood use have been then extrapolated class by class to get the estimate of wood use for Lombardy region



Classes of towns

(Plain 0-250 m; Hill 250-800 m; Mountain >800 m)

Classes	Altitude	Population
B	Hill	<1,000
D	Plain	1,000-5,000
E	Hill	1,000-5,000
G	Plain	5,000-20,000
F	Mountain	1,000-5,000
H	Hill	5,000-20,000
I	Plain	20,000-50,000
L	Hill	20,000-50,000
M	Plain	20,000-50,000
N	Hill	20,000-50,000
O	Plain	>100,000

Results – wood use estimate

Classes altitude/population	Total nr. families	Question nr. filled	Wood use (sample) (t/y)	Wood use per family (t/fam./y)	% of families questioned	Wood use in Lombard y (t/y)
	t	u	v	w = v/u	z = u / t	x = v / z · 100
B (hill; <1.000 in.)	-	382	122	0.32	1.63	7,503
D (plain; 1.000-5.000 in.)	23,493	3,443	4,279	1.24	1.22	351,460
E (hill; 1.000-5.000 in.)	-	3,307	6,152	1.86	1.64	374,275
F (mountain; 1.000-5.000 in.)	282,794	8,629	5,999	0.70	1.50	399,730
G (plain; 5.000-20.000 in.)	201,191	520	1,034	1.99	2.81	36,751
H (hill; 5.000-20.000 in.)	18,482	2,829	2,306	0.82	1.73	133,200
I (plain; 20.000-50.000 in.)	574,973	3,285	826	0.25	1.05	78,559
L (hill; 20.000-50.000 in.)	163,409	246	154	0.63	0.80	19,271
M (plain; 20.000-50.000 in.)	312,430	1,910	671	3.51	0.12	553,663
N (hill; 20.000-50.000 in.)	30,783	287	101	0.35	1.36	7,407
O (plain; >100.000 in.)	157,600	844	134	0.16	0.20	68,662
Others	21,046	-	-	0.85	-	22,546
Total	432,468	25,681	21,778	0.85	1.6	1,914,951

**Results - Total wood combustion in the winter
season 2003-2004 calculated from the present survey
data analyses**

Lombardy wood use for domestic heating: 1.9 Mt

Lombardy population: 9,032,554 inhab.



Per capita consumption: 210 kg/inhab./y



Calculation of PM10 emissions

$$E = W \cdot EF \cdot HV / 10^6$$

where

E = PM10 emission [t/y]

W = Wood amount [t/y]

EF = Emission Factor [g/GJ]

HV = Lower Heating value [GJ/t]



Results - Emissions estimate

Emission Factors *used*:

190 g/GJ (CEPMEIP, 2001)

700 g/GJ (Emission Inventory Guidebook, 2004)

Houck, 2001 : average = 950 g/GJ

PM10 Emissions with different EF (190 –700 g/GJ):

5,800-21,000 t

(vs 10,000 t by traffic in 2001)



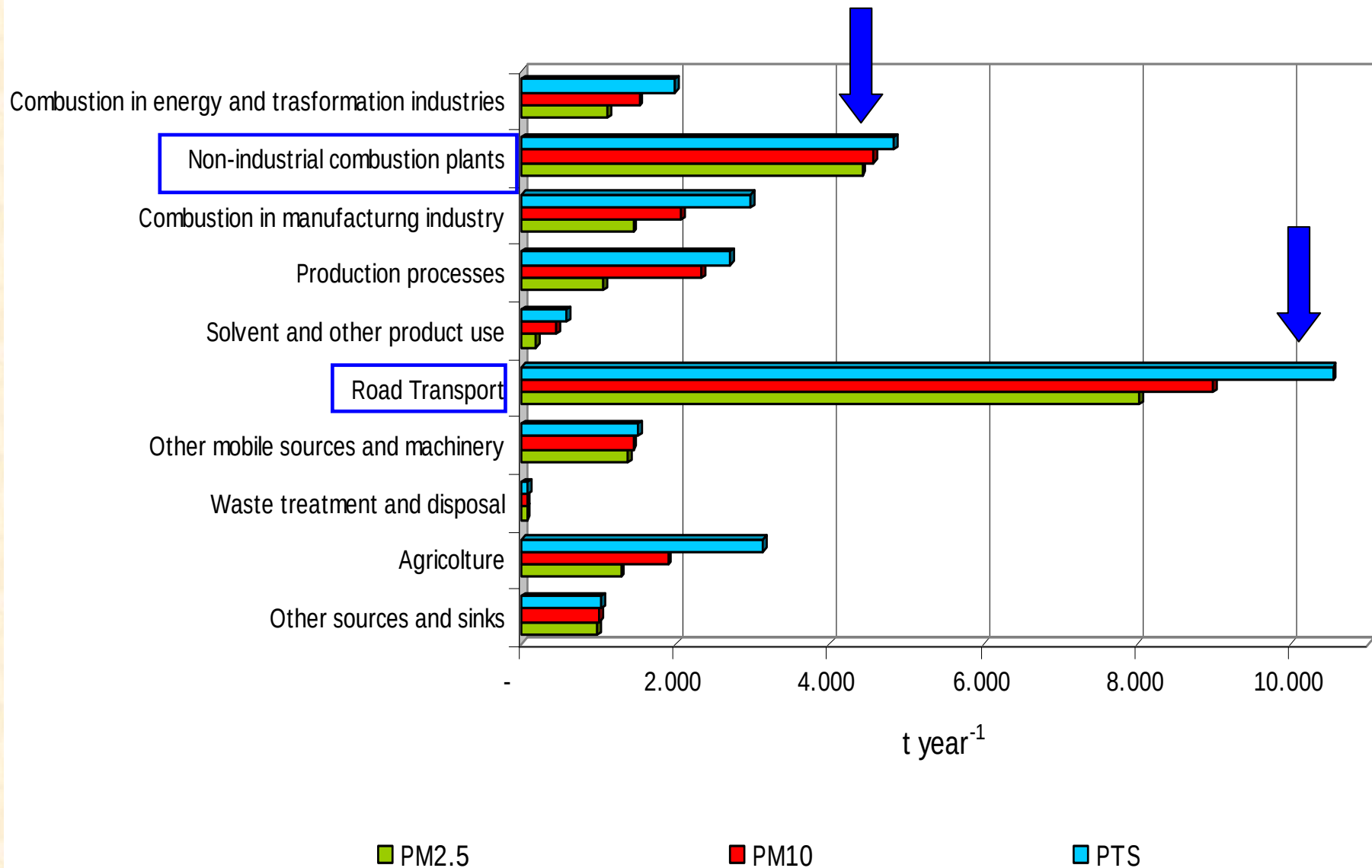
INEMAR - AtmosphereRic EMission Inventory - results about PM10 emissions

