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9G 0. EXECUTIVE SUMMARY

- The aim of this study is to provide a methodological framework for the evaluation of environmental marginal external costs in the city of Florence. The city of Florence, about 380,000 inhabitants in 1999, over the past 10 years has followed a path similar to several western cities belonging to the industrialised world: population falling, increase of urban sprawl and further modification of demographic composition, in particular through the progressive ageing of population and the percentage growth of households with one membership.

- In this study, the environmental marginal costs of air pollution, and noises are analysed, with the aim to assess their impacts on human health. The marginal impacts of air pollutants on natural environment, i.e. agriculture, water availability, are considered negligible in the Florence urban context. The marginal impacts on building materials are not estimated due to the paucity of data and local case studies. Global warming impacts are estimated with limitations, due to the unavailability of specific case studies[1]. In the context of the city of Florence, road transport is the transport mode to be dealt with, since rail transport is negligible. In fact, the provision for the city of Florence of tram network and rail services is only at the initial stage.

- The implementation in an urban context of the well-established Impact Pathway Approach (IPA) methodology for the quantification and estimation of environmental marginal external costs has to cope with a series of drawbacks: from the difficulties of implementation, due to the huge number of variables to be accounted for, to the extreme density of the receptors (human, materials), which could undermine the reliability of the final results. Furthermore, the use of dispersion models is made problematic by the complexity of urban topology.

- In order to cope with such drawbacks, a methodological departure from the traditional implementation of IPA has been proposed. With reference to air pollution, it basically consists in avoiding to run dispersion models through the use of statistical analysis for validating the relationships between concentration data and traffic flows.

- Concerning the noise emissions, a partial overcoming of the difficulties of a full-fledged implementation of the impact pathway approach, has been made possible by the Florence municipality that has conducted between 1987 and 1996, in collaboration with the Regional Agency for Environmental Protection, an extensive urban campaign for noise measurements. Such a campaign has allowed to:

1. provide a classification of urban roads through a set of factors associated with the measured noise emissions, i.e. main street with high traffic flows, local street with bus transit, etc

[1] Without detailed information on CO_2 emissions per vehicle kilometre in specific situation i.e. peak/off-peak, the marginal costs do not differ from average costs.

2. avoid to run dispersion models by means of regression analysis between traffic flows/vehicle type and measured Leq(A).

- The calculation of marginal costs of air pollution for the Florence urban area leads to the following results (per 1000 vkm, table 1, and per vehicle type, table 2).

  In order to favour comparisons, the marginal costs of air pollution for the city of Florence are compared to marginal costs obtained from disaggregated marginal values for vehicle category in urban area- as reported in INFRAS/IWW, (2000) based on ExternE results for German case study – further applied to the vehicles fleet composition of Florence.

Table 1: Marginal external costs of air pollution per 1000 vkm

	Marginal costs of air pollution	
	Florence MC case study	INFRAS/IWW 2000
PM_{10} MC (€/1000 vkm) Urban area	29.2	28.80
PM_{10} MC (€/1000 vkm) Central area	57.8	57.03
PM_{10} MC (€/1000 vkm) Peripheral area	26.2	25.83

Table 2: Marginal external cost of air pollution by vehicle type

	PM_{10}
	MC (€ / 1000 veh Km)
Diesel Car (conventional not cat.)	30.4
Diesel Car (Euro 1)	11.7
Diesel Car (Euro 2)	8.7

- The calculation of marginal costs of noise is the following, expressed as the WTP for the reduction of 1dB(A) arising from the reduction of vehicle flows.

Table 3: Marginal external cost of noise by traffic flow

Vehicle / h	MC [€/((inh. year)*(veh/h)*dB(A))]
891	1.7
708	2.0
562	2.4
447	2.8
355	3.3
282	3.9

Marginal costs for reducing 1 dB(A) with the variation of traffic flows have been assessed through regression analysis based on measured noise level over a particular road with specific fleet composition. Given the same average speed and traffic conditions, the application of regression analysis for estimating marginal costs can be generalised to other similar roads (class B). The generalisation to other roads can't be carried out without specific measurements.

- The generalisation of results to other cities addresses at least two different aspects:

  - generalising the methodology, providing that the required input data are available and the methodology is clearly explained

  - generalising the results, through the direct transferability of marginal costs, providing that a set of key variables have been identified and adjusted accordingly.

- Concerning noise, the generalisation of methodology is recommended. The complexity of urban context, e.g. the extreme variability of morphological conditions, the irregular distribution of receptors, doesn't allow in fact a direct transferability of the results.

- In the case of air pollution, instead, the transferability of results in other contexts could be assessed through the following formula:

$$MC = K * (VCF) * PD$$

Where:

MC = Marginal costs (€/1000 vkm)
K = $I_{Florence} / I_{urban\ area}$
$I_{Florence}$ = total mileage per year in the city (veh. * Km) / urban area (Km2)
$I_{urban\ area}$ = total mileage per year in the city (veh. * Km) / urban area (Km2)

VCF = vehicle category factor (e.g. 0.0014 for petrol car)
PD = Population density (Inh. / km^2)

Population density, total mileage and fleet composition, represent the key variables to be adjusted in such an approach.

The methodological issues suitable to be generalised to other urban contexts when dealing with air pollution, can be summarised as follows:

1. Providing the delimitation of urban areas in urban zones according to specific characteristics, i.e. socio-economic context and traffic situation;

2. Estimating the functional relationship between emissions from traffic flows and concentration levels;

3. Estimating the incidence of primary pollutants, as PM10 and Benzene, directly related to traffic flows and significant from the point of view of health impacts;

4. Applying the dose-response functions and monetary unit values as defined by European research projects for impact evaluation;

5. Adjusting the marginal external costs with factors accounting for the specific population density, traffic flows and fleet composition.

9G 1. INTRODUCTION

Estimating the environmental marginal external costs in the context of urban area entails specific problems and drawbacks, which is important to underline in order to introduce the methodological aspects of Florence environmental marginal cost study.

In general, marginal costs, internal as well as external[2], vary with different transport vehicles, different places and conditions, depending both from environmental factors and transport activities. In order to account for such variability in time and space, the bottom-up evaluation techniques are highly recommended.

The Impact Pathway Approach (IPA), developed in the series of ExternE Projects[3] as well as in further case studies and research projects[4], is a well-established methodological approach based on the building-up of a set of "building blocks", conceived as basic tasks for external costs assessment.

