ANPA
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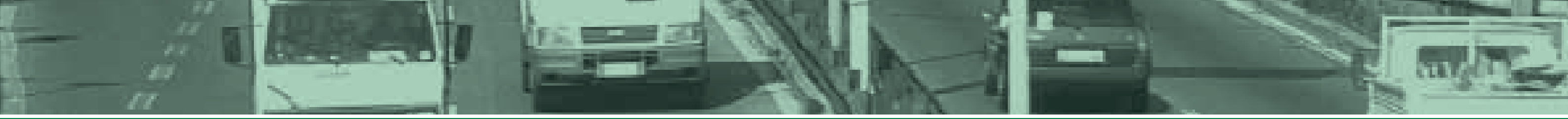
Top-down methodology and multivariate statistical analysis to estimate road transport emissions at different territorial levels

Rapporti 5/2001

ANPA - Dipartimento Stato dell'Ambiente, Controlli e Sistemi Informativi

ANPA - Unità Interdipartimentale Censimento delle Fonti di Emissione



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www.anpa.it

ISBN 88-448-0249-x

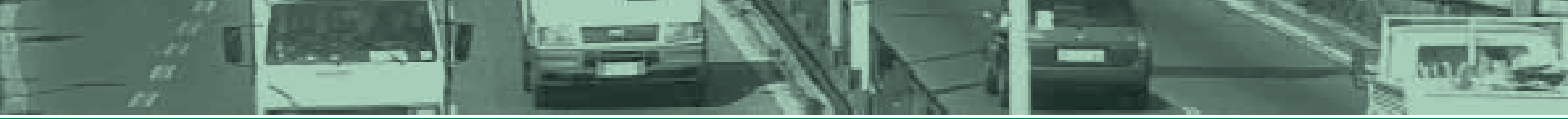
Coordinamento ed elaborazione grafica
ANPA, Immagine
Grafica di copertina: Franco Iozzoli
Foto di copertina: Paolo Orlandi

Coordinamento tipografico
ANPA, Dipartimento Strategie Integrate Promozione e Comunicazione

Impaginazione e stampa
I.G.E.R. srl - Viale C. T. Odescalchi, 67/A - 00147 Roma

Stampato su carta TCF

Finito di stampare nel mese di dicembre 2001



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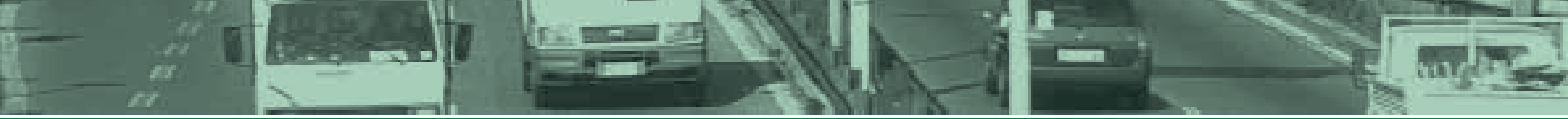

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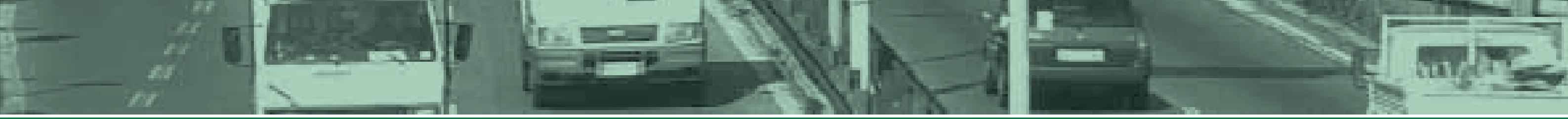
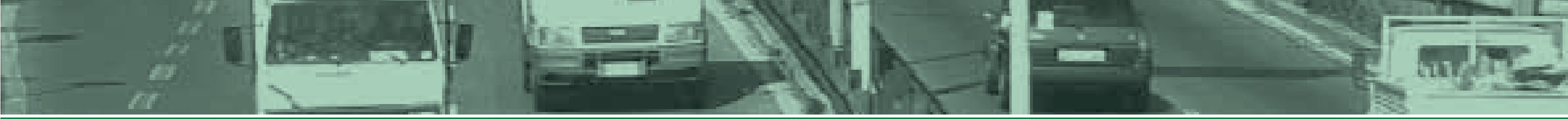


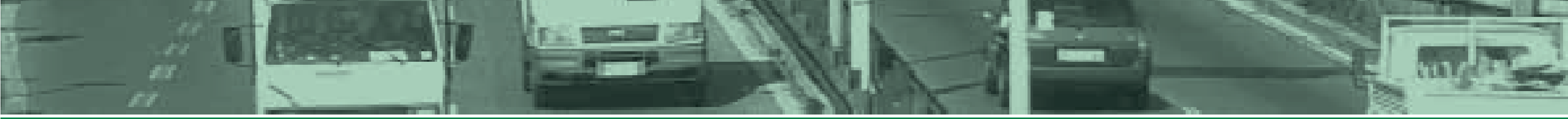
Summary

The goal of the present paper is to analyse and to propose issues regarding the question of the top-down approach for estimating local emissions of the road transport sector from the national level.
A set of indicators related to transport activities is used in order to identify homogeneous areas in the Italian territory. For each area, COPERT methodology is therefore applied to estimate atmospheric emissions of different pollutants.
The results, by vehicle category and driving mode, are compared with those deriving from a spatial disaggregation of national data by means of simple surrogate (proxy) variables.
The study identifies a corrective index which could be used for a more reliable characterization of road transport emissions at local level.



Sommario

L'obiettivo del presente lavoro è quello di analizzare e proporre miglioramenti in merito alla metodologia top-down di stima delle emissioni da trasporto stradale a livello locale.
Un set costituito da indicatori socio-economici ed indicatori legati all'attività dei trasporti stradali viene utilizzato per individuare, nel terittorio italiano, dei cluster, ovvero aree omogenee rispetto alle caratteristiche sintetizzate dagli indicatori prescelti. Per ognuna di queste aree, viene applicata la metodologia COPERT per stimare le emissioni in atmosfera di cinque inquinanti (NO_x, NMVOC, CO, CO_2, PM).
I risultati ottenuti, ripartiti per categoria veicolare e per ciclo di guida (urbano, rurale, autostradale), consentono di individuare le differenze tra i valori delle emissioni stimate applicando la metodologia proposta e quelli derivanti dalla disaggregazione provinciale dei dati nazionali attraverso variabili surrogate o proxy.
Lo studio identifica un indice di correzione delle stime che può essere utilizzato per una più realistica caratterizzazione delle emissioni da trasporto stradale a livello locale.



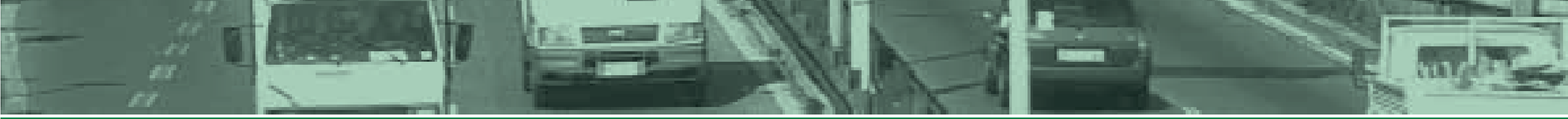
1. Introduction

Road transport is one of the major contributors to air pollution in Italy. In fact, estimates at national level show that, in the recent years, transport is the main source of pollution in urban areas related to different pollutants, such as NO_x (nitrogen dioxide), NMVOC (non methanic volatile organic compounds), CO (carbon monoxide) and PM (particular matter). The transport sector is also responsible for a large part of CO_2 national emissions, the principal greenhouse gas.

The methodology used to estimate national air pollutants and GHGs emissions from road transport is COPERT (Computer Programme to estimate Emissions from Road Traffic) the same that is proposed to be used by EEA (European Environment Agency) member countries for the compilation of CORINAIR emission inventories. COPERT is a mathematical model based on a large database including information on the national automotive fleet and several related parameters such as speed-dependent emission functions, fuel consumption, average speed and mileage for each vehicle. COPERT III (version 2.1b) has been used in this work.

In order to estimate road transport emissions in small territorial units, the same methodology could be used but the need for detailed information cannot always be completely satisfied. For countries for which the required input data are not available at local level, the methodology is usually applied at NUTS (Nomenclature of Territorial Units of Statistics) level 0 (national level) and national emission estimates are roughly allocated to other NUTS level by a top-down approach, with the help of available surrogate data (proxy variables).

A new methodology is identified and proposed, which takes into account local particularities and information and allows having more reliable estimates at local level consistent with national totals.



2. Objectives

This work addresses the question of the top-down approach for the estimation of local road transport emissions starting from NUTS level 0 (national level).

A bottom-up approach should be applied if data required by estimation procedures are available at smaller NUTS level. Otherwise, emissions are allocated from national to smaller levels by a top-down approach with the help of proxy variables.

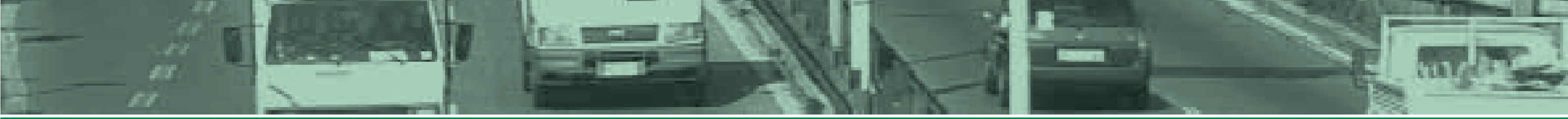
A set of both vehicle categories and socio-economic indicators at provincial level has been considered in order to characterize homogeneous areas in the Italian territory. Data refer to the year 1996.

Four different groups of territorial units have been individuated and COPERT methodology has been applied to each group to estimate road transport emissions of different pollutants.

The results, by vehicle category and driving mode, are compared with average national totals and with those obtained by disaggregating national estimates by means of a simple proxy variable.

Since the spatial aggregation of territorial units is not supposed to change substantially during the years, the macro-areas can be considered representative of different transport typologies.

Therefore, a corrective index is obtained and proposed to ameliorate and better characterize road transport emissions at local level without lacking in consistency with national estimates.



3. Methodological Approach

A set of indicators related to transport activities is used for identifying homogeneous areas in the Italian territory. Both vehicle categories and socio-economic information is considered simultaneously in order to characterize different groups of territorial units.

The base data for the analysis are the values of seventeen variables for the 103 provinces, into which Italy is divided, and refer to the year 1996. A description of the variables is shown in Table 3.1.

Data relating to employees and labour forces are provided by ISTAT (ISTAT, 1996), roads lengths are provided by Ministero dei Trasporti e della Navigazione (Ministero dei Trasporti e della Navigazione, 1998), vehicle fleet data are provided by the Automobile Club d'Italia (ACI, 1999), fuel sales data are provided by Unione Petrolifera (Unione Petrolifera, 1997).

Table n. 3.1: List of indicators used for classifying Italian provinces.

1.	Employees-Manufaturing and construction industry / labour forces
2.	Employees-Electricity, gas, steam and hot water supply / labour forces
3.	Employees-Wholesale and retail trade; repairs of motor vehicles, motorcycles and personal and household goods. Hotels and restaurants. Transport, storage and communication / labour forces
4.	Employees-Financial intermediation. Real estate, renting and business activities / labour forces
5.	Employees-Public administration and defence; compulsory social security / labour forces
6.	Urban road length / surface
7.	Rural road length / surface
8.	Highways road length / surface
9.	Gasoline Passenger cars per capita
10.	Diesel Passenger cars per capita
11.	LPG Passenger cars per capita
12.	Light duty vehicles / vehicle fleet
13.	Heavy duty vehicles / vehicle fleet
14.	Mopeds per capita
15.	Motorcycles per capita
16.	Gasoline distribution / Gasoline Passenger cars
17.	Diesel distribution / Heavy duty vehicles

Cluster analysis has been applied to the set of data and four groups with different numbers of provinces have been individuated. Clusters composition is shown in Table 3.2. The most numerous cluster (cluster 1) is characterized by provinces all situated in the southern part of Italy; the presence of highways is very limited in these areas and an old vehicular fleet shows the highest index of diesel cars per capita.

Cluster 2 shows the highest mean value of rural road length per provincial surface, as well as the highest value of gasoline distribution and LPG cars per capita.

The most numerous gasoline fleet per capita and the newest vehicular cars (Euro1) are observed in cluster 3.

Cluster 4, which includes provinces where the largest cities are situated (Rome, Milan, Naples, Florence), is characterized by high concentration of urban roads and highways, maximum number of mopeds per capita and high gasoline distribution.

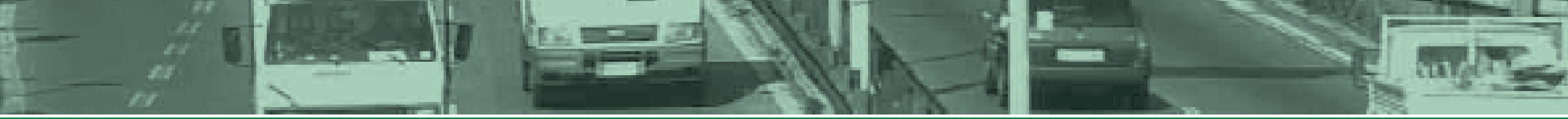
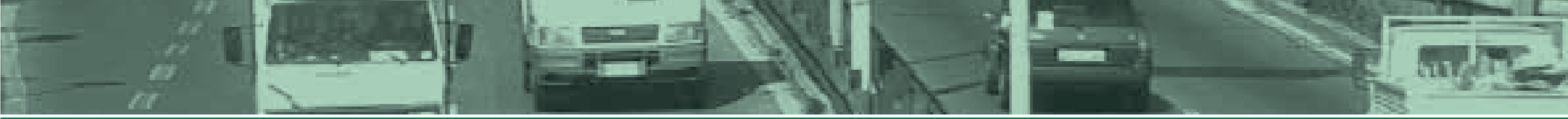


Table n. 3.2: Cluster composition.