Non industrial combustion: 4,057 t/y = 15%
(calculated using wood estimate 1.9 Mt from ENEA
and EF = 190 g/GJ) of the total PM10 estimate in
Lombardy (27,331 t/y)

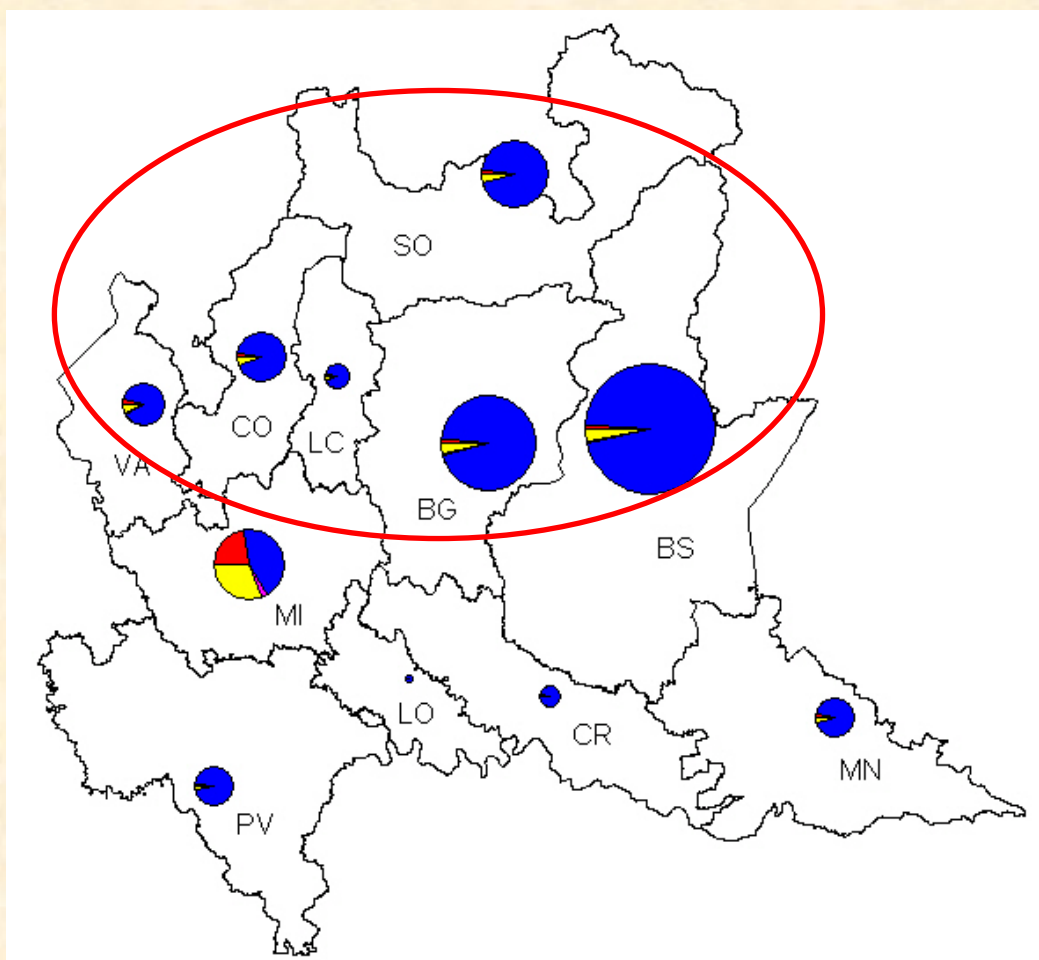
Data available on the INEMAR web page

<http://www.ambiente.regione.lombardia.it/inemar/inemarhome.htm>

Wood combustion a significant source of PM

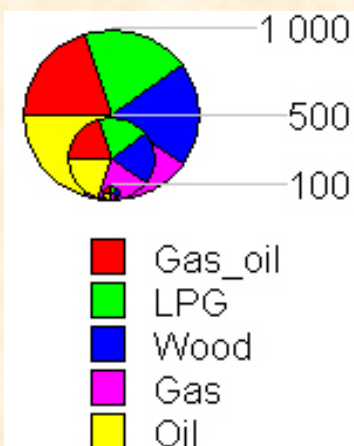


Wood combustion (non-industrial) PM10 emissions (t y⁻¹)



Agenzia Regionale
per la Protezione dell'Ambiente
della Lombardia

ARPA



Conclusions

- 1) The use of a questionnaire survey has been successful to collect reliable data on wood combustion
- 2) Average wood consumption (210 kg/inhab./year) confirms high use rates (data of wood selling increased during last years)
- 3) Wood combustion is confirmed to be an important source of PM10 emissions – more than 20%
- 4) There is still uncertainty about estimates and EF of different combustion systems

PARFIL project (Particulate Fine in Lombardy)

Further work / 1