In the urban context, the implementation of IPA methodology has to cope with drawbacks in the fields of the proper quantification and estimation of environmental external costs.

- Comparing to an extra-urban area, a general characteristic of the urban context is the extreme density of the receptors (human, materials). As a consequence, errors in the evaluation of the impact pathway chain could undermine the reliability of the final results. For instance, even a small error in the evaluation of the burden, i.e. air pollutant emissions, due to the extreme density of receptors, gives as a result unrealistic outcomes in terms of evaluation of impacts.

- Also the quantification of impacts is likely to be affected by the urban context. The huge number of variables to be accounted for complicates the use of transport models for the estimation of pollutant emissions due to urban traffic. In particular, the difficulty to evaluate the incidence of congestion, typically a diffusive phenomenon in urban context, leads to further difficulties in the proper evaluation of emissions.

- Concerning the estimation of pollutants dispersion, which represents an important step in the impact pathway approach, the use of modelling techniques for the calculation of concentrations is complicated by the complexity of urban context, e.g. the topographical influences in the case of the reconstruction of local fluid dynamic effect.

Furthermore, from a methodological point of view, another relevant drawback is the extreme variability of results, caused by the complexity of urban context.

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[2] A theoretical and analytical distinction between "internal" and "external" costs, with reference to the freight transport, can be found in RECORDIT project (2000),
[3] EC funded ExternE Studies, Voll. 9, „External costs of transport", 1999
[4] Inter alia, RECORDIT (2001) and PETS (2000)

Environmental marginal external costs in urban context are likely to change according to specific urban area and zones. A proper methodological approach should be able to account for the high degree of heterogeneity inside the urban area.

According to the Unite D3[5], the following table shows the categories of environmental marginal external costs to be analysed in an ideal framework, compared to the categories actually analysed in the context of Florence case study on the basis of available data and the significance of the categories.

Table 4: Environmental marginal external costs categories analysed in Florence case study

Ideal Framework	**Florence Case Study**
Air pollution	√
-human health	√
-natural environment	
-building materials	
Global warming	
-damage costs (agriculture, health, energy use, water availability, coastal impacts)	√
-avoidance costs	
Noise	
-human health	√
-amenity losses	
Soil and water pollution	
-heavy metals, oil	
-de-icing salts	
Nuclear risks	
-operation of power plants	
-accident risks	

The significant environmental categories of air pollution and noises are analysed, in particular considering their impacts on human health and amenity losses. The impacts of air pollutants on natural environment and building materials are considered negligible in urban context (i.e. natural environment) or difficult to estimate due the paucity of data and case studies (i.e. building materials).

Global warming impacts are estimated with limitations, due to the unavailability of local case studies.

[5] UNITE Project, D3 “Marginal Cost Methodology”

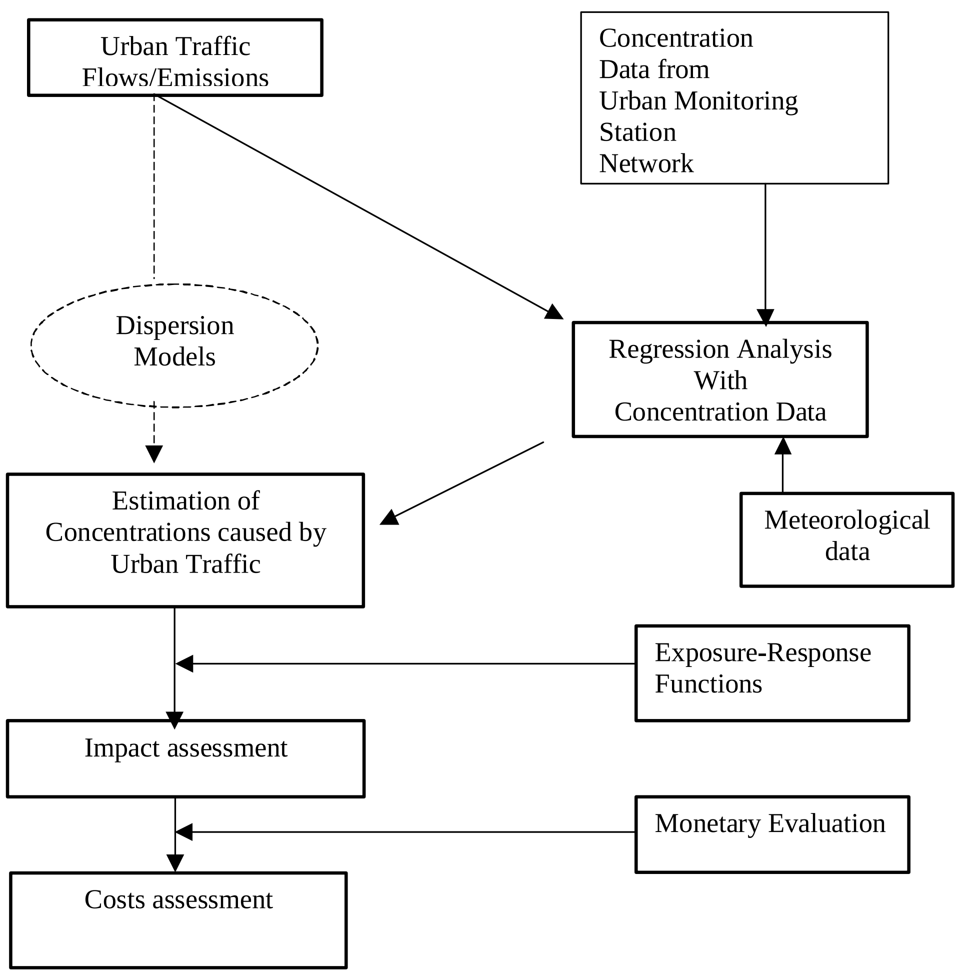
The environmental categories of soil and water pollution and nuclear risks are not considered, due to their insignificant weight at urban level.

From a methodological point of view, the departure from the traditional implementation of IPA concerns basically the estimation of air pollution and noise. As "traditional implementation of IPA" we mean the complete estimation of "building blocks" through the use of models, according to the following steps:

1) the quantification of burden (air pollutant emissions or noise emissions);
2) the evaluation of the dispersion in the environment;
3) the estimation of physical impacts,
4) the monetary evaluation of welfare losses resulting from impacts
5) the final costs estimation.

With reference to air pollution the following scheme outlines the methodology adopted.