Cluster 1 (33 provinces)	Cluster 2 (29 provinces)	Cluster 3 (26 provinces)	Cluster 4 (15 provinces)
Agrigento	Ancona	Alessandria	Bologna
Avellino	Arezzo	Aosta	Firenze
Bari	Ascoli Piceno	Belluno	Genova
Benevento	Asti	Bergamo	La Spezia
Brindisi	Brescia	Biella	Livorno
Cagliari	Chieti	Bolzano	Milano
Caltanissetta	Cuneo	Como	Napoli
Campobasso	Ferrara	Cremona	Palermo
Caserta	Forlì	Gorizia	Prato
Catania	Grosseto	Imperia	Rimini
Catanzaro	Macerata	Lecco	Roma
Cosenza	Mantova	Lodi	Terni
Crotone	Massa	Lucca	Torino
Enna	Modena	Novara	Trieste
Foggia	Padova	Pavia	Venezia
Frosinone	Parma	Pisa	
Isernia	Perugia	Pistoia	
L'Aquila	Pesaro	Pordenone	
Latina	Pescara	Savona	
Lecce	Piacenza	Siena	
Matera	Ravenna	Sondrio	
Messina	Reggio Emilia	Trento	
Nuoro	Rieti	Udine	
Oristano	Rovigo	Varese	
Potenza	Teramo	Verbania	
Ragusa	Treviso	Vercelli	
Reggio Calabria	Verona		
Salerno	Vicenza		
Sassari	Viterbo		
Siracusa			
Taranto			
Trapani			
Vibo Valentia			



The results of cluster analysis are mapped in Figure 3.1.

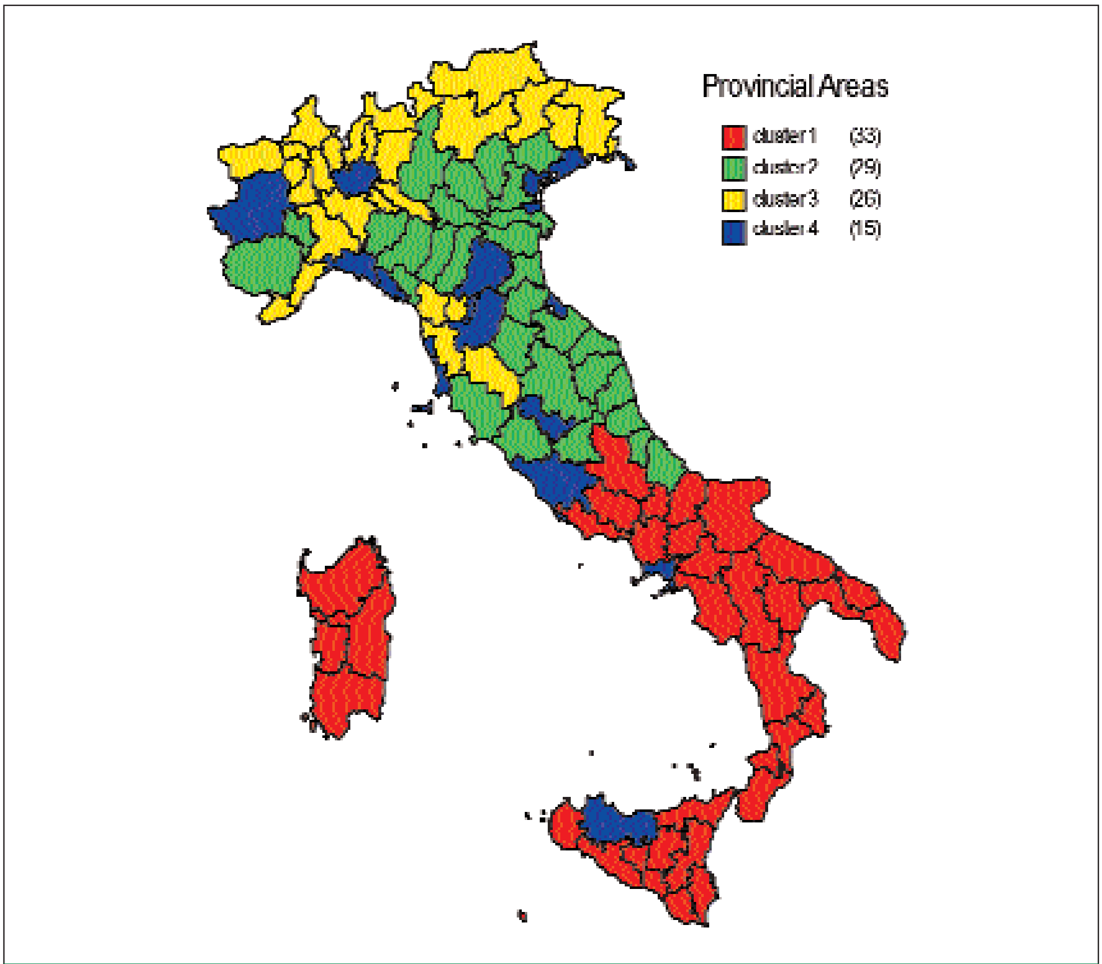


Figure n. 3.1: Localisation of the clusters on Italian territory.

For each cluster, COPERT methodology has been applied to estimate road transport emissions of five pollutants (NO_x, NMVOC, CO, CO_2, PM).

Information deriving from cluster analysis has been taken into account in order to differentiate the input variables considered in the estimation methodology (average annual mileage driven by vehicle category, distribution of mileage by driving mode), and to balance the calculated consumption (per fuel type) of each cluster with the corresponding statistical data.

Since consumption data are not available at a lower territorial level, statistical consumptions per cluster have been estimated from national data (provided by Ministero dell'Industria del Commercio e dell'Artigianato, 1997), allocating consumption to provincial level by means of provincial sales of fuel (Unione Petrolifera, 1997) as surrogate variable. For each cluster, statistical consumptions per fuel type are shown in Table 3.3. Distribution of cluster consumption per fuel type is shown in Figure 3.2 and distribution of national statistical consumption per cluster and vehicle sector is shown in Figure 3.3.

Table n. 3.3: Fuel consumption for road transport sector in Italy in 1996.

Cluster	Unleaded Gasoline (t)	Leaded Gasoline (t)	Diesel (t)	LPG (t)
Cluster 1	1.496.434	2.382.246	3.419.530	377.306
Cluster 2	2.029.343	2.295.181	3.787.289	453.814
Cluster 3	1.520.268	1.525.791	2.357.375	209.933
Cluster 4	2.837.534	3.214.203	4.884.806	468.947
Italia	7.883.579	9.417.421	14.449.000	1.510.000

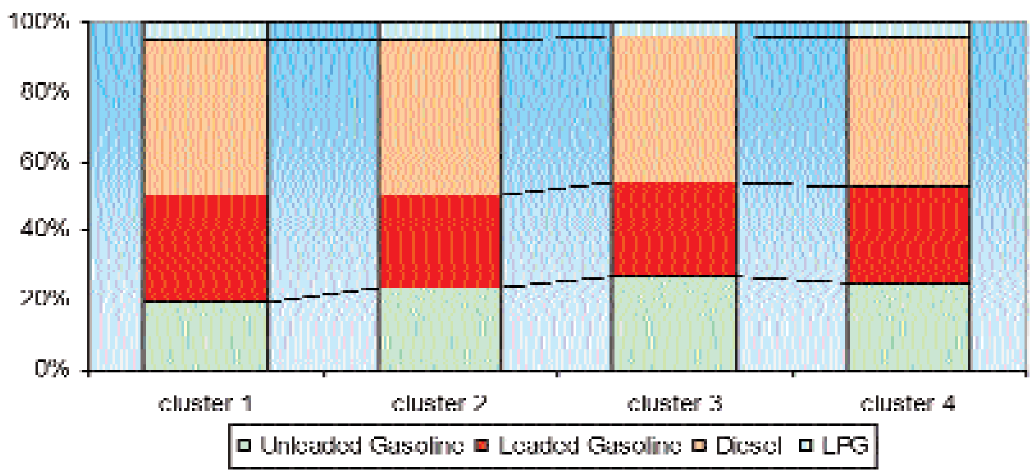


Figure n. 3.2: Distribution of cluster consumption per fuel type.

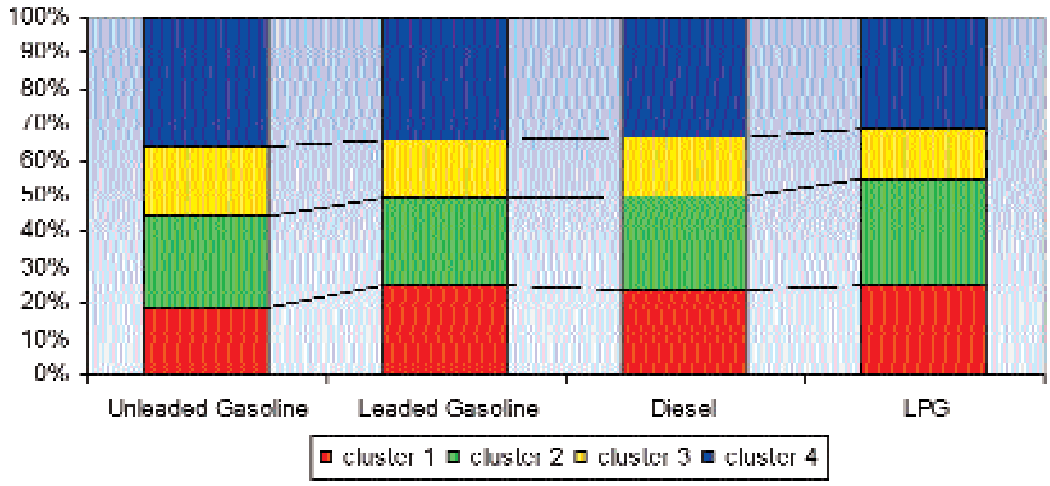
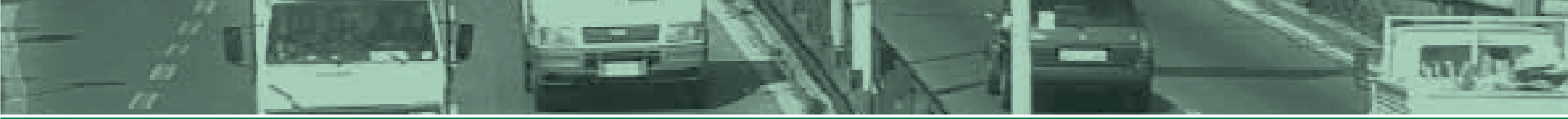


Figure n. 3.3: Distribution of national statistical consumption per cluster and vehicle sector.



Fleet data per cluster (number of vehicles per vehicle category, ACI, 1999) are shown in Table 3.4. Distribution of national fleet per cluster and vehicle sector is shown in Figure 3.4 and distribution of cluster fleet per vehicle sector is shown in Figure 3.5.

Table n. 3.4: Composition of vehicle fleet (n. of vehicles) of the clusters. Data for Italy in 1996.

Vehicle Sector	Cluster 1	Cluster 2	Cluster 3	Cluster 4	Italy
Passenger Cars	7.869.430	6.986.880	4.993.021	10.734.509	30.583.840
(Gasoline)	*(6.336.754)*	*(5.862.622)*	*(4.489.285)*	*(9.365.699)*	*(26.054.360)*
(Diesel)	*(1.203.608)*	*(655.964)*	*(380.405)*	*(994.925)*	*(3.234.903)*
(LPG)	*(329.068)*	*(468.293)*	*(123.330)*	*(373.885)*	*(1.294.577)*
Light Duty Vehicles	492.433	572.772	384.704	697.933	2.147.842
Heavy Duty Vehicles & Buses	322.073	282.235	158.903	294.496	1.057.707
Mopeds & Motorcycles	1.947.167	1.472.536	1.035.888	3.287.333	7.742.923
Total	10.631.103	9.314.422	6.572.515	15.014.270	41.532.311

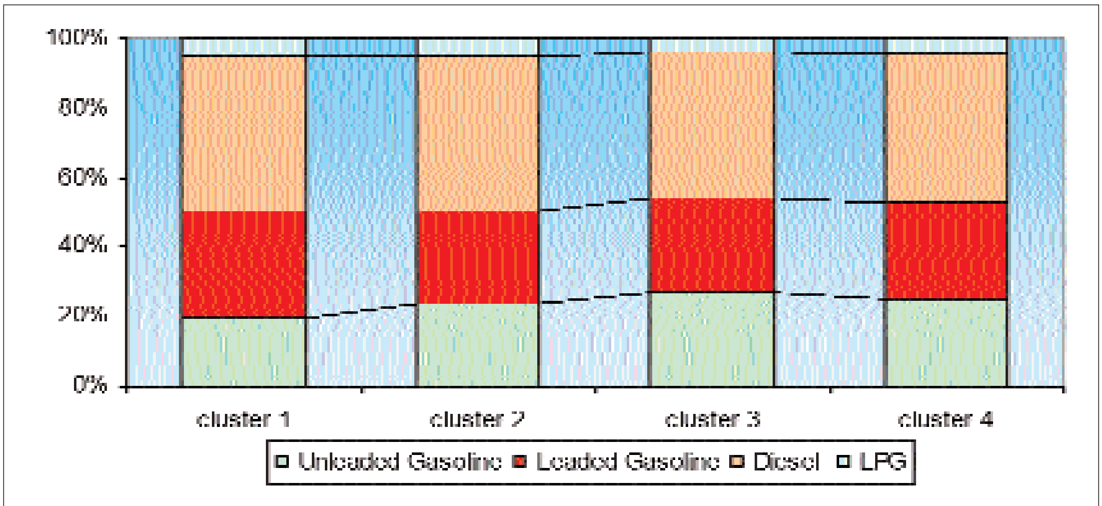


Figure n. 3.4: Distribution of Italian fleet per cluster and vehicle sector in 1996.

As shown in Figure 3.4, the highest percentage of the Italian vehicular fleet, for the different categories, occurs in cluster 4, where the largest provinces are situated (only for heavy duty vehicles, the largest percentage occurs in cluster 1); the lowest percentages for different vehicle categories are to be attributed to cluster 3, which includes provinces situated in the centre and north-east of Italy.

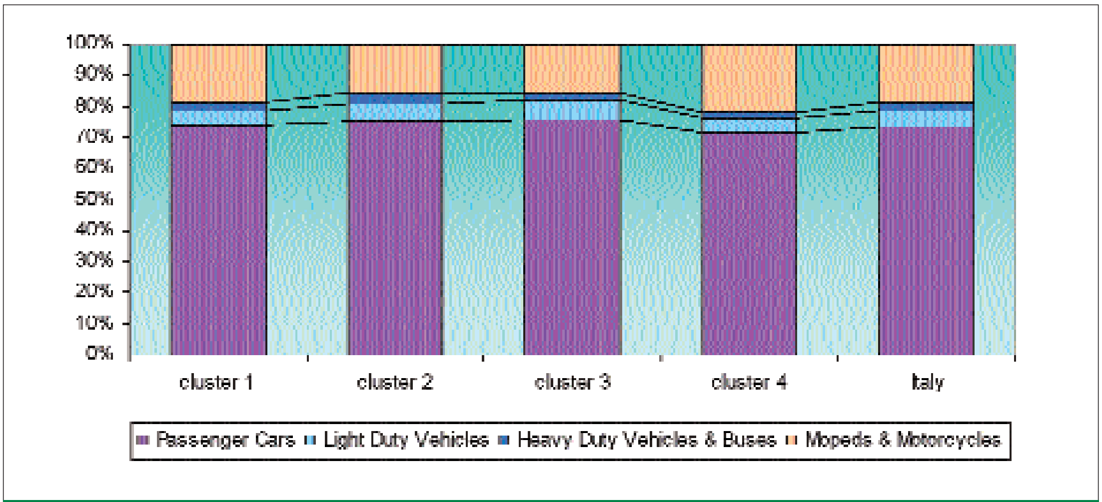


Figure n. 3.5: Distribution of clusters fleet per vehicle sector in 1996.