- Creation of specific indicators about wood consumption on the regional territory
- Detailed analysis for macro-areas in order to better understand the behaviour of families respect to wood use

PARFIL project (Particulate Fine in Lombardy)

Further work / 2

Creation of a descriptive model of wood consumption in Lombardy through multivariate statistics:

i.e. - Principal Component Analysis:

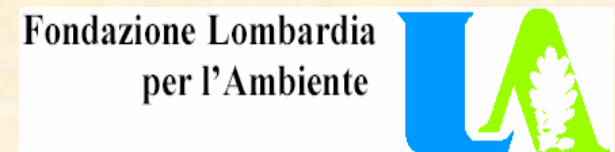
Significance analysis – *t*-test

Variables: wood use – type of house, geographic position, type of town, distance from woods and forests (thus availability of wood) etc.

Kyoto Project : communication of the results

Further work / 3

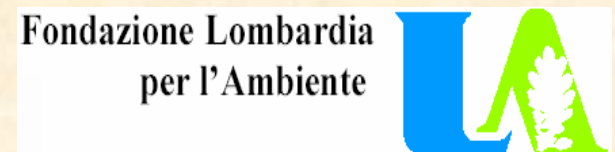
The results of the survey will be communicated to schools to sensitize students about different aspects of the air pollution problem



Thank you for your attention!

Dr. Luca Marazzi
Lombardy Foundation for the Environment

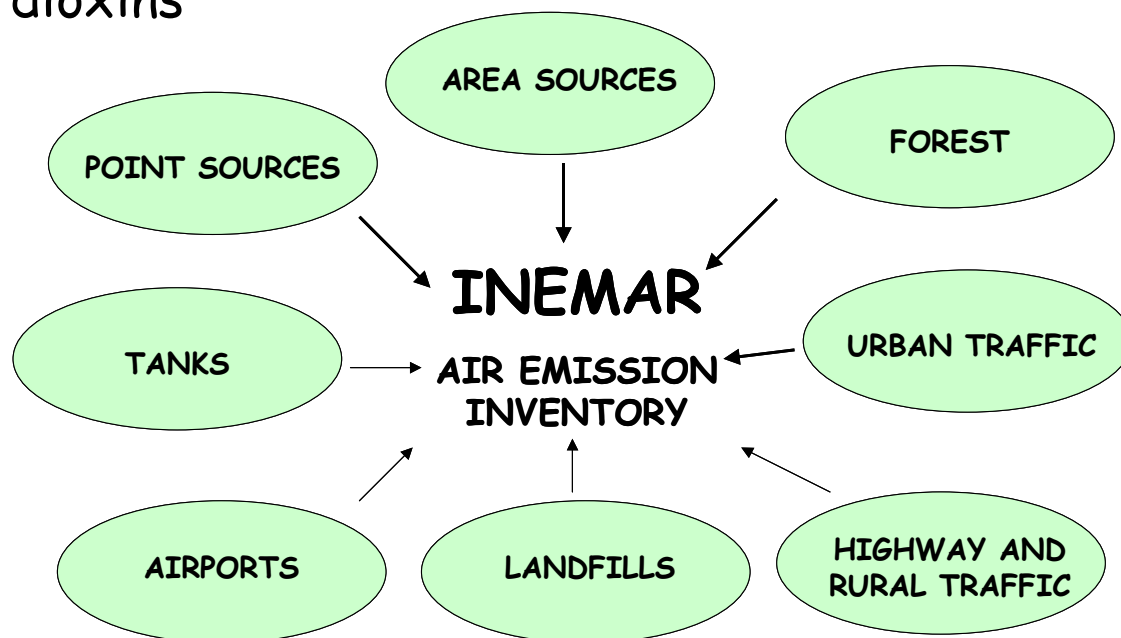
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Methodology