Figure 1: Methodological framework for estimating environmental air pollution marginal costs



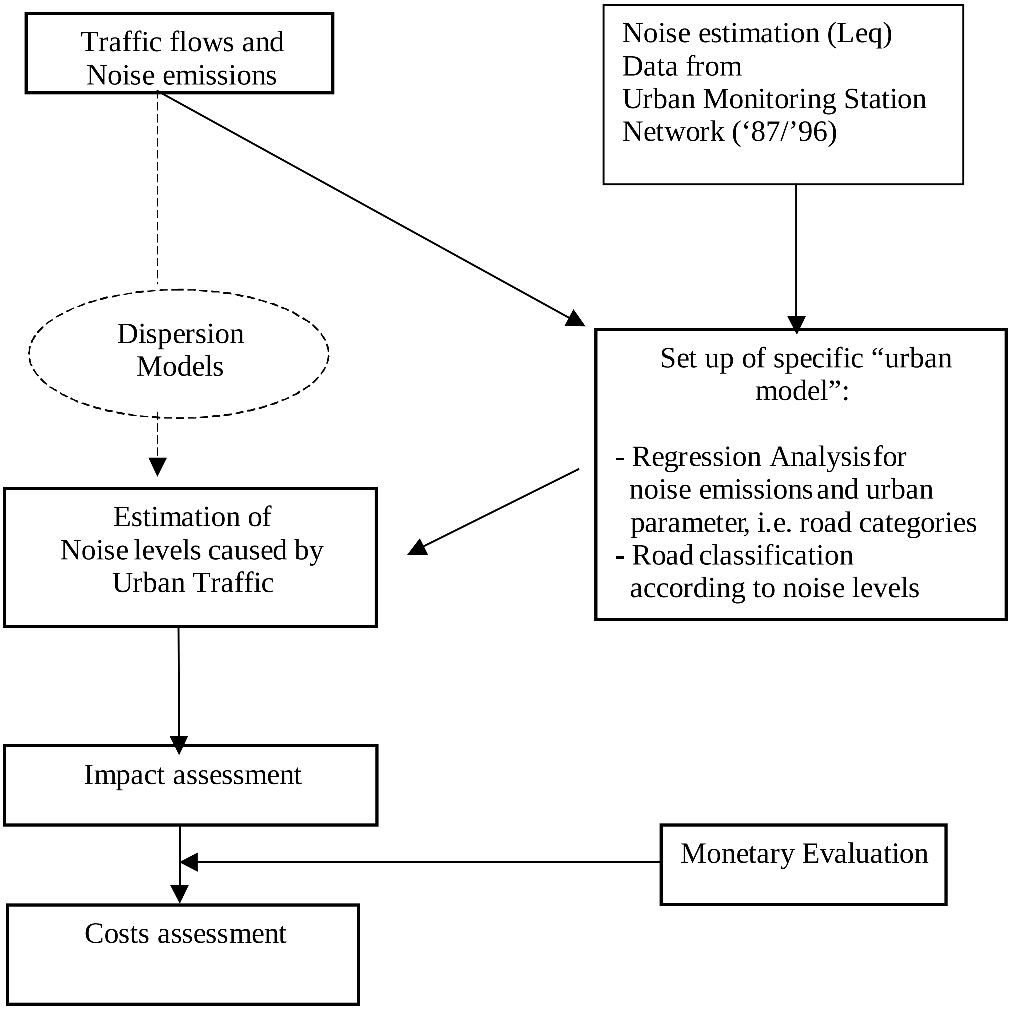
The above figure helps to capture the main characteristics of the proposed methodology, which will be explained in detail in the next chapters, and that can be identified as follow:

- avoiding the recourse to dispersion models (in dotted line on the above figure) through the use of statistical analysis for validating the relationships between concentration data and traffic flows.

With reference to the noise, the implementation of the traditional IPA methodology would entail the modelling of noise dispersion from the source to the receptors in urban area, according to the role of specific factors (i.e. topography, road type).

The following figure shows the proposed methodology in order to avoid collecting the highly detailed data requirements needed to run the dispersion models.

Figure 2: Methodological framework for estimating environmental noise marginal costs



The proposed methodology is based on the campaigns for monitoring the noise levels in the city of Florence from 1987 to 1996. The bulk of information has operated as input-data for statistical analysis that has led to set up a specific “urban noise model”.

The urban noise model allows classifying the noise levels measured in the city of Florence according to several parameters, covering from meteorological to topographical aspects:

- road categories, i.e. asphalt composition, traffic conditions
- time periods, i.e. day, night, season, working day
- urban topology, i.e. presence/absence of building row, bus transit, proximity to ZTL

As results, both in the air pollution and noise’s case, a tentative approach is made for replacing the need to run sophisticate and highly data requirements dispersion models, particularly difficult in the complex urban context, with the use of statistical tools, i.e. regression analysis, aiming at produce a bridge between emissions and impacts.

9G 2. CASE STUDY DESCRIPTION

2.1 THE SOCIO-ECONOMIC CONTEXT

Over the past 40 years the relationships between the city of Florence and its hinterland have followed a path similar to several western cities belonging to the industrialised world. This path could be described from a theoretical point of view by the so-called “theory of disurbanisation” (L.Klaassen *et al*. 1981).

According to such a theory, two crucial issues can be underlined:

1. the cities had shown a lost of population which has shifted progressively towards the outskirts;

2. the result has been the inner city decline, followed later by the decline in the outskirts.

Although the urban growth model underlying such a theory is not exempt from theoretical problems[6], the empirical observations based on census data have confirmed these trends[7].

	Population				% rates			
	1971	1981	1991	1999	1981/ 1971	1991/ 1981	1999/ 1991	1999/ 1971
City of Florence	457,803	448,331	404,002	376,662	-2.10%	-9,90%	-6.77%	-17.7%
Province of Florence[8] - less the City of Florence -	688,564	753,682	780,679	793,449	+9.50%	+3.60%	+1.64%	+15.2%
Total	1,146,367	1,202,013	1,184,681	1,170,111	+4.90%	-1.4%	-1.23%	+2.1%