Fleet distribution is very similar within the different clusters and at national scale (Italy). The largest percentage of each cluster vehicle fleet occurs for passenger cars as also for the Italian fleet (about 70%). Cluster 4 shows the largest percentage of mopeds & motorcycles, about 22% of its total vehicle fleet.

In Figure 3.6 the distribution of passenger car fleet per cluster and fuel type is shown.

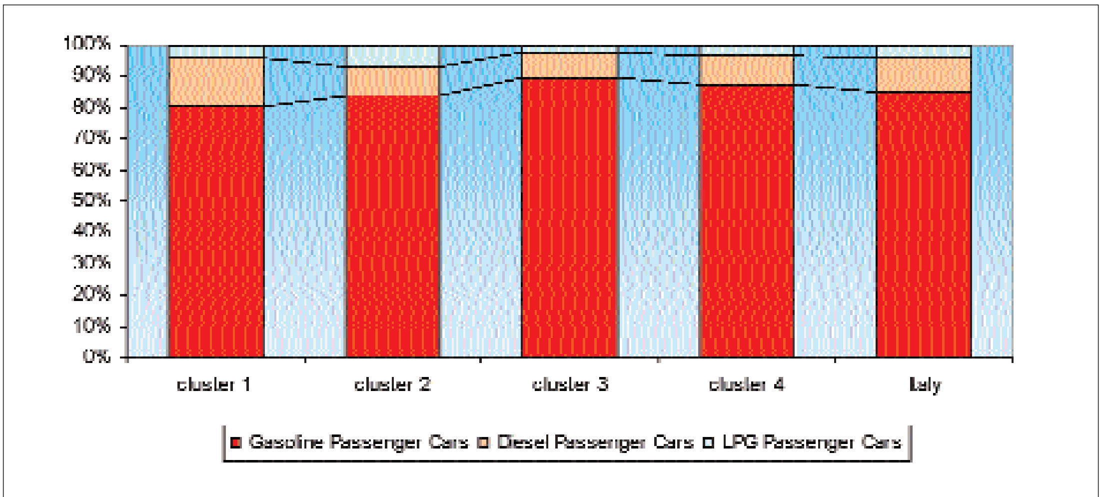
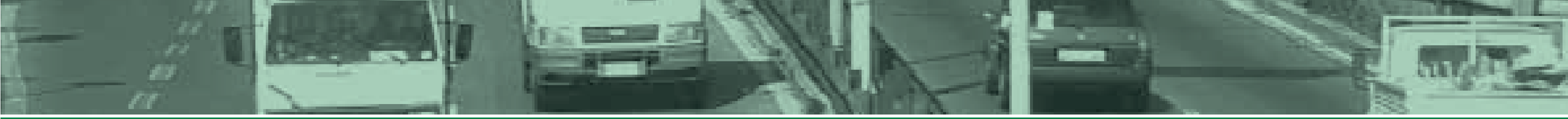


Figure n. 3.6: Distribution of passenger car fleet per cluster and fuel type in 1996.

Cluster 3 shows the largest percentage of gasoline passenger cars (about 90% of the total passenger car fleet). On the other hand, the largest percentage of diesel passenger cars is observed in cluster 1 (about 15% of the total), while for LPG passenger cars the highest value occurs in cluster 2 (about 7% of its total passenger car fleet).
For each cluster, vehicle annual mileage per sector (vehicle ∗ km/year) is shown in Table 3.5. For each cluster, deviations of annual mileage per vehicle sector from national estimates are shown in Figure 3.5. National annual mileage per vehicle sector has been estimated as a wei-



ghted average of cluster data (labelled "Italy" in Table 3.5) and then national emissions have been calculated by COPERT. This approach allows emissions data at cluster level to be consistent with the national estimates.

Table n. 3.5: Vehicle annual mileage per sector, for each cluster and for Italy, in 1996.

Vehicle Sector	Cluster 1	Cluster 2	Cluster 3	Cluster 4	Italy
Passenger Cars	10.531	12.545	11.732	11.166	11.410
(Gasoline)	*(9.180)*	*(11.415)*	*(10.386)*	*(9.427)*	*(9.980)*
(Diesel)	*15.026)*	*(19.566)*	*(21.846)*	*(23.573)*	*(19.377)*
(LPG)	*(20.100)*	*(16.858)*	*(29.500)*	*(21.686)*	*(20.281)*
Light Duty Vehicles	13.786	15.154	17.139	20.832	17.041
Heavy Duty Vehicles & Buses	31.726	40.306	43.170	43.988	39.149
Mopeds & Motorcycles	5.587	5.616	5.642	5.580	5.597

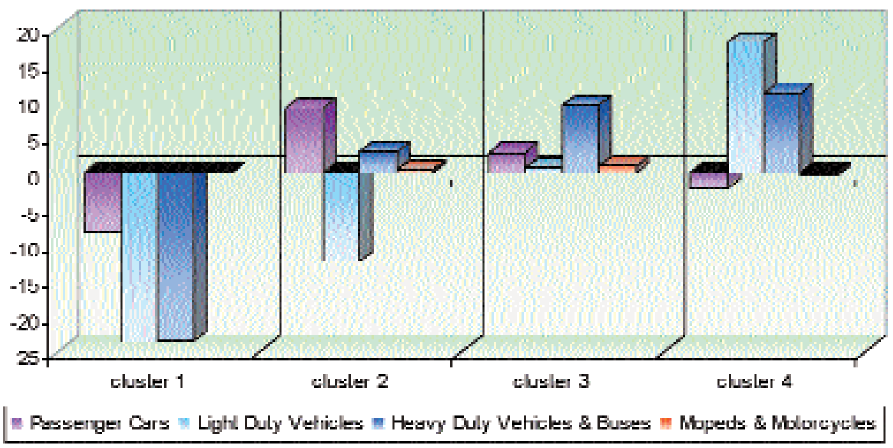
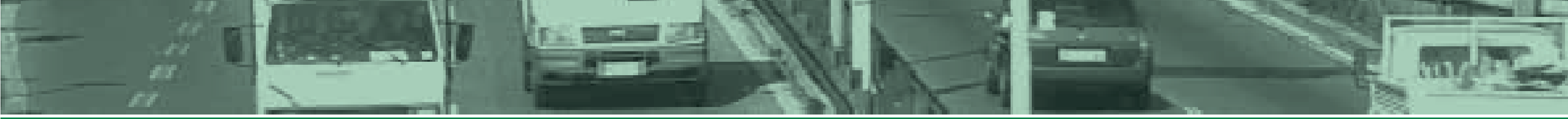


Figure n. 3.5: Deviations (%) of cluster annual mileage per vehicle sector from national estimates.



4. Results and discussion

Emission results of the new methodological approach for each cluster have been compared with the provincial CORINAIR emissions aggregated by cluster.
For each pollutant (NO_x, NMVOC, CO, CO_2, PM), provincial CORINAIR emissions per vehicle sector and driving mode (urban, rural, highway) are calculated by the standard top-down approach which uses population and highways length, as proxy variables, to allocate the national total.

With regard to CORINAIR approach, urban emissions are disaggregated to urban areas of the provinces by localising geographically all the local areas with more than 20.000 inhabitants and allocating the emissions via the population living in each of these areas; rural emissions are spread all over the province, outside urban areas, by taking the non-urban population density (population living in the areas with less than 20.000 inhabitants) of the province; highway emissions are allocated to highways only, taking the length of such roads in the province as a simple distribution key; NMVOC evaporative emissions (from gasoline vehicles) are distributed to the provincial area via the number of gasoline vehicles circulating. Therefore, the formula to be applied is:

$$e_{i,j}^k = e_N^k \times \frac{p_{i,j}}{p_N}$$

where,

$e_{i,j}^k$ = CORINAIR emission in province *i* (i = 1,…, 103) for vehicle sector *k* (k = 1,…, 5) and driving mode *j* (j = 1,…, 3);

e_N^k = national emission for vehicle sector *k*;

$p_{i,j}$ = *proxy* value for province *i* and driving mode *j*;

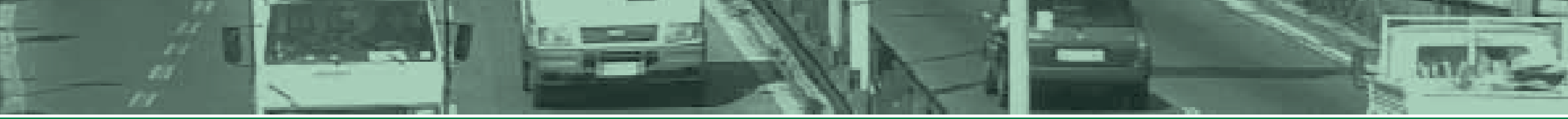
p_N = national *proxy* value.

The information provided by the characterisation of homogeneous areas, applying COPERT methodology to each cluster, has been used to correct standard CORINAIR emissions by province, by means of the following indexes:

$$V_c^k = \frac{e_c^k - \sum_{i=1}^{m} e_i^k}{\sum_{i=1}^{m} e_i^k}$$

where,

V_c^k = variation index for cluster *c* (c= 1,…, 4) and vehicle sector *k*;



$\tilde{e}_c^k$ = COPERT estimated emission for cluster *c* and vehicle sector *k*;

m = dimension of cluster *c*.

Variation index values (%) for the different clusters and vehicle sectors are shown in Table 4.1.

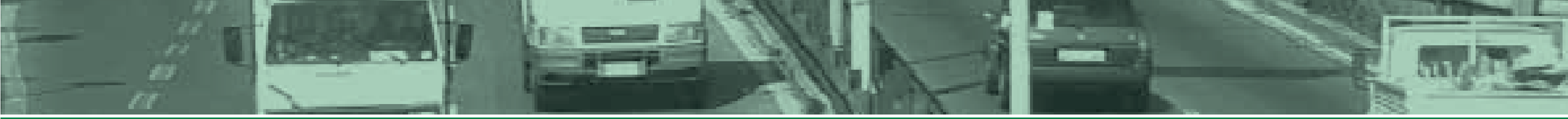
Table n. 4.1: New methodology (COPERT per cluster) emission results. Deviation (%) from standard CORINAIR methodology estimates (variation index, V_c^k, for cluster *c* and vehicle sector *k*).

Cluster	Vehicle Sector	NO_x	NMVOC	CO	CO_2	PM
Cluster 1	Passenger Cars	-16,0%	-9,6%	-9,9%	-17,1%	-0,3%
	Light Duty Vehicles	-35,5%	-31,8%	-30,6%	-34,5%	-29,0%
	Heavy Duty Vehicles & Buses	-12,9%	-8,8%	-7,6%	-14,6%	-10,2%
	Mopeds	-4,6%	-4,7%	-4,6%	-4,7%	-
	Motorcycles	-21,5%	-18,5%	-19,9%	-19,8%	-
	Gasoline Evaporation	-	2,6%	-	-	-
Cluster 2	Passenger Cars	5,9%	24,2%	24,9%	12,0%	-16,7%
	Light Duty Vehicles	2,8%	10,5%	7,2%	2,4%	1,0%
	Heavy Duty Vehicles & Buses	27,8%	17,3%	14,6%	24,1%	23,7%
	Mopeds	-16,9%	-17,1%	-16,9%	-16,8%	-
	Motorcycles	-0,3%	18,1%	8,9%	9,8%	-
	Gasoline Evaporation	-	11,4%	-	-	-
Cluster 3	Passenger Cars	-13,5%	16,9%	20,6%	-2,5%	-33,8%
	Light Duty Vehicles	2,3%	16,5%	12,5%	0,6%	-1,8%
	Heavy Duty Vehicles & Buses	-16,6%	-14,7%	-17,7%	-16,7%	-15,8%
	Mopeds	-30,5%	-30,9%	-30,5%	-30,5%	-
	Motorcycles	12,7%	54,5%	32,1%	34,3%	-
	Gasoline Evaporation	-	0,8%	-	-	
Cluster 4	Passenger Cars	18,0%	-11,4%	-13,8%	7,4%	28,0%
	Light Duty Vehicles	24,0%	11,5%	12,4%	30,2%	28,8%
	Heavy Duty Vehicles & Buses	3,0%	6,7%	9,5%	7,7%	4,7%
	Mopeds	22,8%	23,2%	22,8%	22,8%	-
	Motorcycles	13,0%	-13,1%	-2,8%	-4,0%	-
	Gasoline Evaporation	-	-8,6%	-	-	-

Finally the corrected emission ($\hat{e}_i^k$) for province i (included in cluster c) and vehicle sector k is:

$$\hat{e}_i^k = e_i^k(1 + V_c^k)$$

For each cluster, the results of the comparison between the corrected emissions ($\hat{e}_i^k$) and the corresponding CORINAIR estimates are described in Figure 4.1 (NO_x), Figure 4.2 (NMVOC), Figure 4.3 (CO), Figure 4.4 (CO_2), Figure 4.5 (PM).



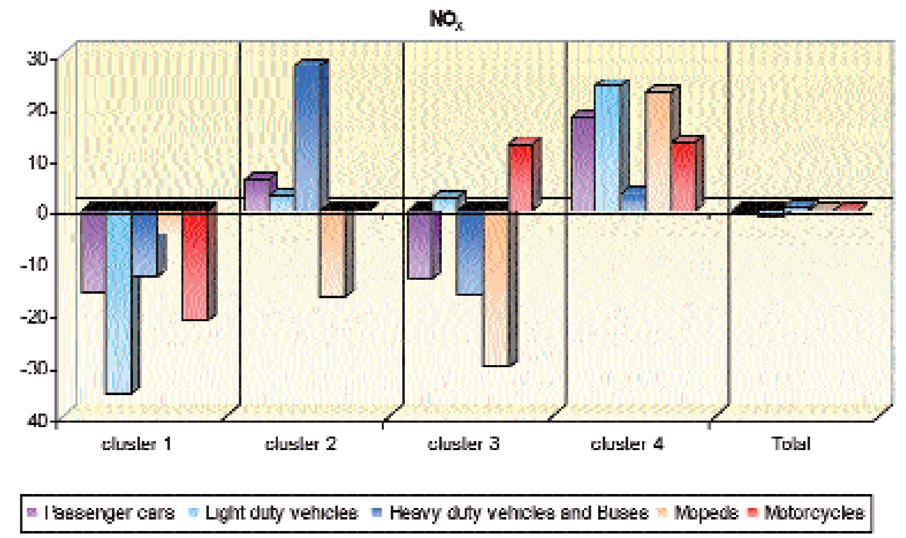


Figure n. 4.2: NMVOC emissions (4 clusters) for vehicle categories: deviation (%) from CORINAIR methodology estimates.