Pollutants: acidifying substances (SO_2 , NO_x , NH_3 , CO),
ozone precursors (NMVOC),
greenhouse gases (CO_2 , CH_4 , N_2O),
PM10 and dioxins

Activities: SNAP 97
from CORINAIR



Inemar: AtmospheRic EMission INventory

first edition of the emissions inventory: reference year 1997
(Regional Air Quality Management Plan)



October 2003: Emission inventory for the reference year 2001

- about 220 activities from different sources type (point, area, road transport, agriculture...),
- SO₂, NO_x, NH₃, CO, NMVOC, CO₂, CH₄, N₂O, PM10
- about 20 fuel type,
- 1546 municipalities of Lombardy.



Point sources

Emission and other data from about 250 big industrial plants (power plants, cement industries, municipal waste incinerators, refineries, chemical and manufacturing plants) have been collected by means of a form.

macro-pollutants
(SO₂, NO_x, dust,
CO)



continuous monitoring system or single
measurements, computed on specific
data of the plant (flue gas concentration,
flow rate, temperature, etc.)

other pollutants



specific data of the plant (activity
rate, number of employees, etc.);
emission factors from literature



Area sources

Emissions from smaller industrial plants or, in general, area sources (i.e. emissions from household heating plants, agricultural activities) assessed by the usual methodology:

$$Q = A * EF$$

A = Activity data (survey forms, statistical surveys on provincial and regional scales, trade associations data)

EF = Emission factors (EEA Guidebook, U.S.EPA Air CHIEF, APAT-CTN ACE).



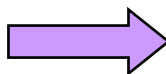
Traffic emissions/1

Algorithms proposed by Corinair COPERT III methodology:

- non-urban driving (highway and other main roads)
- urban driving (municipal roads)

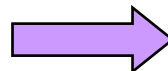
Traffic data available for:

- 9000 road sections
- 4 vehicle categories



passenger cars
light duty vehicles < 3.5 t
heavy duty vehicles and buses
motorcycles > 50 cm³

- temporal distribution profiles

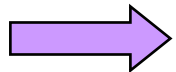


4 seasons
3 days
3 hours



Traffic emissions/2

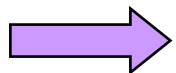
All available data processed by an Equilibrium Traffic Assignment Algorithm model



traffic flows

driving speeds on all the region road network

Urban traffic emissions: difference between total fuel sold in Lombardy and fuel used by vehicles on main roads



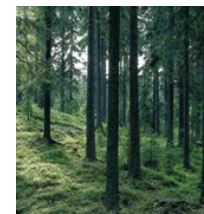
allocation of urban emissions to the 1546 municipalities made by a surrogate variable:

vehicles number at municipal level multiplied by
annual mileage per vehicle type and fuel consumption

Other methodologies

Specific algorithms developed for different emissions:

- Biogenic emissions (NMVOC emitted by vegetation)
- Landfill emissions (IPCC detailed methodology)
- Tanks emissions (American Petroleum Institute methodology)
- Airport traffic emissions (landing/take-off cycle data)
- Agriculture emissions (enteric fermentation, manure management in animal husbandry, fertilized agricultural land)
- Detailed approach for dioxin



PM / Point sources

Emission and other data from about 250 big industrial plants (power plants, cement industries, municipal waste incinerators, refineries, chemical and manufacturing plants) have been collected by means of a form.