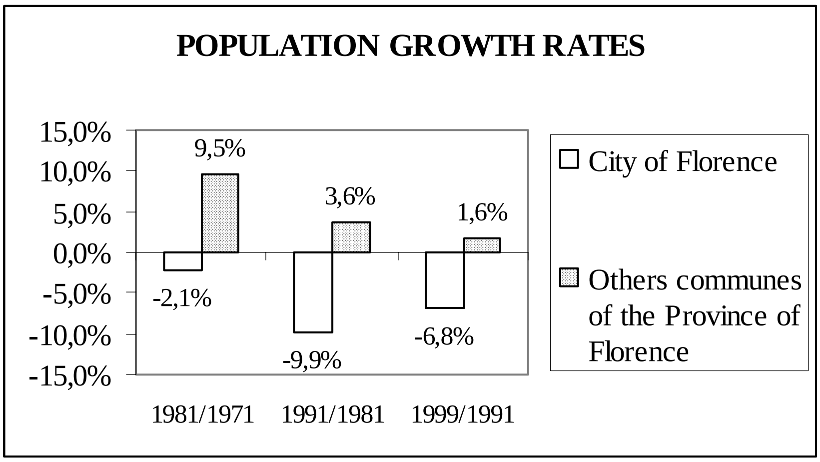
[6] For instance the difficulty to explain the new forms of urban development as the grouping of several communes on the basis of contiguous residential occupations, “extremely dependent on the city for jobs, services, consumptions and so forth”(Bonnafous, 1993), despite the falling rate of population growth in the core city.

[7] The census data, based on population data, could represent a simple criterion in order to analyse the complexity of the new forms of urban development.

[8] In order to allow the comparison, in 1999 the Province of Florence include the population of the new Province of Prato, from 1995, formerly belonging to the Province of Florence.

From 1971 to 1999 the population in the overall Province of Florence, including the City of Florence, has slightly increased on average by 2.1%, with a peak from 1971 and 1981 (+4.9%) and a continuing decreasing slope from 1981 to 1999, i.e. –1.4% (1981-1991) and –1.2% (1991-1999).

Very different trends can be observed by comparing the city of Florence population growth rate and others municipalities of the Province.



The graph shows the opposite trends observed in the city of Florence and others municipalities of the Province: decreasing but positive in the latter, continuously negative in the case of the city of Florence.

Looking backward to the last 40 years of socio-economic development in the city of Florence, at least five phases can be identified, each of one with specific impacts on the urban transport systems:

1. **50s years**. Before the affirmation of private cars, the city experienced a growth both in dimension and density with the increase of public transports and two wheels vehicles: scooters, bicycles, and motorcycles;

2. **60s years**. In this period the growth affected both the dimension of the city, through new outskirts, and the progressive affirmation of private cars. The public transport failed to play an important role in the urban transport system;

3. **70s years**. Two trends can be identified: a process of slight population shifting from historical centre to the outskirts (in favour of tertiary economic activities) and a continuing growth both in private cars (partially arrested during the so-called oil-shock of 1973) and public transport.

4. **80s years**. The first half confirmed the trends of the 70s, with the lost of population in the historical centre, but not in the overall city, and a strong growth in the public and private transport sector. The second half experienced the development of new trends in population growth rates and socio-economic profile, which impacts will influence the future shape of the city. Population

growth rates became negative, both in the inner and the outskirts, tertiary economic activities started to expand in the outskirts too, displacing the residential ones. About 50,000 inhabitants left out from the city towards new area in the hinterland, maintaining anyway deep relationships (economic, social, etc) with the city.

5. **90s years**. This phase saw a further amplification of the 80s second half trends, i.e. the falling of population (the amount of population reached the 1951 level: 376,000 inhabitants) and the increase of urban sprawl and the further modification of the demographic composition, in particular through the progressive ageing of population (table 2) and the growth of households with one membership (table 3).

Table 5: Age of population in the City of Florence (% values)

Classes of Age	*1991*	*1992*	*1993*	*1994*	*1995*	*1996*	*1997*	*1998*
Up to 15	9,7	9,6	9,6	8,8	9,5	9,5	10,4	10,6
From 16 to 30	21,6	21,2	20,9	21,0	19,5	16,9	17,6	16,9
From 31 to 45	20,4	20,2	21,1	20,2	20,5	21,0	21,4	22,0
From 46 to 60	20,5	20,8	21,0	21,2	21,4	21,0	21,1	20,9
From 61 to 75	18,3	18,7	19,1	19,6	19,9	20,4	19,3	19,1
More than 75	9,5	9,5	9,3	9,2	9,2	11,2	10,1	10,6
TOTAL	100	100	100	100	100	100	100	100

Table 6 Households per number of members

Number of members	*1992*	*1993*	*1994*	*1995*	*1996*	*1997*	*1998*	*Rate '97/'98*
1	68.386	69.226	69.555	69.396	70.080	71.327	72.210	1,24%
2	45.005	45.259	45.311	45.330	45.231	45.381	45.487	0,23%
3	34.926	34.567	34.265	33.908	33.589	33.406	33.166	-0,72%
4	23.490	22.658	22.087	21.546	21.147	20.911	20.331	-2,77%
5	5.603	5.320	5.097	4.924	4.719	4.590	4.442	-3,22%
More than 6	1847	1778	1667	1586	1517	1540	1484	-3,64%
TOTAL	179.257	178.808	177.982	176.690	176.283	177.155	177.120	-0,02%
Average number of memberships	2,20	2,18	2,18	2,17	2,15	2,14	2,12	-0,68%

The impacts on the urban transport system of the above tendencies, a mixture of socio-economic and demographic ones, are manifold:

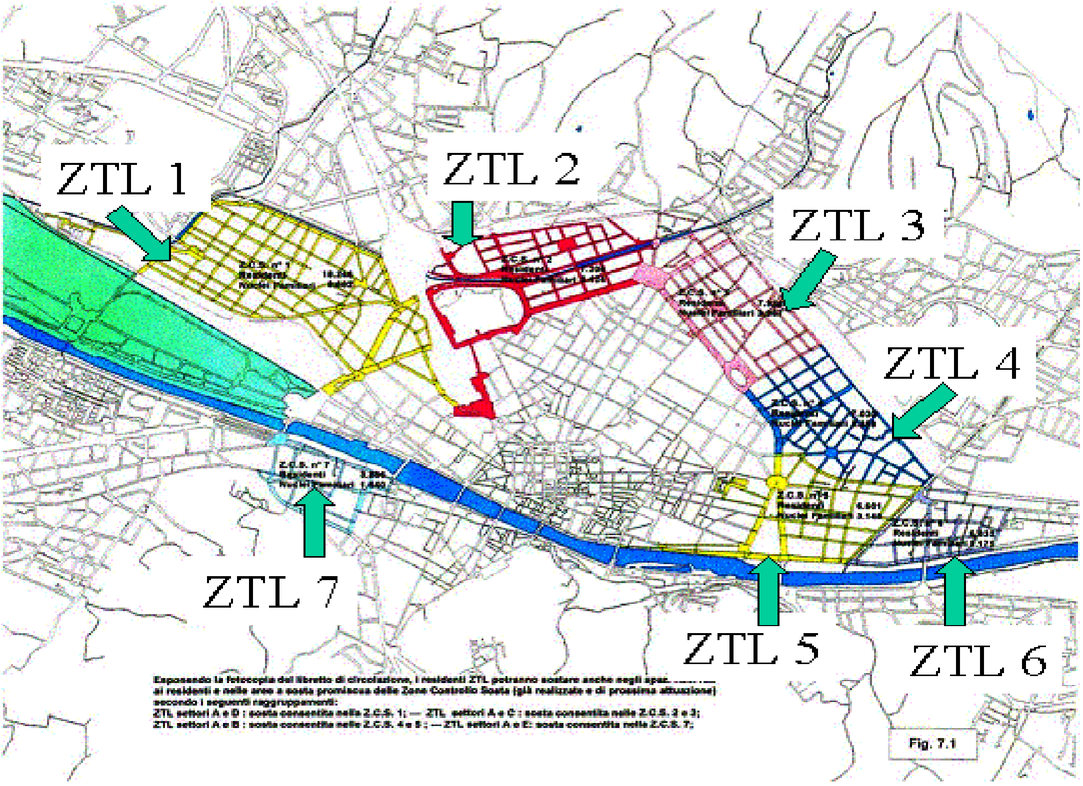
- the public transport system has to cope with the urban sprawl and the consequently high diffusion of suburban areas, which cannot be easily connected by public transport without incurring in growing operating costs;

- a new pattern of mobility is emerging, based on non-systematic movements tailored to the new configuration of economic activities, i.e. decentralisation. The old pattern of mobility (the one home based travel) is now replaced by travels with more segments.

- As results, the private transport mode, i.e. cars and mopeds, is growing and the public transport system is losing passengers.

In order to limit the use of private cars and improve the use of public transport, in particular in the historical centre, the city of Florence has relied on the strong development of ZTL (Limited Traffic Zone or Blue Zone).

Nowadays, about 15% of population live in the seven ZTLs (see map below), which involve as a whole about 60,000 inhabitants and 28,000 households.



2.2 THE MOBILITY IN THE URBAN AREA

2.2.1 DEMAND SIDE

The pattern satisfying the demand of mobility in the city of Florence is well represented by the following two tables, drawn by the Census 1991[9], the last available source of information in terms of comprehensive analysis of origin-destination trips[10].

The table 4 shows the amount of origin/destination trips for working/studying purposes from/to the city of Florence towards the communes of the first ring and from/to the others communes of the Province between 1981 and 1991.

Table 7: Origin/destinations trips for working/studying purposes in the city of Florence (1981-1991)

	ORIGIN				DESTINATION			
COMMUNES	1981	1991	diff.	Diff. %	1981	1991	diff.	diff. %
FIRST RING	13,204	16,319	3,115	**23.6%**	33,893	40,260	6,367	**18.8%**
OTHERS COMMUNES OF PROVINCE	4,541	5,703	1,162	**25.6%**	17,577	25,145	7,568	**43.1%**
PROVINCE OF FLORENCE	17,745	22,022	4,277	**24.1%**	51,470	65,405	13,935	**27.1%**

The growing role of Florence as attractive pole in the area is confirmed by the comparison between the trips from/to the communes of the first ring and others communes of the Province.

From 1981 to 1991 the growth rates of trips from/to the communes of the first ring have substantially been in equilibrium, i.e. 23.6% (from Florence) against 18.8% (towards Florence). On the other hand, the trips originating from others communes of the Province towards the city of Florence have increased by 43.1% against 25.6% of the trips originating from Florence.

The table 5 shows the distribution of origin/destinations trips for working/studying purposes according to the prevailing mode of transport.

Table 8:Origin/destination trips for working/studying purposes by mode of transport. Census 1991

[9] 13º General Census of Population and Households, Istat, 1991

[10] With reference to the area of Florence, a partial updating of the information concerning the origin/destination matrix has been conducted between April and May 1998.

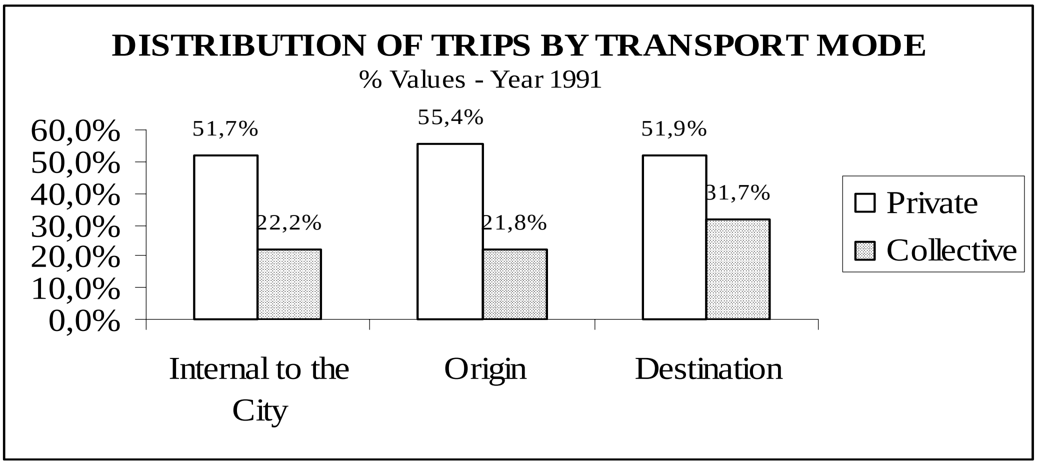
	Internal to the City		Origin (*)		Destination (**)	
Walking	36,330	21.5%	36,642	18.8%	37,461	13.4%
Train	324	0.2%	1,696	0.9%	26,394	9.4%
Bus	37,162	22.0%	40,663	20.9%	62,571	22.3%
Car	57,027	33.8%	75,323	38.7%	105,503	37.6%
Motorcycle	30,165	17.9%	32,484	16.7%	40,207	14.3%
Bicycle	7,440	4.4%	7,644	3.9%	8,039	2.9%
Other	227	0.1%	275	0.1%	413	0.1%
TOTAL	**168,675**	**100.0%**	**194,727**	**100.0%**	**280,588**	**100.0%**

(*) Towards the Toscana Region
(**) From Toscana Region and others Regions

Two important aspects can be stressed:

- the prevailing weight of mobility “attracted” compared to the mobility “generated”, i.e. 280,000 trips against 195,000, equal to a ratio of 1,44;

- the prominent role of private transport modes (cars and motorcycles) compared with the collective ones (bus and trains).