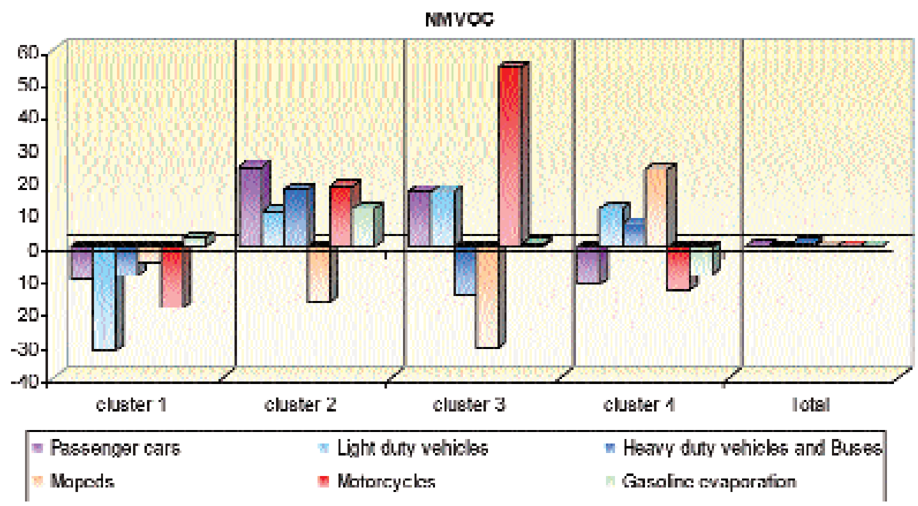


Figure n. 4.1: NO_x emissions (4 clusters) for vehicle categories: deviation (%) from CORINAIR methodology estimates.

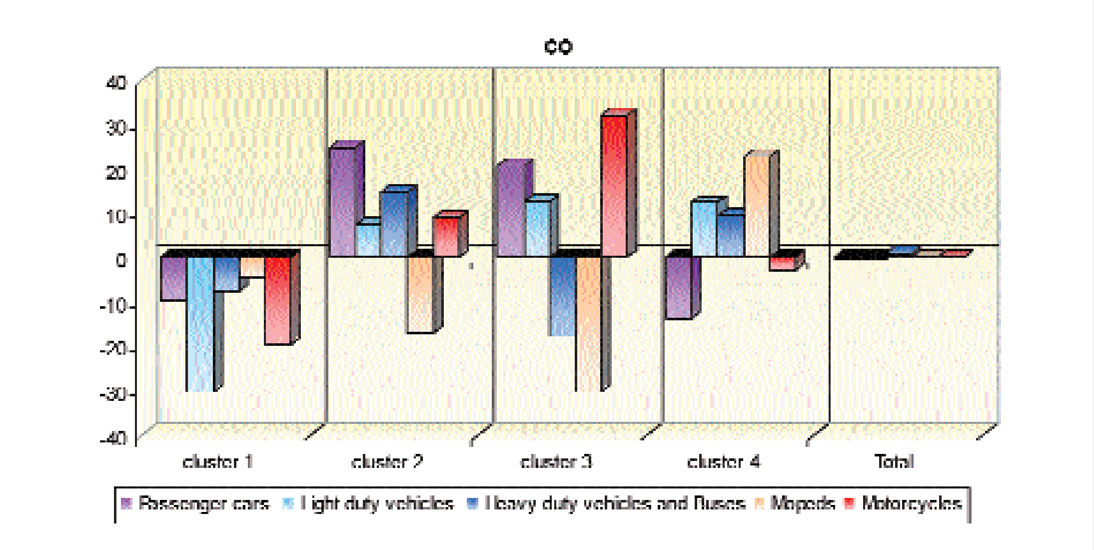


Figure n. 4.3: CO emissions (4 clusters) for vehicle categories: deviation (%) from CORINAIR methodology estimates.

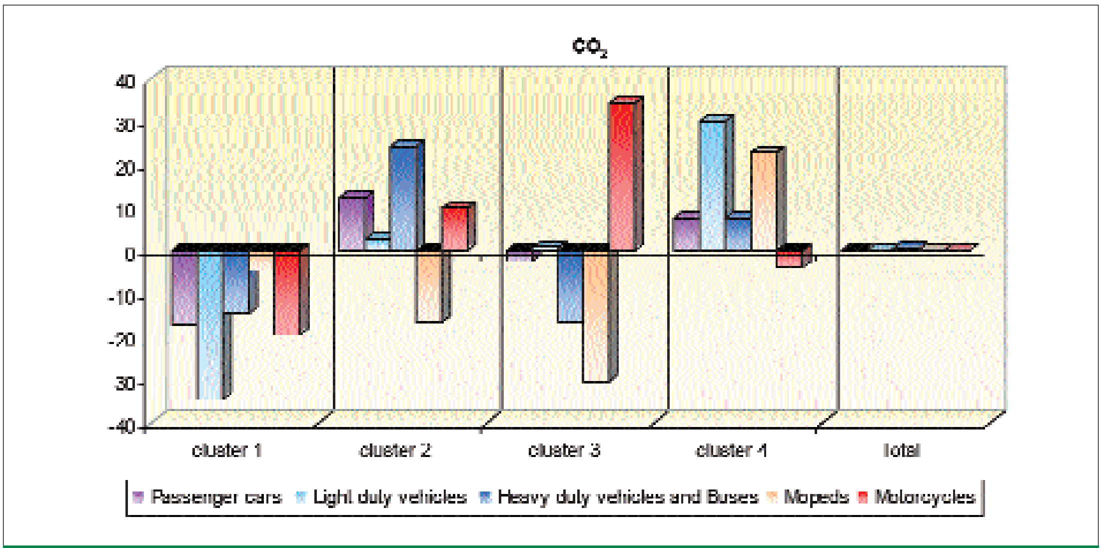


Figure n. 4.4: CO_2 emissions (4 clusters) for vehicle categories: deviation (%) from CORINAIR methodology estimates.

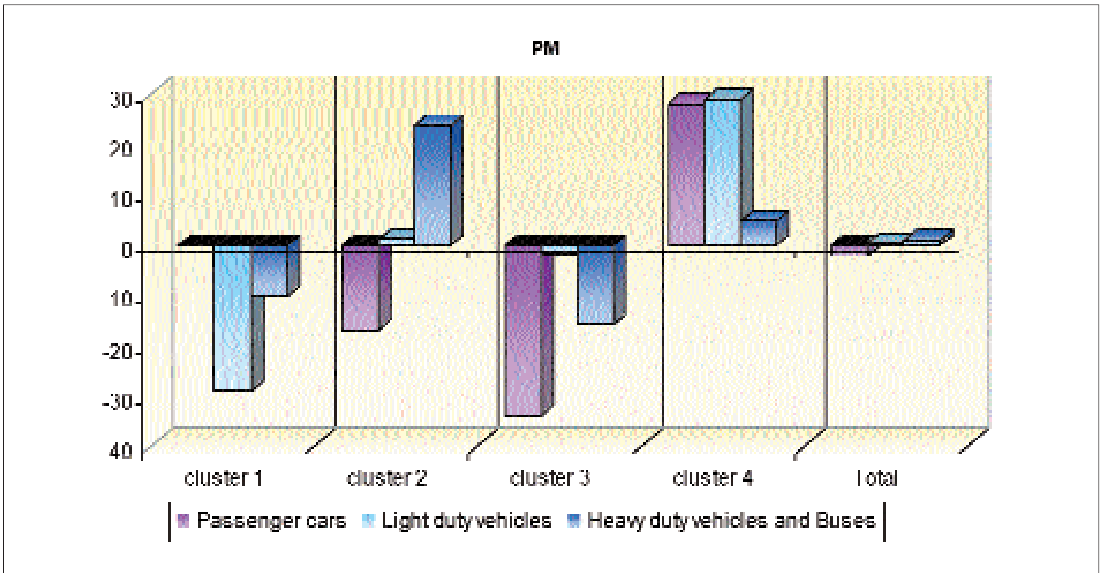


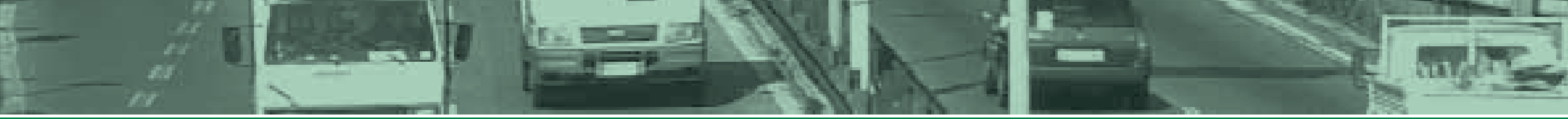
Figure n. 4.5: PM emissions (4 clusters) for vehicle categories: deviation (%) from CORINAIR methodology estimates.

Differences by vehicle sectors are significant at cluster level, reflecting particularities related to transport activities, while, for each pollutant, the deviation V_N^k observed at national level ("Total") is under the 1% threshold, in consequence only of model adjustments:

$$V_N^k = \frac{\sum_{c=1}^{4}\left[\tilde{e}_c^k - \sum_{i=1}^{m} e_i^k\right] - e_N^k}{e_N^k} \leq 0{,}01$$

Moreover for each cluster and pollutant, emissions per vehicle sector have also been calculated according to three different driving modes (urban, rural, highway).

Therefore variation index values (and the corresponding information) are also available with this more detailed split and the results are shown in figures from 4.6 to 4.25 with regard to all five pollutants emissions, for the different clusters.



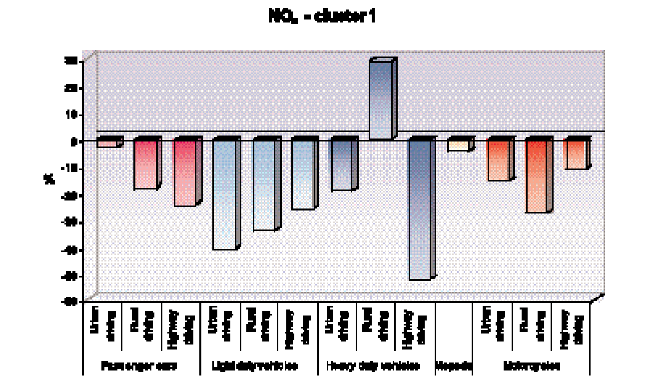


Figure n. 4.6: NO_x emissions (cluster 1; 33 provinces) for vehicle categories and driving mode: devation (%) from CORINAIR methodology estimates.

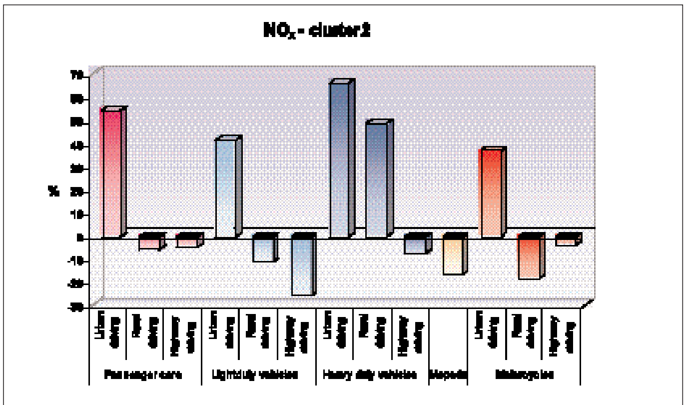


Figure n. 4.7: NO_x emissions (cluster 2; 29 provinces) for vehicle categories and driving mode: devation (%) from CORINAIR methodology estimates.

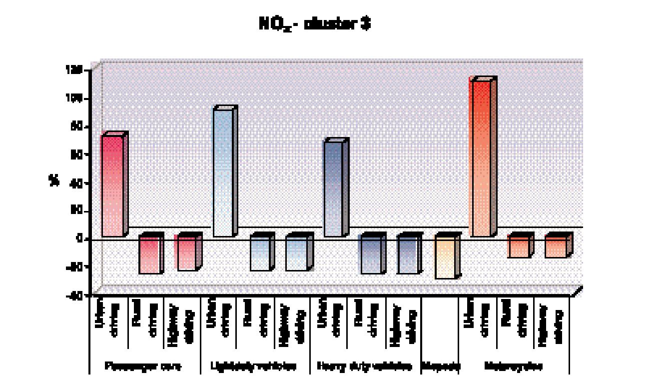


Figure n. 4.8: NO_x emissions (cluster 3; 26 provinces) for vehicle categories and driving mode: devation (%) from CORINAIR methodology estimates.

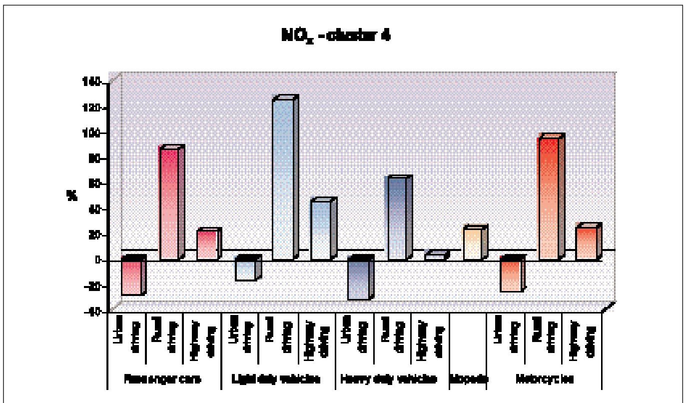


Figure n. 4.9: NO_x emissions (cluster 4; 15 provinces) for vehicle categories and driving mode: devation (%) from CORINAIR methodology estimates.

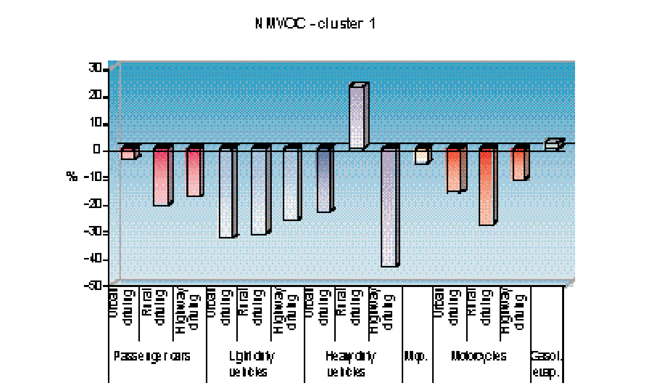


Figure n. 4.10: NMVOC emissions (cluster 1; 33 provinces) for vehicle categories and driving mode: devation (%) from CORINAIR methodology estimates.