SO₂, NO_x, CO, TSP
measured continuously or
periodically



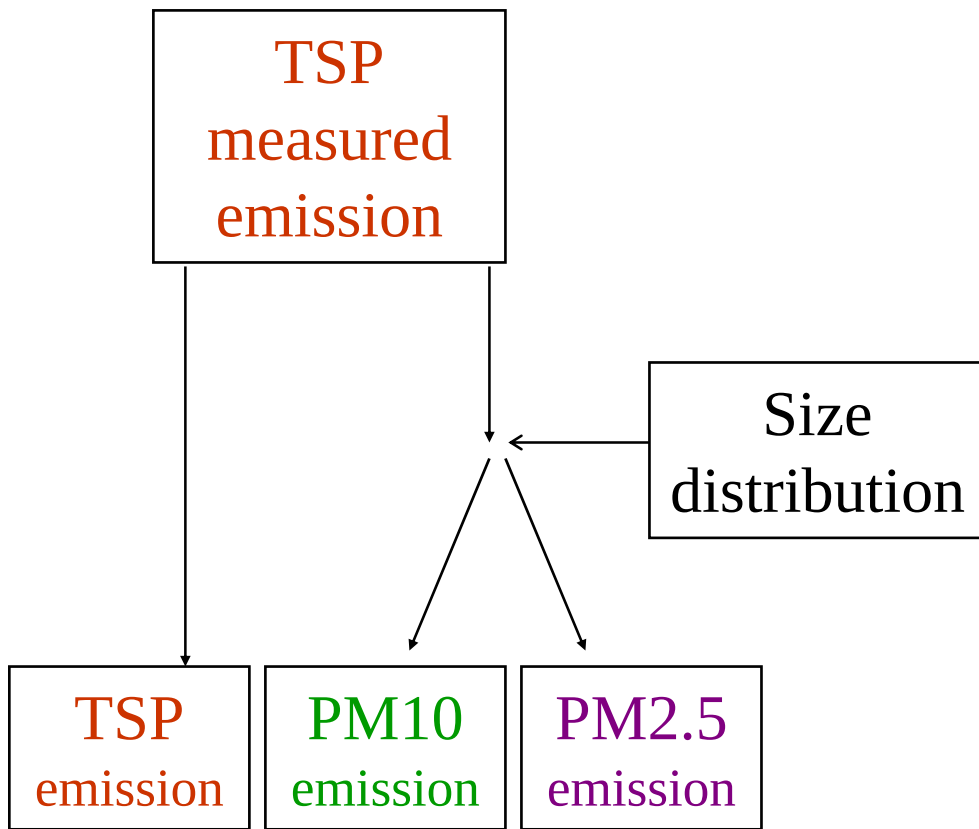
SO₂, NO_x, CO, **TSP**
emission data available