The above graph shows that private transport modes account for more than 50% of mobility needs. The higher collective transport modes share is observed with reference to the trips entering in Florence, thanks to the contribution of train (9.4%).

On the other hand the breakdown of the mobility internal to the city shows an important role of the non-motorised transport modes (walking and cycling), accounting for about 26%.

It's important to mention that the above tendencies, emerging with reference to the period 1981-1991, have been confirmed in the following years.

In particular, it has been reinforced the relationship between the urban development, i.e. urban sprawl, the formation of conurbations, etc, and the use of private transport modes to meet the growing mobility demand.

2.2.1.1 Private transport

As seen in the above table 5, considering separately the trips internal to the city, originating from and entering in Florence, the private transport modes (cars and motorcycles) account for about 50% of total trips for working/studying purposes.

If total trips were considered (adding the internal ones with the trips with destination to Florence), the share of the private transport modes would be higher.

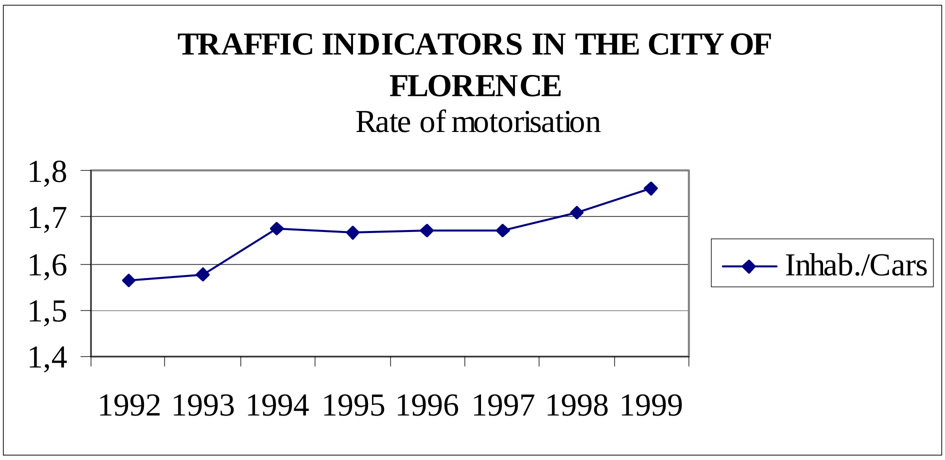
The table on the right shows that about 54% of the total trips internal to the city (both passengers and drivers) are carried out by private transport modes, in particular 40.4% by cars and 13.9% by motorcycles.

Collective transport modes (buses and trains) account for another 30%, i.e. 21.5% bus and 9.1% train, while the remaining 16% is related to walking and cycling.

	Total trips	
Walking	37,773	12.3%
Train	27,666	9.1%
Bus	66,072	21.5%
Car	123,799	40.4%
Motorcycle	42,526	13.9%
Bicycle	8,243	2.7%
Other	461	0.2%
TOTAL	**306,640**	**100.0%**

Looking at a typical traffic indicators, i.e. the rate of motorisation, over the past ten years two distinct trends can be observed[11].

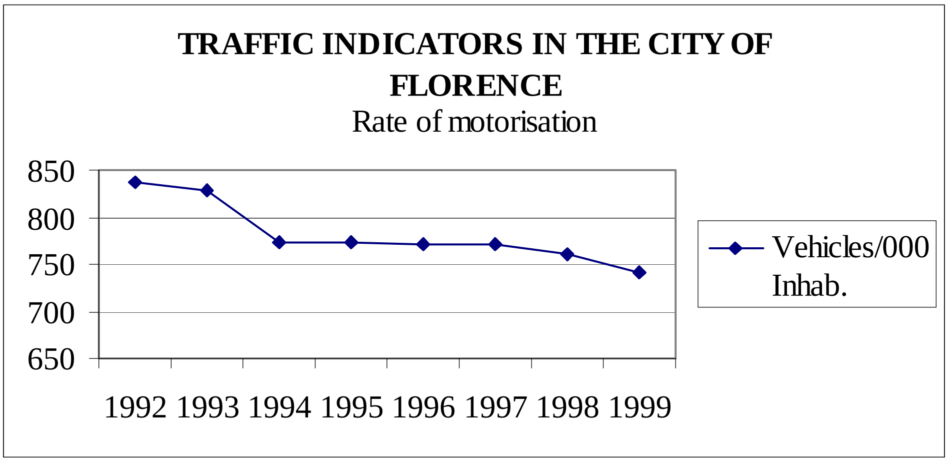
Firstly, the graph below shows a positive trend in the rate inhabitants/number of cars, growing at average rate of about 1.7% pa, with a peak between 1993 and 1994 (+ 6.4%).



In 1999, the city of Florence recorded about 1.8 inhabitants per circulating car[12].

On the other hand, considering the overall vehicles circulating in Florence, i.e. trucks, van, buses, etc, a falling rate can be observed: about 850 vehicles per 1,000 inhabitants in 1992, against about 750 in 1999, corresponding to a decreasing yearly average rate of –1.7%.

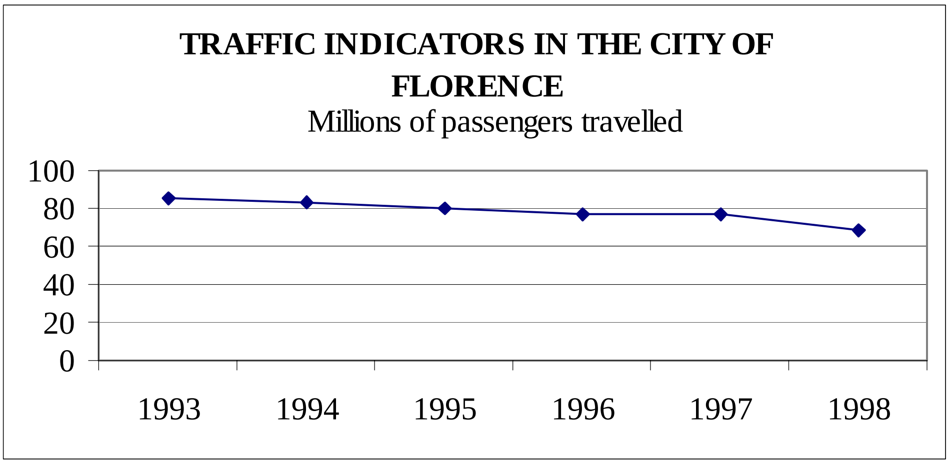
[11] Automobile Italian Club, 2000
[12] Up to 1998 the notion of circulating car included all cars with a regular payment of the circulation tax; from 1999 onward the number of cars has been updated with the cars scrapped, demolished, etc.