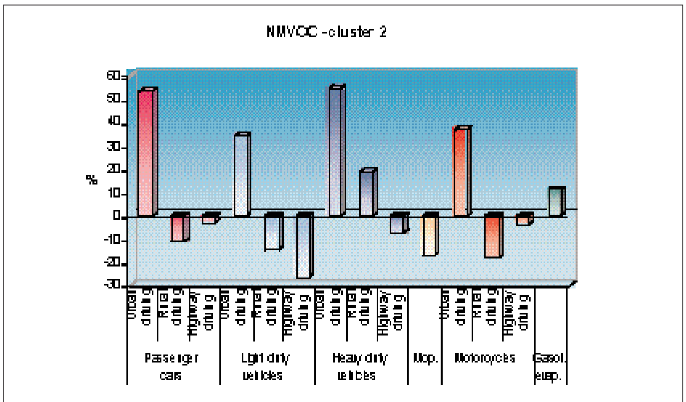
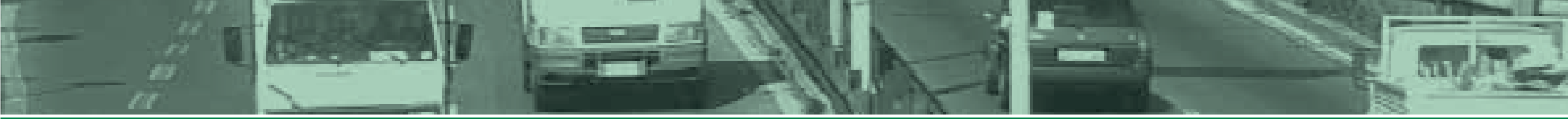


Figure n. 4.11: NMVOC emissions (cluster 2; 29 provinces) for vehicle categories and driving mode: devation (%) from CORINAIR methodology estimates.



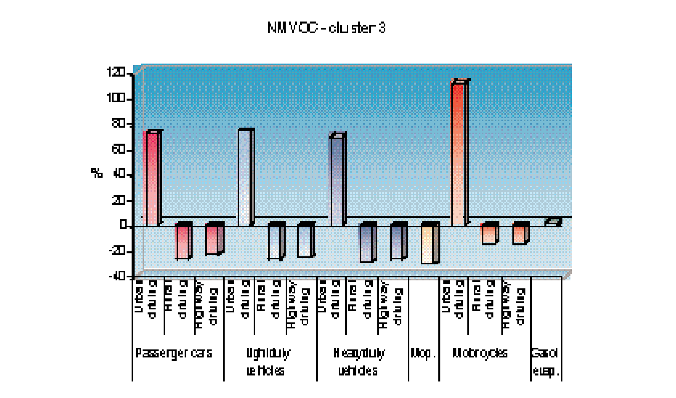


Figure n. 4.12: NMVOC emissions (cluster 3; 26 provinces) for vehicle categories and driving mode: devation (%) from CORINAIR methodology estimates.

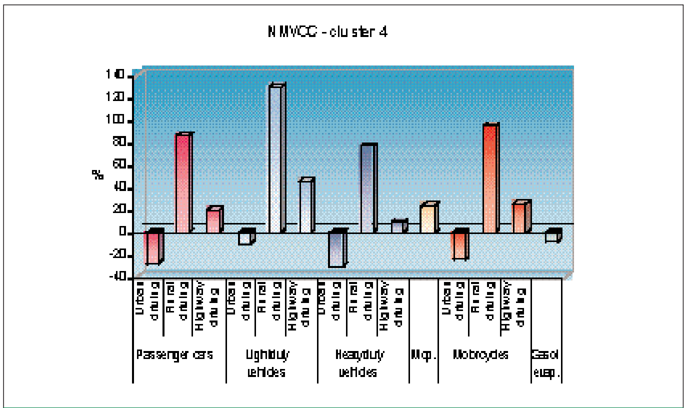


Figure n. 4.13: NMVOC emissions (cluster 4; 15 provinces) for vehicle categories and driving mode: devation (%) from CORINAIR methodology estimates.

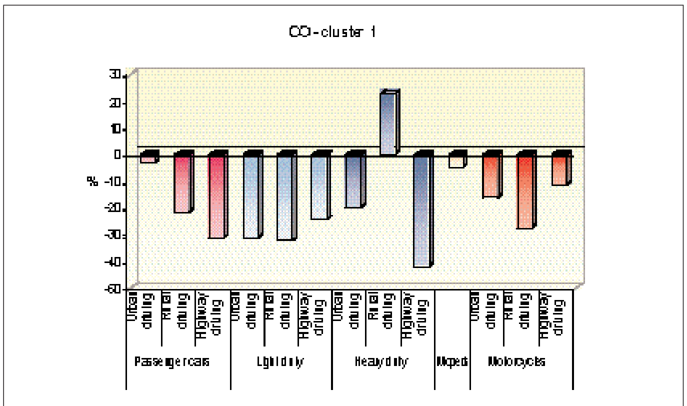


Figure n. 4.14: CO emissions (cluster 1; 33 provinces) for vehicle categories and driving mode: devation (%) from CORINAIR methodology estimates.

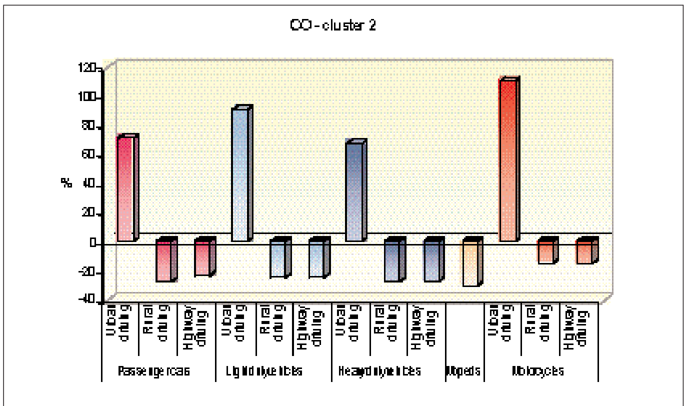


Figure n. 4.15: CO emissions (cluster 2; 29 provinces) for vehicle categories and driving mode: devation (%) from CORINAIR methodology estimates.

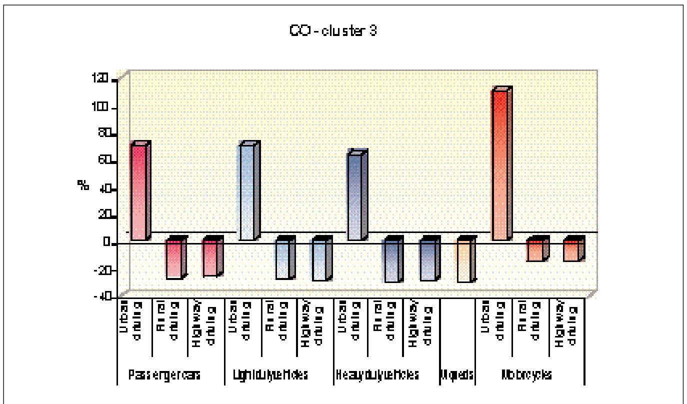


Figure n. 4.16: CO emissions (cluster 3; 26 provinces) for vehicle categories and driving mode: devation (%) from CORINAIR methodology estimates.

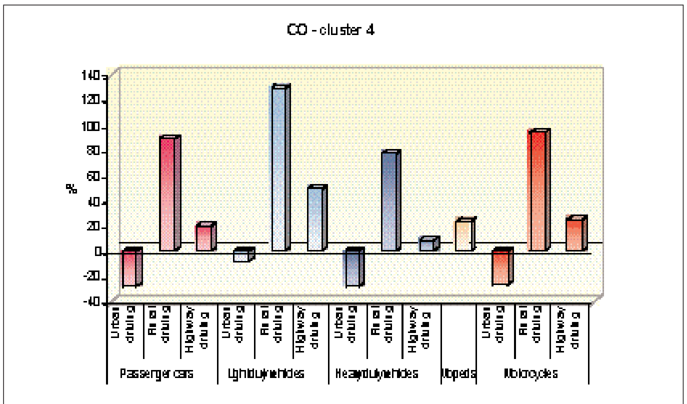
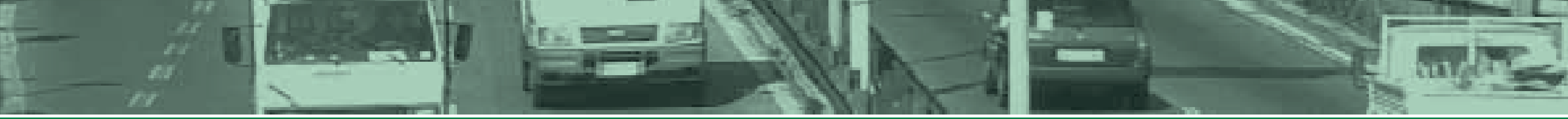


Figure n. 4.17: CO emissions (cluster 4; 15 provinces) for vehicle categories and driving mode: devation (%) from CORINAIR methodology estimates.



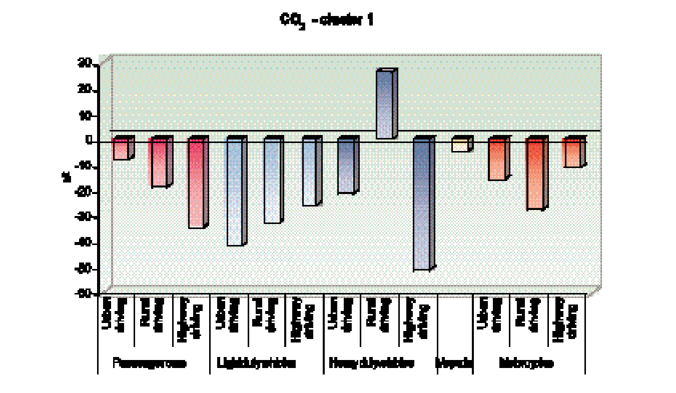


Figure n. 4.18: CO_2 emissions (cluster 1; 33 provinces) for vehicle categories and driving mode: devation (%) from CORINAIR methodology estimates.

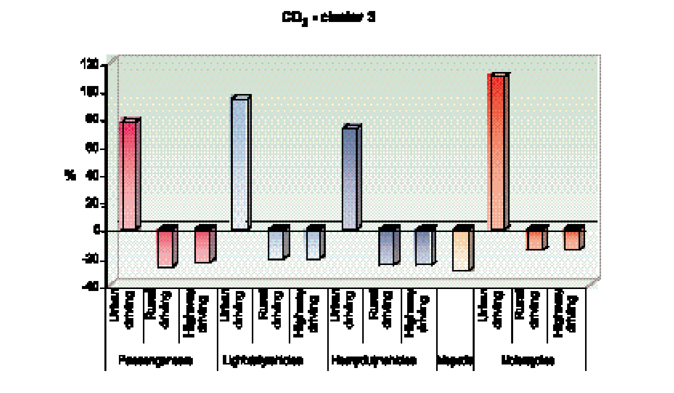


Figure n. 4.19: CO_2 emissions (cluster 2; 29 provinces) for vehicle categories and driving mode: devation (%) from CORINAIR methodology estimates.

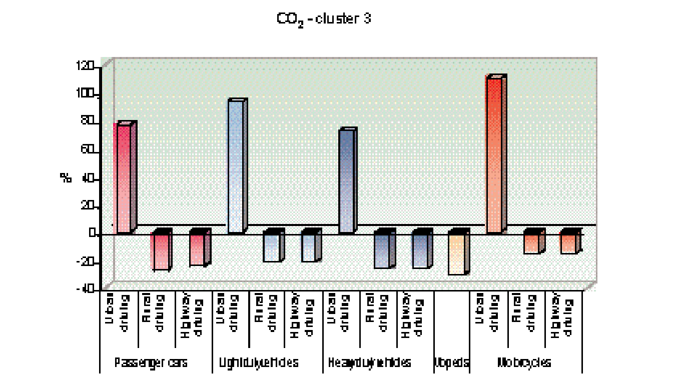


Figure n. 4.20: CO_2 emissions (cluster 3; 26 provinces) for vehicle categories and driving mode: devation (%) from CORINAIR methodology estimates.

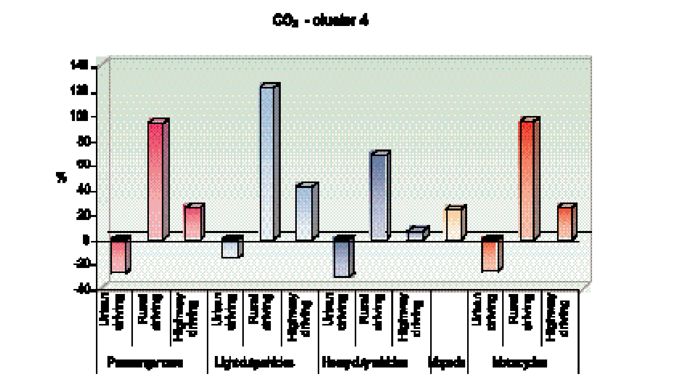


Figure n. 4.21: CO_2 emissions (cluster 4; 15 provinces) for vehicle categories and driving mode: devation (%) from CORINAIR methodology estimates.

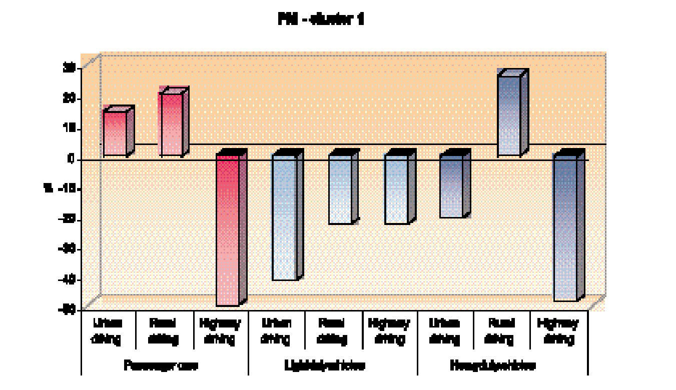


Figure n. 4.22: PM emissions (cluster 1; 33 provinces) for vehicle categories and driving mode: devation (%) from CORINAIR methodology estimates.