PM₁₀ and PM_{2.5}
not measured



PM₁₀ and PM_{2.5}
emission data not available

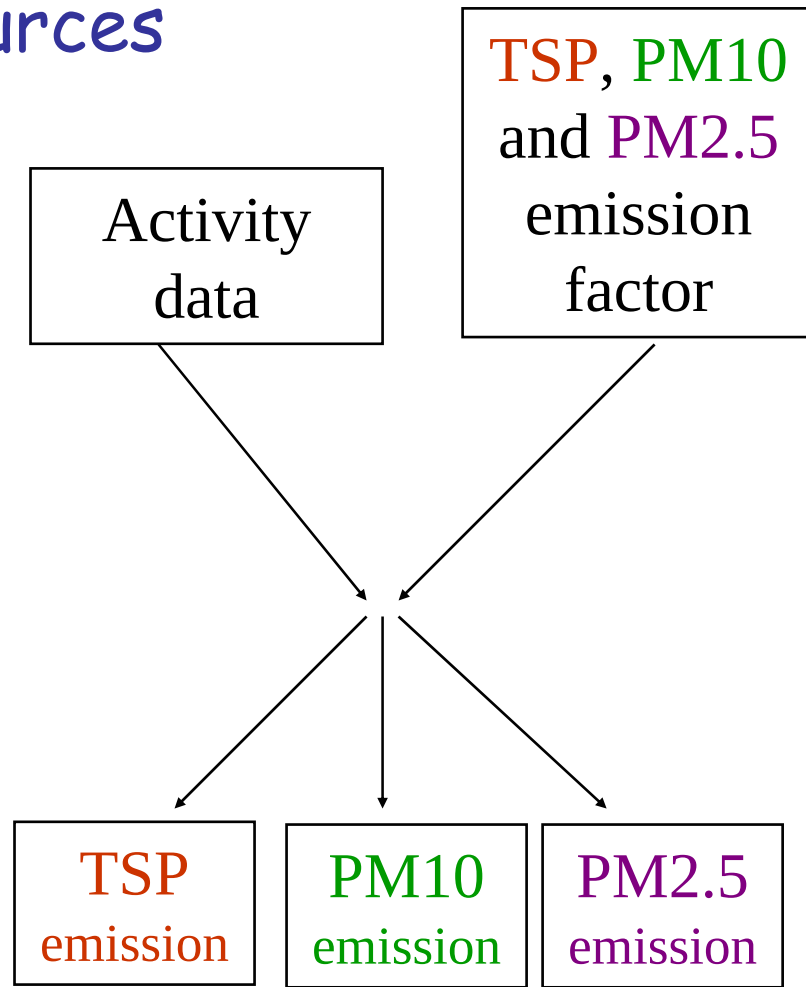
Point sources



93 %

95 %

90 %

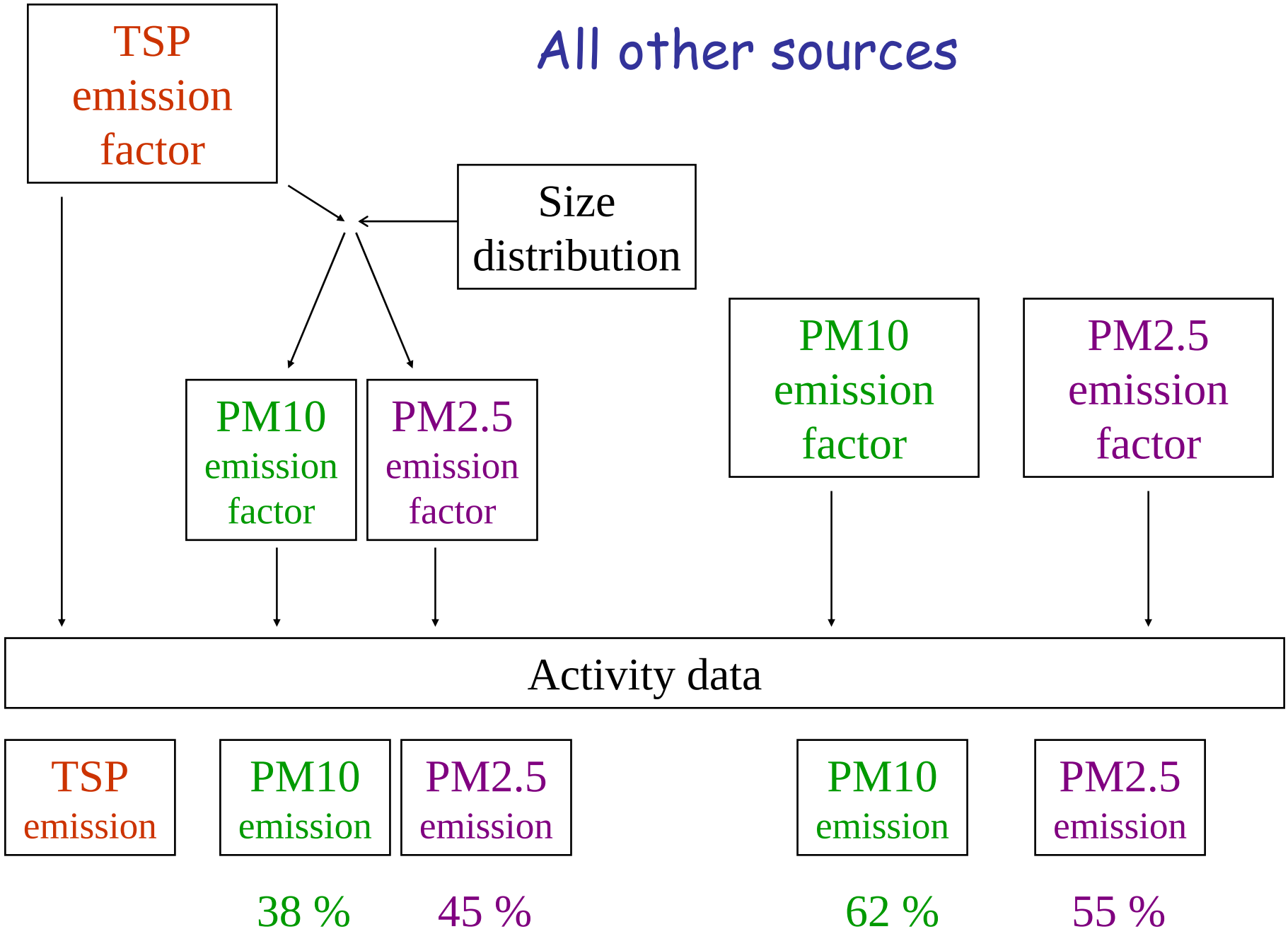


7 %

5 %

10 %

All other sources



Emission factors

- EEA Guidebook
- U.S.EPA Air CHIEF
- CEPMEIP
- RAINS project
- APAT- CTN ACE (Italy)
- Other literature data (wood burning, animal husbandry, tobacco smoking, fireworks)