The growing role of private cars in the urban transport system is also confirmed by the evidence that over the past 14 years, from 1985 to 1999, the number of new cars in Florence has increased by 108%, against a national average of 131%[13].

2.2.1.2 Collective transport

Over the past ten years the public transport in the city of Florence had suffered of a continuing decrease in the number of passengers travelled[14].



This trend has occurred despite of an increase in the public transport network, measured in kilometres, by an average yearly value of +4.3% (from 536 km in 1993 to 630 km in 1997).

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[13] Automobile Italian Club, 2000.The average value is related to eight Italian cities with more than 400,000 inhabitants.
[14] Passengers travelled by ATAF the Local Transportation Company

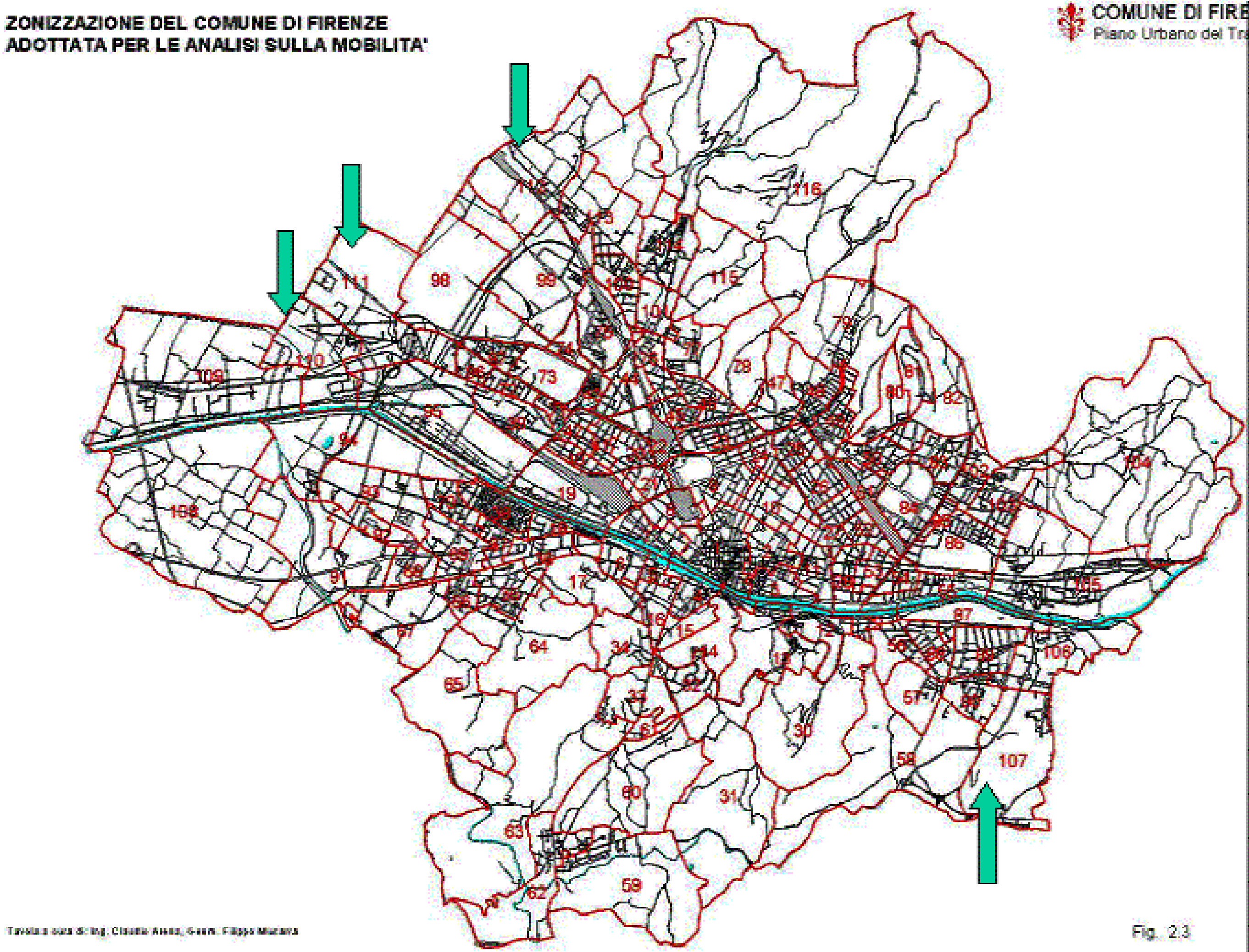
In order to analyse with a great detail the transport demand and supply, 116 zones covering all the urban area of Florence have been defined, with reference to the volume of internal trips for working/studying purposes (based on 1991 Census).

For each zone an index of urban mobility has been calculated, reporting the ratio between the number of trips by car and by bus. Hence, the ratio grater than 1 indicates the prevalence of car usage, the opposite (more public transport usage) when the ratio is < 1.

The map in the next page shows the value of the ratio for the first ten zones (located in proximity of the historical centre) and for the last ones, in the outskirts areas (marked with an arrow).

It can be observed that in the first ten zones the ratio is generally < 1, while in the outskirts zones the value is above 1, indicating a more intensive use of cars.

In practice, the urban public transport is really competitive with the private one, only on a restricted portion of the city, in particular in the inner part, near to the historical centre, and along the main routes.



ZONES
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2.2.2 SUPPLY SIDE

2.2.2.1 Road network

The road network of the city of Florence is characterised by an extreme variety of situation and geometries, i.e. availability of parking zones, functionality, etc,

The length of urban road network is about 700 kilometres and its breakdown, with reference to the most densely populated area only, is the following:

Road type	Lengths (km)
Main roads connecting quarters	71.0
Secondary roads connecting quarters	94.3
Strictly quarters' roads	33.5
Roads connecting specific zones	60.6

The supply of free parking space in the urban area is not easy to be quantified. A rough estimation accounts for about 180,000 places-car available in the city of Florence.