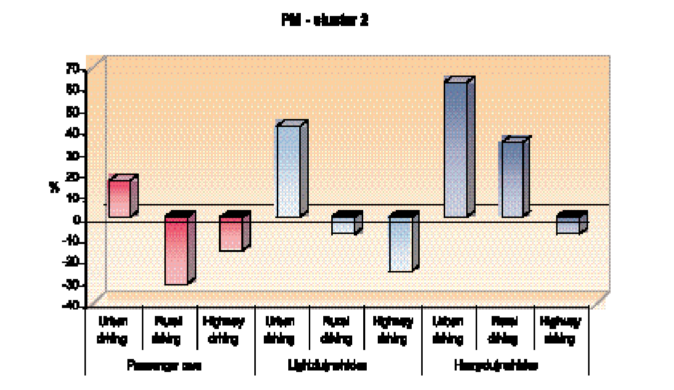
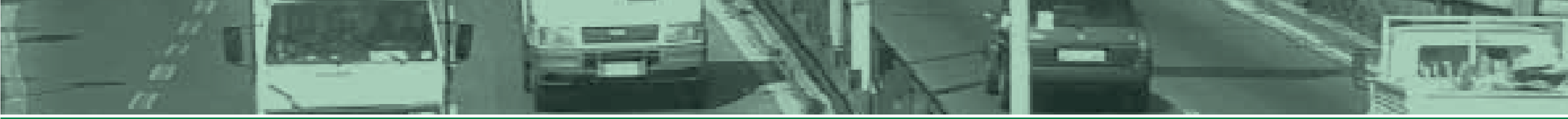


Figure n. 4.23: PM emissions (cluster 2; 29 provinces) for vehicle categories and driving mode: devation (%) from CORINAIR methodology estimates.



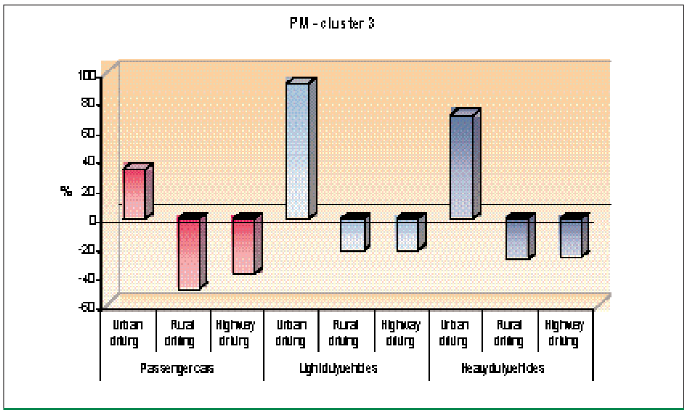


Figure n. 4.24: PM emissions (cluster 3; 26 provinces) for vehicle categories and driving mode: devation (%) from CORINAIR methodology estimates.

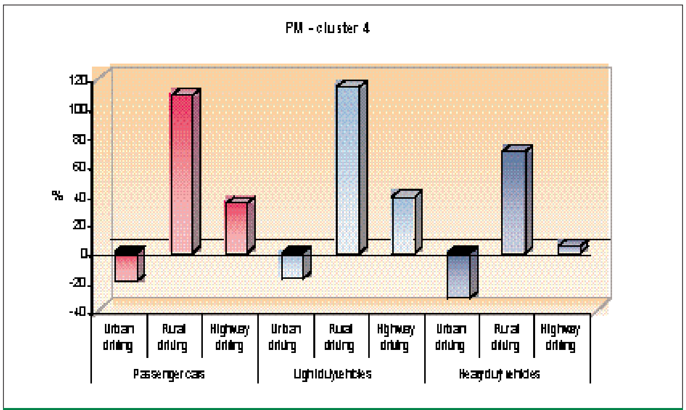


Figure n. 4.25: PM emissions (cluster 4; 15 provinces) for vehicle categories and driving mode: devation (%) from CORINAIR methodology estimates.

The subsequent step is to select urban areas, which are those with more than 20.000 inhabitants, and estimate road transport emissions at local scale. In this case-study, only urban areas with more than 40.000 inhabitants (in all 186 areas) have been considered in order to simplify the application of the methodology.

For each province of the cluster, the quota of urban emissions of five pollutants (NO_x, NMVOC, CO, CO_2, PM) has been allocated via the population living in each urban area as well as total NMVOC evaporative emissions from gasoline vehicles.

The results for all 186 urban areas are shown in Table 4.2, where NMVOC emissions data include the evaporative quota.

The information provided by the estimates is shown in the figures from 4.26 to 4.45 with regard to all five pollutants emissions, for the different clusters. For each cluster, urban areas in evidence cover the 25° percentile value.

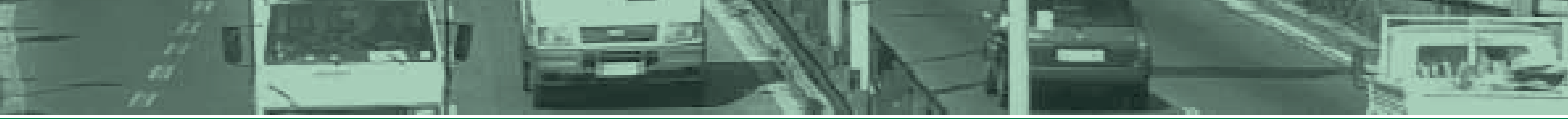


Table n. 4.2: Emissions (tons) in Italian urban areas with more than 40.000 inhabitants in 1996.

Cluster	Urban Area	Province	NO_x (t)	NMVOC (t)	CO (t)	CO_2 (t)	PM (t)
I	Acireale	Catania	355	1.144	5.714	56.469	18
I	Agrigento	Agrigento	384	1.253	6.186	61.128	20
I	Alcamo	Trapani	298	934	4.806	47.496	15
I	Alghero	Sassari	277	971	4.471	44.185	14
I	Altamura	Bari	421	1.228	6.788	67.073	21
I	Andria	Bari	639	1.862	10.293	101.711	33
I	Aprilia	Latina	381	1.194	6.135	60.625	19
I	Avellino	Avellino	385	1.781	6.206	61.329	20
I	Aversa	Caserta	375	1.436	6.051	59.792	19
I	Barcellona Pozzo di Gotto	Messina	285	995	4.588	45.336	14
I	Bari	Bari	2.306	6.725	37.174	367.343	117
I	Barletta	Bari	624	1.820	10.063	99.435	32
I	Battipaglia	Salerno	347	1.164	5.598	55.321	18
I	Benevento	Benevento	437	1.907	7.047	69.641	22
I	Bisceglie	Bari	344	1.005	5.553	54.871	18
I	Bitonto	Bari	388	1.130	6.249	61.747	20
I	Brindisi	Brindisi	651	2.016	10.499	103.751	33
I	Cagliari	Cagliari	1.198	4.097	19.304	190.757	61
I	Caltanissetta	Caltanissetta	432	1.328	6.969	68.868	22
I	Campobasso	Campobasso	356	1.279	5.745	56.768	18
I	Caserta	Caserta	502	1.922	8.097	80.015	26
I	Catania	Catania	2.348	7.579	37.844	373.963	120
I	Catanzaro	Catanzaro	668	2.291	10.773	106.458	34
I	Cava de' Tirreni	Salerno	366	1.228	5.906	58.360	19
I	Cerignola	Foggia	385	1.163	6.201	61.273	20
I	Corato	Bari	308	897	4.957	48.983	16
I	Cosenza	Cosenza	531	2.003	8.560	84.591	27
I	Crotone	Crotone	410	1.467	6.610	65.316	21
I	Foggia	Foggia	1.075	3.249	17.323	171.182	55
I	Frosinone	Frosinone	318	1.208	5.125	50.646	16
I	Gela	Caltanissetta	526	1.616	8.481	83.805	27
I	Gravina in Puglia	Bari	280	816	4.509	44.555	14
I	L'Aquila	Catanzaro	476	1.673	7.673	75.824	24
I	Lamezia Terme	L'Aquila	492	1.685	7.924	78.301	25
I	Latina	Latina	768	2.408	12.378	122.311	39
I	Lecce	Lecce	686	2.870	11.057	109.261	35
I	Licata	Agrigento	282	921	4.548	44.938	14
I	Manfredonia	Foggia	400	1.210	6.452	63.755	20
I	Marsala	Trapani	555	1.737	8.939	88.335	28
I	Martina Franca	Taranto	320	983	5.160	50.991	16
I	Matera	Matera	386	1.500	6.229	61.555	20
I	Mazara del Vallo	Trapani	358	1.121	5.767	56.989	18
I	Messina	Messina	1.803	6.303	29.063	287.189	92
I	Misterbianco	Catania	307	992	4.954	48.950	16
I	Modica	Ragusa	356	1.091	5.742	56.739	18

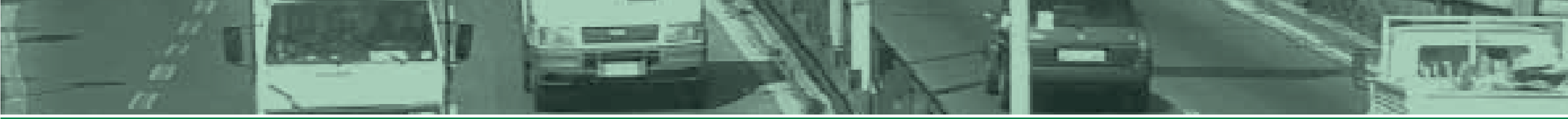


Table n. 4.2 *(continued)*

Cluster	Urban Area	Province	NO_x (t)	NMVOC (t)	CO (t)	CO_2 (t)	PM (t)
1	Molfetta	Bari	452	1.317	7.280	71.942	23
1	Monopoli	Bari	332	968	5.352	52.887	17
1	Nocera Inferiore	Salerno	336	1.127	5.420	53.557	17
1	Olbia	Sassari	301	1.055	4.856	47.984	15
1	Paterno'	Catania	318	1.028	5.132	50.713	16
1	Potenza	Potenza	455	2.226	7.330	72.428	23
1	Quartu Sant'Elena	Cagliari	462	1.581	7.449	73.608	24
1	Ragusa	Ragusa	477	1.461	7.691	75.995	24
1	Reggio di Calabria	Reggio di Calabria	1.238	4.867	19.953	197.174	63
1	Salerno	Salerno	988	3.313	15.932	157.437	50
1	San Severo	Foggia	381	1.151	6.140	60.670	19
1	Sassari	Sassari	835	2.923	13.456	132.971	43
1	Scafati	Salerno	316	1.059	5.093	50.325	16
1	Siracusa	Siracusa	875	2.724	14.100	139.336	45
1	Taranto	Taranto	1.455	4.469	23.459	231.811	74
1	Trani	Bari	364	1.062	5.868	57.981	19
1	Trapani	Trapani	479	1.500	7.721	76.296	24
1	Vittoria	Ragusa	405	1.241	6.529	64.517	21
2	Ancona	Ancona	1.210	2.902	16.662	188.498	59
2	Arezzo	Arezzo	1.106	3.005	15.226	172.256	54
2	Ascoli Piceno	Ascoli Piceno	637	1.659	8.765	99.164	31
2	Asti	Asti	895	2.590	12.322	139.406	43
2	Brescia	Brescia	2.309	7.988	31.792	359.673	112
2	Carpi	Modena	734	1.816	10.110	114.373	36
2	Carrara	Massa	805	1.870	11.092	125.483	39
2	Cesena	Forlì	1.088	2.601	14.980	169.470	53
2	Chieti	Chieti	693	1.732	9.547	108.004	34
2	Cuneo	Cuneo	667	2.097	9.183	103.886	32
2	Faenza	Ravenna	651	1.511	8.962	101.395	31
2	Fano	Pesaro	671	1.796	9.241	104.551	32
2	Ferrara	Ferrara	1.634	3.875	22.499	254.539	79
2	Foligno	Perugia	644	1.592	8.868	100.326	31
2	Forli'	Forlì	1.312	3.137	18.064	204.369	63
2	Grosseto	Grosseto	878	2.356	12.089	136.770	42
2	Macerata	Macerata	514	1.580	7.080	80.097	25
2	Mantova	Mantova	603	2.711	8.304	93.941	29
2	Massa	Massa	828	1.923	11.406	129.039	40
2	Modena	Modena	2.131	5.269	29.339	331.920	103
2	Padova	Padova	2.586	8.301	35.608	402.840	125
2	Parma	Parma	2.038	5.172	28.062	317.477	99
2	Perugia	Perugia	1.865	4.611	25.687	290.605	90
2	Pesaro	Pesaro	1.071	2.866	14.749	166.858	52
2	Pescara	Pescara	1.435	3.475	19.762	223.569	69
2	Piacenza	Piacenza	1.213	3.353	16.697	188.899	59

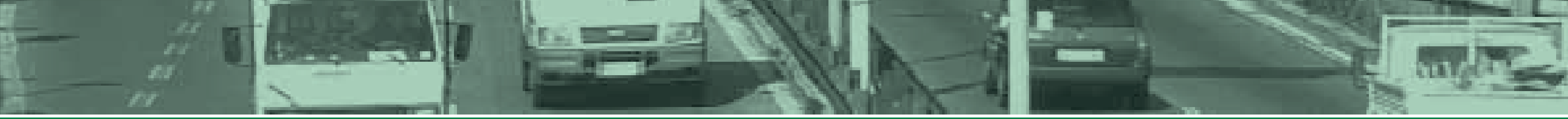


Table n. 4.2 *(continued)*

Cluster	Urban Area	Province	NO_x (t)	NMVOC (t)	CO (t)	CO_2 (t)	PM (t)
2	Ravenna	Ravenna	1.671	3.879	23.008	260.301	81
2	Reggio nell'Emilia	Reggio nell'Emilia	1.670	4.556	22.992	260.121	81
2	Rieti	Rieti	558	1.619	7.688	86.977	27
2	Rovigo	Rovigo	620	1.731	8.538	96.590	30
2	San Benedetto del Tronto	Ascoli Piceno	545	1.419	7.500	84.845	26
2	Sassuolo	Modena	495	1.223	6.812	77.068	24
2	Senigallia	Ancona	507	1.215	6.976	78.926	25
2	Teramo	Teramo	635	1.756	8.747	98.960	31
2	Treviso	Treviso	988	2.983	13.612	153.997	48
2	Verona	Verona	3.096	8.387	42.640	482.403	150
2	Vicenza	Vicenza	1.317	3.790	18.140	205.230	64
2	Viterbo	Viterbo	736	2.604	10.133	114.642	36
3	Alessandria	Alessandria	1.222	2.872	17.616	199.285	62
3	Bergamo	Bergamo	1.572	5.346	22.666	256.421	80
3	Biella	Biella	645	2.058	9.296	105.158	33
3	Bolzano	Bolzano	1.300	3.528	18.751	212.126	66
3	Busto Arsizio	Varese	1.040	2.898	14.997	169.653	53
3	Capannori	Lucca	589	1.333	8.487	96.008	30
3	Como	Como	1.129	3.703	16.287	184.247	58
3	Cremona	Cremona	970	2.572	13.991	158.275	49
3	Gallarate	Varese	616	1.717	8.888	100.546	31
3	Imperia	Imperia	544	1.285	7.846	88.761	28
3	Lecco	Lecco	609	2.338	8.777	99.295	31
3	Lodi	Lodi	565	1.668	8.154	92.245	29
3	Lucca	Lucca	1.150	2.605	16.579	187.551	59
3	Novara	Novara	1.374	3.915	19.807	224.071	70
3	Pavia	Pavia	1.002	2.621	14.448	163.443	51
3	Pisa	Pisa	1.256	2.962	18.109	204.867	64
3	Pistoia	Pistoia	1.157	2.816	16.690	188.809	59
3	Pordenone	Pordenone	652	2.289	9.397	106.303	33
3	San Remo	Imperia	755	1.783	10.892	123.223	38
3	Savona	Savona	861	2.439	12.418	140.482	44
3	Siena	Siena	737	2.069	10.624	120.190	38
3	Trento	Trento	1.388	3.846	20.013	226.403	71
3	Udine	Udine	1.276	4.530	18.393	208.076	65
3	Varese	Varese	1.134	3.159	16.347	184.931	58
3	Vercelli	Vercelli	649	1.929	9.356	105.848	33
3	Viareggio	Lucca	779	1.764	11.231	127.054	40
3	Vigevano	Pavia	804	2.104	11.595	131.170	41
3	Voghera	Pavia	542	1.418	7.818	88.444	28
4	Acerra	Napoli	242	842	3.868	40.832	14
4	Afragola	Napoli	341	1.185	5.448	57.509	19
4	Anzio	Roma	226	798	3.606	38.069	13
4	Arzano	Napoli	227	787	3.616	38.171	13