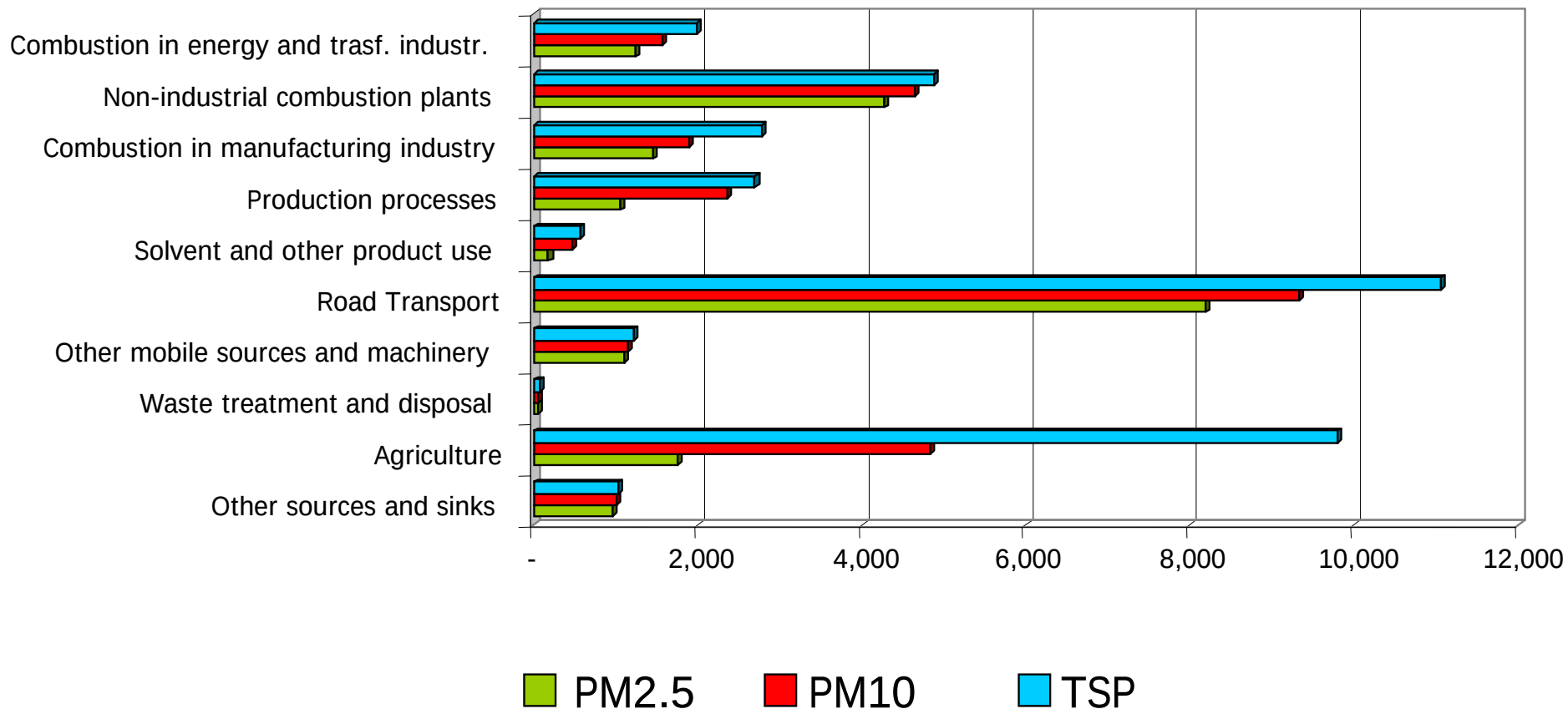
Results

	PM2.5	PM10	TSP	NOx	SO ₂	VOC	NH ₃	CO ₂	CH ₄	N ₂ O
1-Combustion in energy and transformation industries	1,249	1,579	1,990	26,996	51,456	689	1.8	16,404	710	273
2-Non-industrial combustion plants	4,273	4,649	4,871	16,977	6,244	13,929	209	16,881	7,720	1,837
3-Combustion in manufacturing industry	1,456	1,892	2,783	44,491	11,472	4,902	12	13,698	1,122	743
4-Production processes fossil fuels and geothermal energy	1,063	2,361	2,700	1,459	3,524	30,076	73	3,697	138	19
						8,919			92,143	
6-Solvent and other product use	183	467	570	306	1.4	147,614	16			
7-Road Transport	8,201	9,326	11,051	114,151	2,913	72,704	2,504	18,794	3,079	1,740
8-Other mobile sources and machinery	1,094.7	1,151	1,212	11,471	1,214	1,721	1.6	1,007	32	246
9-Waste treatment and disposal	60	61	70	1,778	271	268	3.7	813	116,917	147
10-Agriculture	1,748	4,835	9,802	1,568		1,301	94,823		216,520	10,656
11-Other sources and sinks	970	1,009	1,038	364	83	27,787	83		5,688	12
Total	20,299	27,331	36,088	219,562	77,178	309,910	97,728	71,295	444,070	15,672