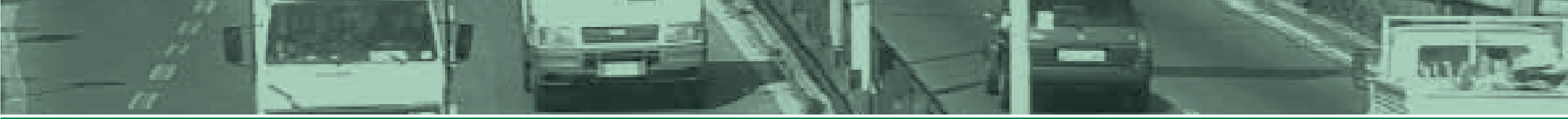


Table n. 4.2 *(continued)*

Cluster	Urban Area	Province	NO_x (t)	NMVOC (t)	CO (t)	CO_2 (t)	PM (t)
4	Bagheria	Palermo	297	1.069	4.735	49.985	17
4	Bollate	Milano	252	944	4.028	42.515	14
4	Bologna	Bologna	2.147	8.308	34.251	361.542	121
4	Casalnuovo di Napoli	Napoli	239	829	3.809	40.210	13
4	Casoria	Napoli	468	1.625	7.472	78.869	26
4	Castellammare di Stabia	Napoli	371	1.290	5.928	62.570	21
4	Chioggia	Venezia	294	1.054	4.684	49.438	16
4	Cinisello Balsamo	Milano	422	1.577	6.726	70.998	24
4	Civitavecchia	Roma	287	1.014	4.586	48.409	16
4	Collegno	Torino	265	1.021	4.229	44.635	15
4	Cologno Monzese	Milano	279	1.045	4.457	47.050	16
4	Empoli	Firenze	242	927	3.861	40.752	14
4	Ercolano	Napoli	330	1.144	5.258	55.501	19
4	Firenze	Firenze	2.118	8.120	33.799	356.775	119
4	Fiumicino	Roma	275	972	4.395	46.391	15
4	Genova	Genova	3.642	13.144	58.120	613.492	205
4	Giugliano in Campania	Napoli	469	1.627	7.480	78.953	26
4	Grugliasco	Torino	227	876	3.628	38.298	13
4	Guidonia Montecelio	Roma	359	1.268	5.732	60.507	20
4	Imola	Bologna	356	1.377	5.676	59.915	20
4	La Spezia	La Spezia	545	2.137	8.690	91.726	31
4	Legnano	Milano	297	1.112	4.743	50.065	17
4	Livorno	Livorno	914	3.333	14.580	153.906	51
4	Marano di Napoli	Napoli	312	1.083	4.976	52.529	18
4	Milano	Milano	7.267	27.188	115.961	1.224.044	408
4	Moncalieri	Torino	326	1.255	5.200	54.893	18
4	Monza	Milano	664	2.485	10.600	111.895	37
4	Napoli	Napoli	5.829	20.235	93.012	981.802	328
4	Nichelino	Torino	252	970	4.020	42.435	14
4	Paderno Dugnano	Milano	249	933	3.980	42.007	14
4	Palermo	Palermo	3.834	13.810	61.173	645.716	215
4	Pomezia	Roma	236	835	3.773	39.824	13
4	Pomigliano d'Arco	Napoli	238	825	3.794	40.043	13
4	Portici	Napoli	354	1.227	5.642	59.551	20
4	Pozzuoli	Napoli	450	1.562	7.179	75.774	25
4	Prato	Prato	941	3.468	15.020	158.545	53
4	Rho	Milano	289	1.082	4.613	48.692	16
4	Rimini	Rimini	722	2.784	11.525	121.657	41
4	Rivoli	Torino	292	1.126	4.664	49.234	16

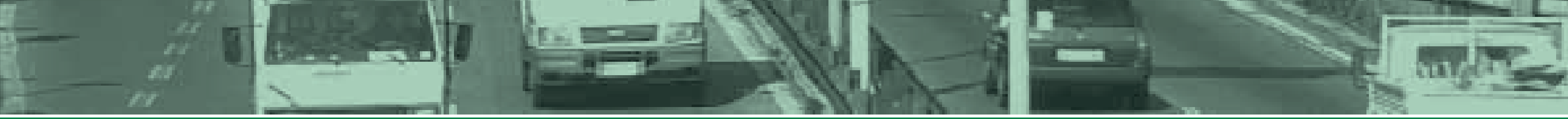


Table n. 4.2 *(continued)*

Cluster	Urban Area	Province	NO_x (t)	NMVOC (t)	CO (t)	CO_2 (t)	PM (t)
4	Roma	Roma	14.744	52.040	235.255	2.483.264	829
4	San Giorgio a Cremano	Napoli	337	1.170	5.376	56.747	19
4	Scandicci	Firenze	287	1.099	4.576	48.301	16
4	Sesto Fiorentino	Firenze	263	1.007	4.193	44.261	15
4	Sesto San Giovanni	Milano	464	1.736	7.405	78.159	26
4	Settimo Torinese	Torino	266	1.024	4.243	44.782	15
4	Terni	Terni	604	2.244	9.643	101.789	34
4	Tivoli	Roma	293	1.035	4.677	49.374	16
4	Torino	Torino	5.125	19.740	81.783	863.275	288
4	Torre Annunziata	Napoli	274	951	4.370	46.124	15
4	Torre del Greco	Napoli	543	1.885	8.665	91.469	31
4	Trieste	Trieste	1.235	4.424	19.703	207.978	69
4	Velletri	Roma	270	953	4.309	45.487	15
4	Venezia	Venezia	1.652	5.931	26.362	278.263	93

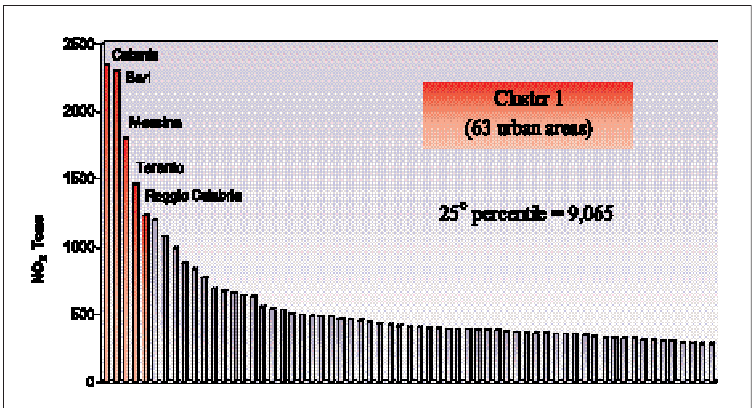


Figure n. 4.26: NO_x emissions (tons) in urbans areas of Cluster 1 in 1996.

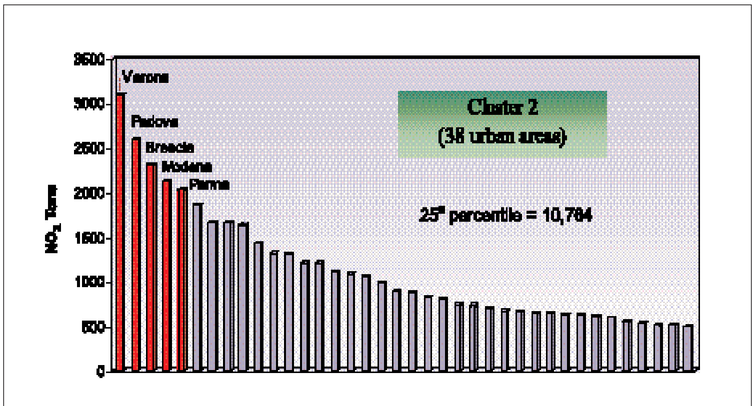


Figure n. 4.27: NO_x emissions (tons) in urbans areas of Cluster 2 in 1996.

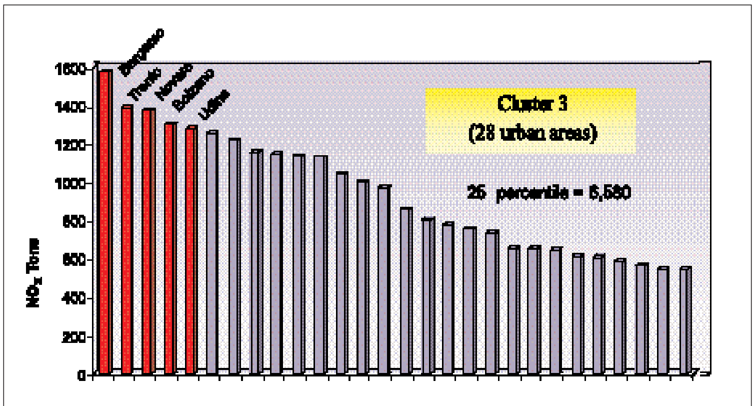


Figure n. 4.28: NO_x emissions (tons) in urbans areas of Cluster 3 in 1996.

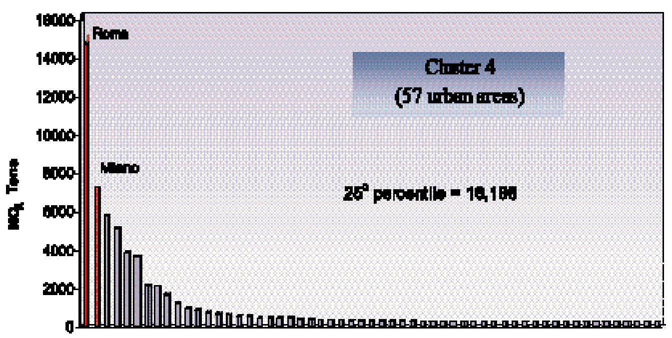


Figure n. 4.29: NO_x emissions (tons) in urbans areas of Cluster 4 in 1996.

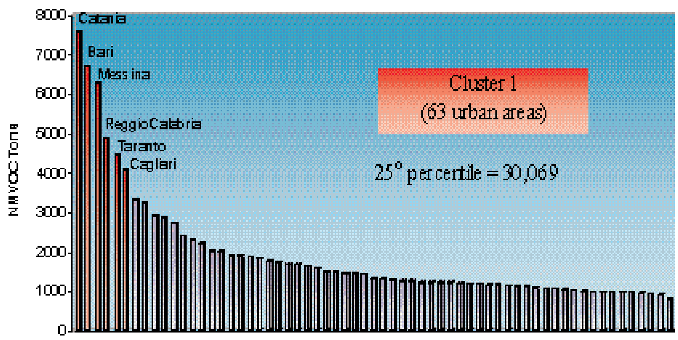


Figure n. 4.30: NMVOV emissions (tons) in urbans areas of Cluster 1 in 1996.

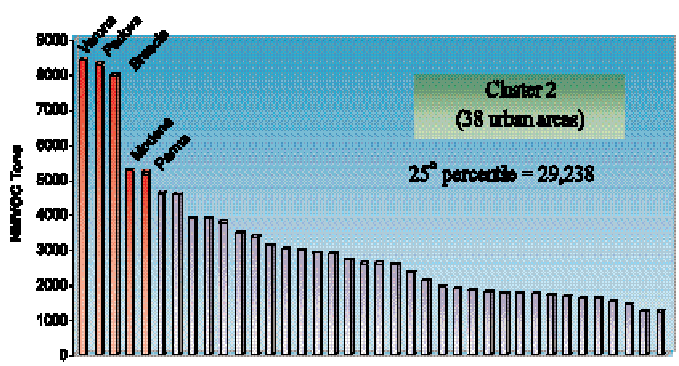
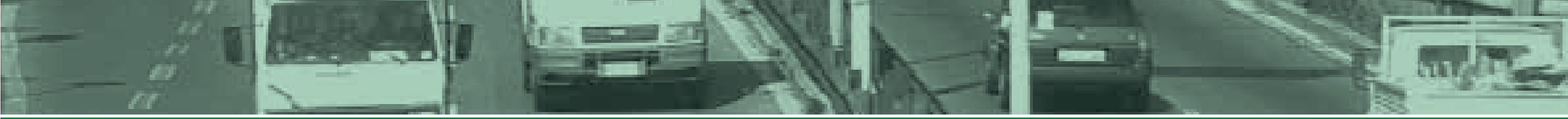


Figure n. 4.31: NMVOV emissions (tons) in urbans areas of Cluster 2 in 1996.



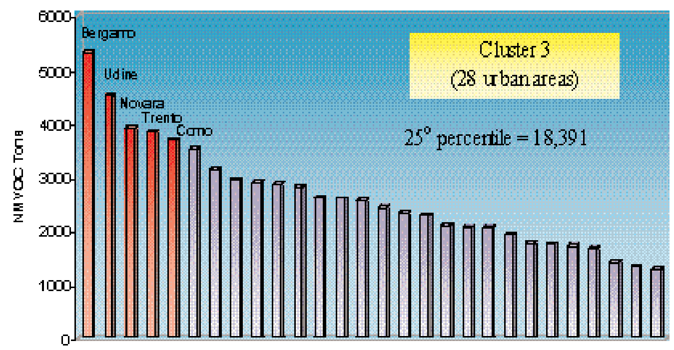


Figure n. 4.32: NMVOC emissions (tons) in urbans areas of Cluster 3 in 1996.