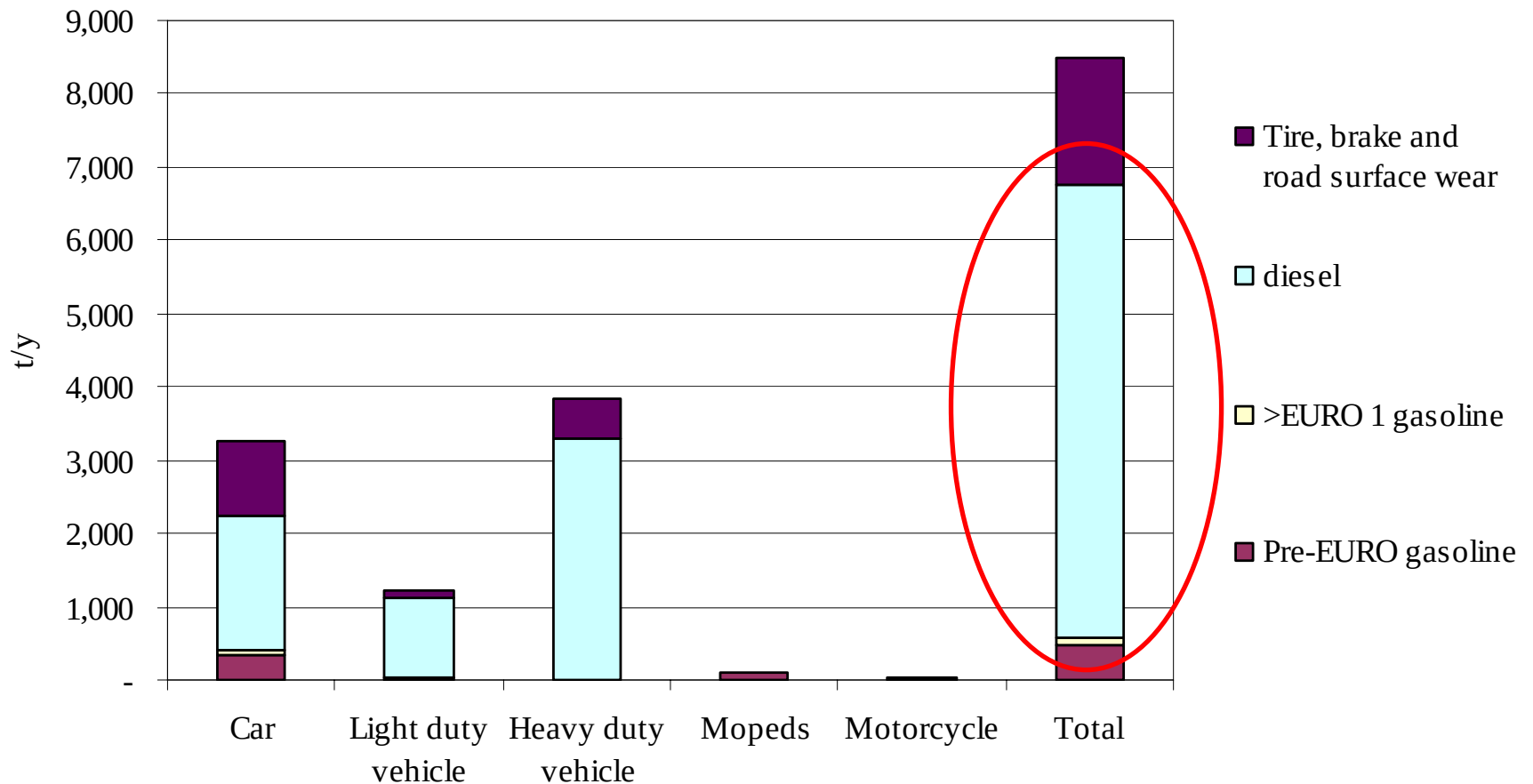
PM emissions in Lombardy (t y⁻¹) - top SNAP 2 level

Group	Sub-group	PM2.5	PM10	PTS
2 Non-industrial combustion plants	2 Residential plants	4,011	4,361	4,561
7 Road transport	3 Heavy duty vehicles > 3.5 t and buses	3,749	4,111	4,757
7 Road transport	1 Passenger cars	3,098	3,787	4,719
10 Agriculture	10 Animal husbandry	738	3,653	8,118
4 Production processes	2 Processes in iron and steel industries and collieries	883	1,784	2,091
7 Road transport	2 Light duty vehicles < 3.5 t	1,209	1,278	1,417
10 Agriculture	3 On-field burning of stubble, straw,...	1,010	1,182	1,684
3 Combustion in manufacturing industry	1 Comb. in boilers, gas turbines and stationary engines	1,006	1,084	1,211
8 Other mobile sources and machinery	6 Agriculture	994	1,046	1,101
1 Combustion in energy and transformation ind.	1 Public power	656	920	1,146
3 Combustion in manufacturing industry	3 Processes with contact	450	807	1,571
1 Combustion in energy and transformation ind.	3 Petroleum refining plants	592	658	843
11 Other sources and sinks	3 Forest and other vegetation fires	511	549	578
4 Production processes	6 Processes in wood, paper pulp, food, drink and other ind.	118	491	504
11 Other sources and sinks	25 Other (tabacco smoking and fireworks)	459	459	459
6 Solvent and other product use	3 Chemical products manufacturing or processing	159	437	528
2 Non-industrial combustion plants	1 Commercial and institutional plants	252	278	300
7 Road transport	4 Mopeds and Motorcycles < 50 cm3	111	111	111
9 Waste treatment and disposal	2 Waste incineration	56	57	65
8 Other mobile sources and machinery	3 Inland waterways	38	41	43
7 Road transport	5 Motorcycles > 50 cm3	34	39	47
4 Production processes	5 Proc. in organic chemical industr. (bulk production)	34	39	44
4 Production processes	1 Processes in petroleum industries	11	26	37
8 Other mobile sources and machinery	8 Industry	24	24	26
8 Other mobile sources and machinery	5 Air traffic	19	20	20
8 Other mobile sources and machinery	2 Railways	19	20	21
6 Solvent and other product use	1 Paint application	20	20	29
4 Production processes	3 Processes in non-ferrous metal industries	10	11	12
4 Production processes	4 Processes in inorganic chemical industries	7	10	12
2 Non-industrial combustion plants	3 Plants in agriculture, forestry and aquaculture	10	10	10
Others		9	16	20
Total		20,299	27,331	36,088

Particulate matter emissions in Lombardy Region, reference year 2001 (t y^{-1})



Road transport PM10 emissions (t y^{-1})



Road transport PM10 emissions (t y⁻¹)