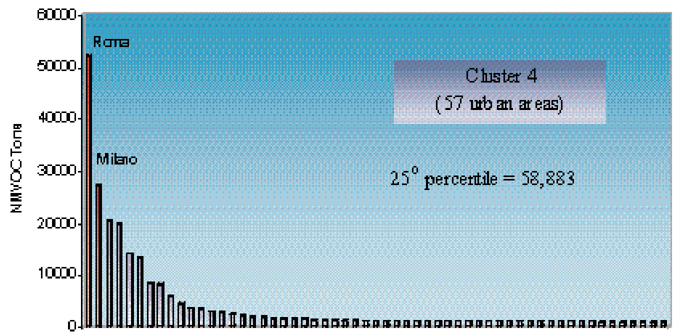


Figure n. 4.33: NMVOC emissions (tons) in urbans areas of Cluster 4 in 1996.

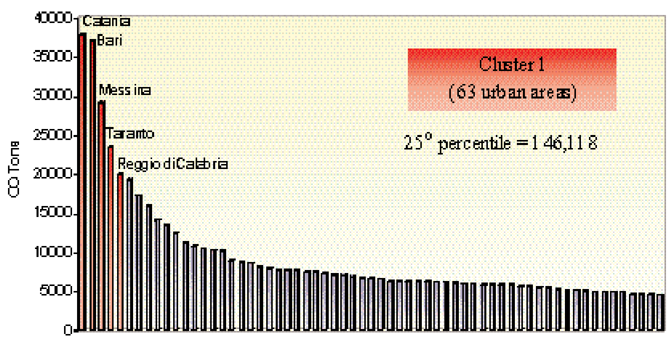
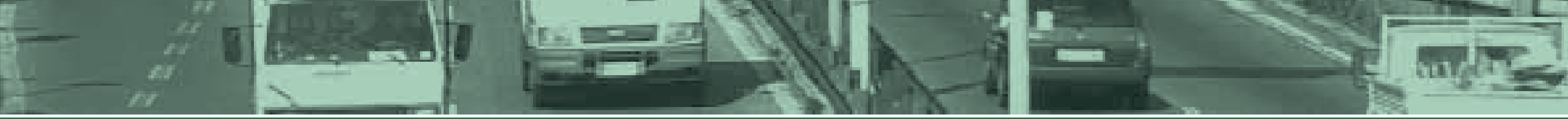


Figure n. 4.34: CO emissions (tons) in urbans areas of Cluster 1 in 1996.



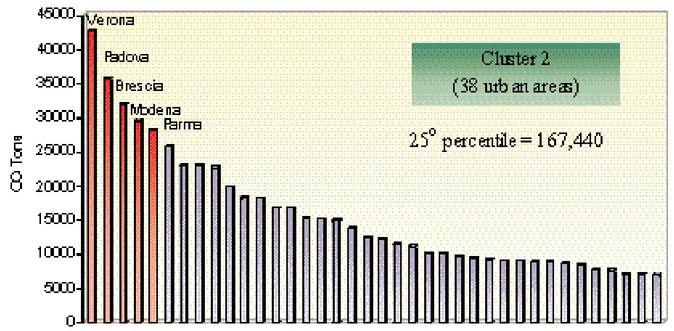


Figure n. 4.35: CO emissions (tons) in urbans areas of Cluster 2 in 1996.

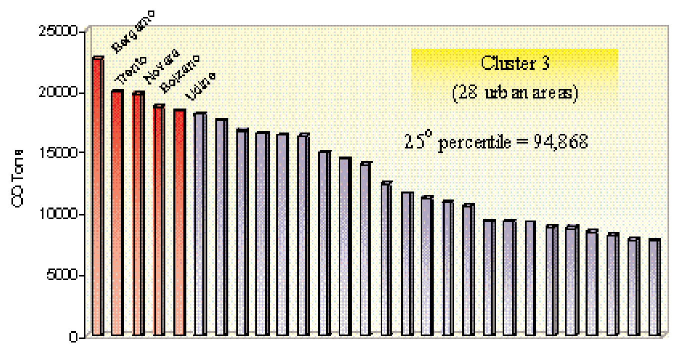


Figure n. 4.36: CO emissions (tons) in urbans areas of Cluster 3 in 1996.

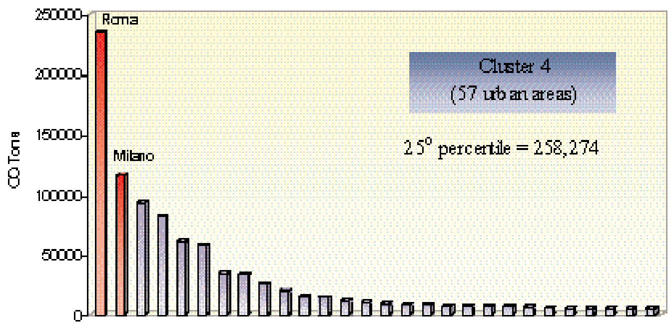


Figure n. 4.37: CO emissions (tons) in urbans areas of Cluster 4 in 1996.

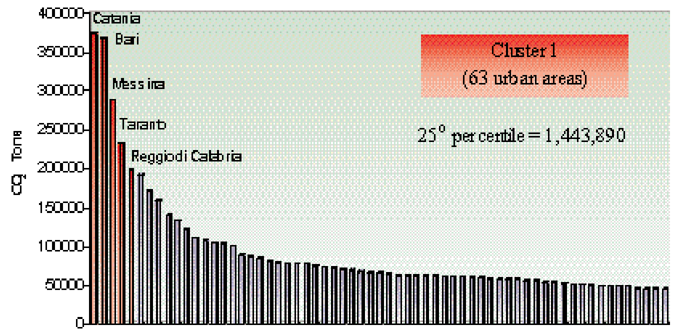


Figure n. 4.38: CO_2 emissions (tons) in urbans areas of Cluster 1 in 1996.

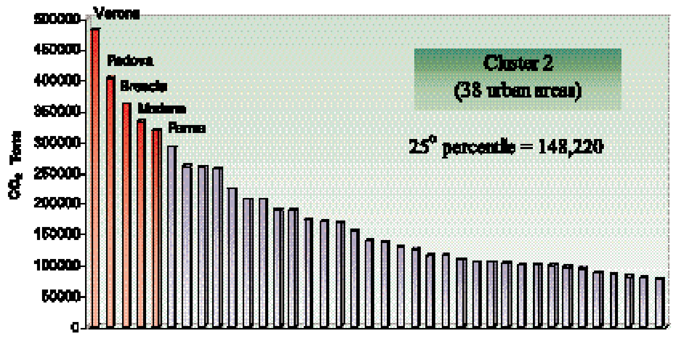


Figure n. 4.39: CO_2 emissions (tons) in urbans areas of Cluster 2 in 1996.

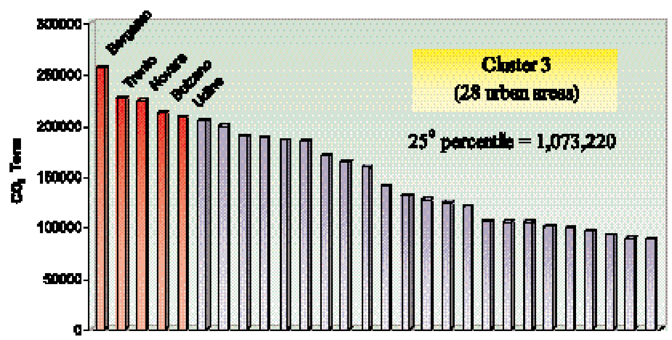
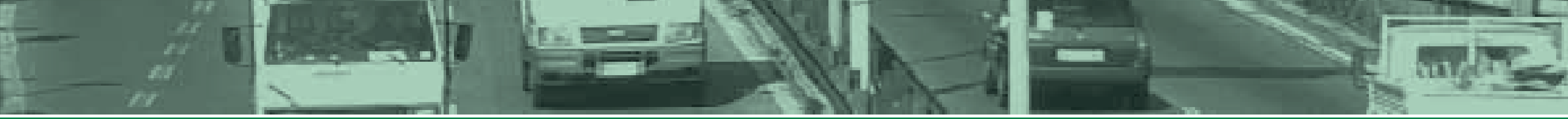


Figure n. 4.40: CO_2 emissions (tons) in urbans areas of Cluster 3 in 1996.



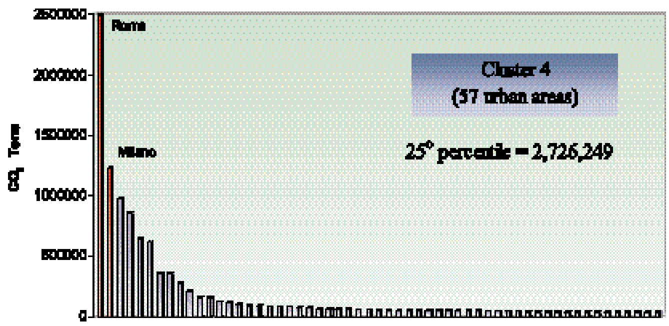


Figure n. 4.41: CO_2 emissions (tons) in urbans areas of Cluster 4 in 1996.

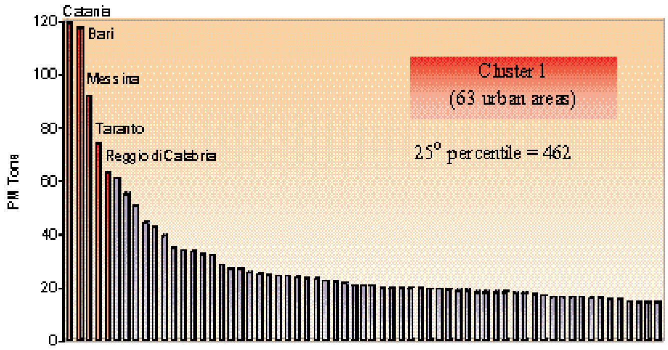


Figure n. 4.42: PM emissions (tons) in urbans areas of Cluster 1 in 1996.

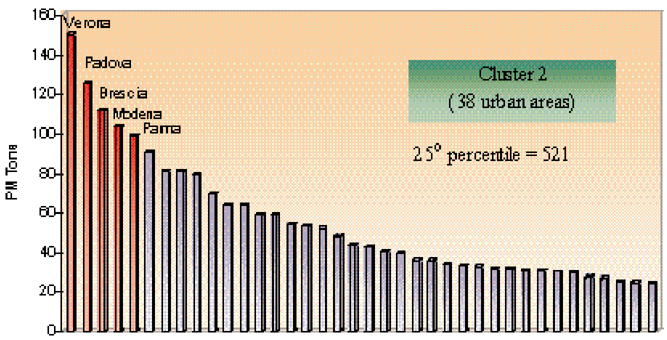


Figure n. 4.43: PM emissions (tons) in urbans areas of Cluster 2 in 1996.

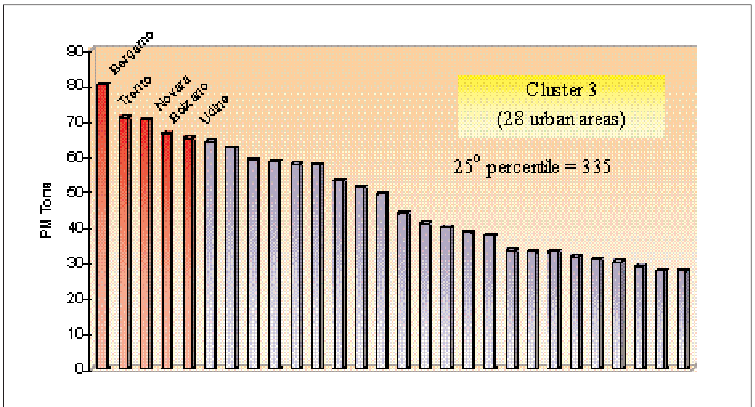


Figure n. 4.44: PM emissions (tons) in urbans areas of Cluster 3 in 1996.

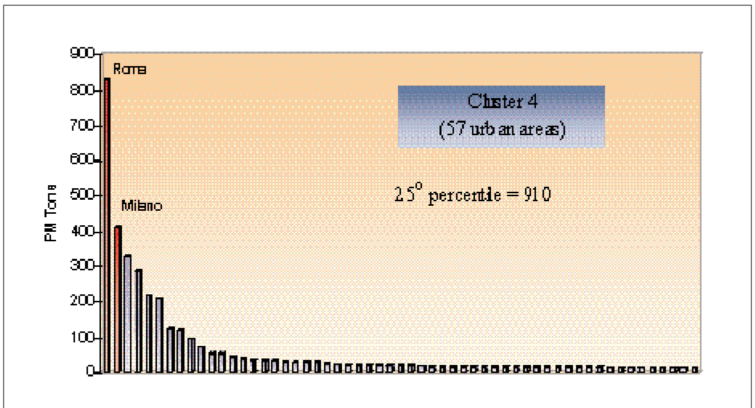
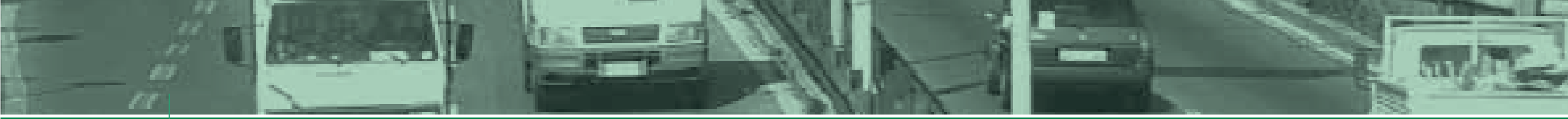


Figure n. 4.45: PM emissions (tons) in urbans areas of Cluster 4 in 1996.



5. Conclusion

In this work the issue of the top-down approach for the estimation of local road transport emissions from estimates at national level has been analysed.

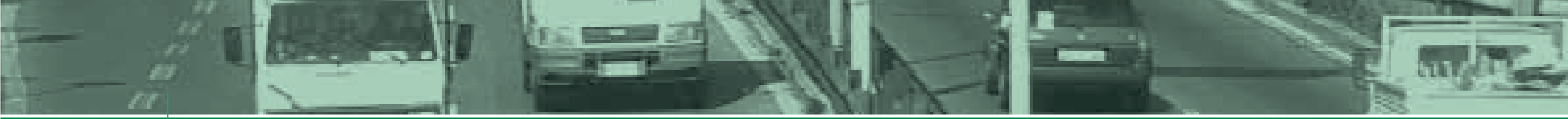
A new methodology that takes into account local particularities and information has been proposed and applied to Italian provinces.

By means of a set of indicators related to transport activities, four homogeneous areas have been identified. Information provided by the cluster analysis results allows the local characterization and differentiation of COPERT emission estimates consistent with the national total estimates.

A variation index has been calculated for each of the four areas and used to correct standard CORINAIR emissions for provinces within the same cluster.

Therefore, urban emissions have been estimated from provincial ones by means of population as proxy variable.

Further study will complete the methodological aspects, regarding the estimation of emissions in rural areas and highways, for a detailed characterisation of road transport pollution at local level.



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