More reliable information concerns the supply of parking space with charging, both private and public, accounting for about 6,000 places-car.

2.2.2.2 Public transport

The supply of public transport network, managing by ATAF, the local transportation company, relies on an endowment of about 630 kilometres, at 1997, of which 7.5% with protected lanes, and about 1,900 stops.

The following table shows the trends over the past six years for some public transport supply indicators, i.e. the number of buses and their average age, the length of network and the seats * kilometres[15].

	1993	***1994***	***1995***	***1996***	***1997***
Number of buses	478	484	479	481	505
Fleet Average Age	14,0	15,0	15,1	15,0	9,8
Length of network (km)	536	540	625	618	630
Seats * km (millions)	2,289	2,222	2,207	2,343	2,427

[15] This indicator is calculated as the sum of the seats multiplied the kilometres travelled and represents a measure of the service supplied to the users.

A general improvement of the quantitative standard of service provided can be observed, i.e. the number of buses and the seats * kilometres have risen on average respectively at 1.4% and 1.5% yearly rates.

With reference to the rail urban network, two types of services can be identified:

1. regional service, connecting the city of Florence with regional urban area

2. urban services, connecting quarters around the city.

The first type of service has a key role in the context of urban mobility system (see table 4 above), providing about 10% of total trips towards Florence, with a growing trend in terms of the number of commuters involved.

Further enhancements of the services standard will be obtained through the provision of infrastructures supply in order to favour the interchanges and modal split (parking area, terminals, etc).

On the other hand, the rail urban service needs relevant improvements in infrastructures supply (new stations and parking area) in order to meet the demand. A comprehensive development programme should fulfil such requirements.

Concerning the other rail services, the provision for the city of Florence of a tram network is only at the initial stage. The project is to develop the tram services in the inner zone of historical centre aiming at reducing the mobility share satisfying by road urban transport.

With reference to the interurban road transport two types of services can be identified in the city of Florence:

1. the suburban services
2. the interurban services

The suburban service aims at connecting the urban area with the “second ring” communes. The function of strengthens the connection of inner urban area with the hinterland has to be improved through the inclusion of the main roads crossing the city from East to West in the suburban lines paths’.

The interurban services aim at connecting the second rings communes with the inner city, in particular the more attractive area, favouring the interchange with urban buses.

9G 3. RESULTS

3.1 AIR POLLUTION

As explained in the chapter 1, the methodology adopted for the calculation of marginal external costs for air pollution applies a specific version of the well-established IPA, avoiding the recourse to dispersion models.

In such alternative approach, a key feature is the set up of correlation functions, through regression analysis, between pollutant emissions and concentration levels.

The methodological approach can be summarised through the following steps[16]:

1. analysis of meteorological data and pollutants concentration levels gathered from the urban network of monitoring stations;

2. analysis of traffic flows data, gathered from the urban network of sensors inside the urban area;

3. set up of correlation analysis between pollutant emissions and concentration level with reference to a primary pollutant, directly connected with traffic activity;

4. estimation of concentration of PM_{10} due to traffic activity

The further steps of impact assessment and monetary evaluation follow the traditional approach based respectively on exposure-response functions and evaluation methods, i.e. the contingent evaluation through willingness to pay estimations.

3.1.1 The delimitation of urban area in homogeneous zones

The implementation of the first two steps, i.e. the analysis of concentration levels and traffic flows, leads to examine an important issue concerning the delimitation of urban area in homogeneous zones.

Due to the extreme variability of urban context, both with reference to the density of receptors and morphological characteristics, the environmental external costs will vary accordingly. The delimitation of urban area in homogeneous zones would be the first step to undertake, in order to estimate environmental external costs that reflect the specific urban conditions.

The main parameters to be accounted for, as criteria for the delimitation of urban area would be the following:

- Meteorological conditions

[16] Further applications of this methodology can be found in ENEA-ISIS, 2001

- Morphological factors
- The amount of pollutant emissions related to the urban traffic;
- Population density

A certain degree of uniformity of the meteorological conditions can be approximately assumed along the overall urban area.

The morphological aspects should be taken in consideration only if they are characterised by outstanding features able to delimitate the urban area, like mountains zones with particular meteorological conditions, i.e. leeward or up-wind.

The most significant parameter is the amount of pollutant emissions related to traffic flows. Such a parameter is strongly correlated with the socio-economic characteristics of urban area, e.g. urban zones with pronounced economic activity, measured by the concentration of tertiary activities, both commercial and financial, are usually associated with high emissions values.

As result, the urban area can be classified in two broad categories:

- zones with intensive economic activities and high emissions levels;
- zones mainly residential, with a lower level both of economic activity and emissions.
-

Emissions caused by domestic heating and industrial sources are not considered as delimitation criteria, due to their emitting activity in higher quotas that determine a uniform distribution along the urban area.

The delimitation of urban area in zones according to the pollutant emissions levels has finally to be associated with the analysis of the distribution of population density.

The criteria established by national legislation for the localization of the monitoring station[17], in association with the criteria suggested by the WHO[18], have leaded in the city of Florence to the following network of urban monitoring station:

Station	***Type***	***Pollutants analysed***	***Location***
Boboli	A	PM_{10}, SO_2, CO, NO_X	Public park near historical centre
Viale U.Bassi	B	PM_{10}, SO_2, CO, NO_X	Garden in residential quarter

17 DM 20/5/91 " Criteria for the collection of quality air-related data"

18 "Health-related air quality indicators and their application in health impact assessment in HEGIS (Health and Environment Geographic Information System for Europe)", World Health Organisation, 1995

Station	***Type***	***Pollutants analysed***	***Location***
Via di Scandicci	B	SO_2, CO, NO_X	Garden in residential quarter
Via di Novoli	B	SO_2, CO, NO_X; O_3	Garden in residential quarter
Viale A.Gramsci	C	PM_{10}, CO, NO_X	High traffic road (3000 veh/hour)
Viale F.Rosselli	C	PM_{10}, NMHC, CO, NO_X	High traffic road (5000 veh/hour)
Via Ponte alle Mosse	C	PM_{10}, SO_2, CO, NO_X	High traffic road (1000 veh/hour)
Settignano	D	NO_x, O_3	Rural Area 5 Km from historical centre

The monitoring station classified with "A" indicates an urban zone without traffic emissions, e.g. in the middle of park, suitable for estimating the background concentrations originating from non-transport sources.

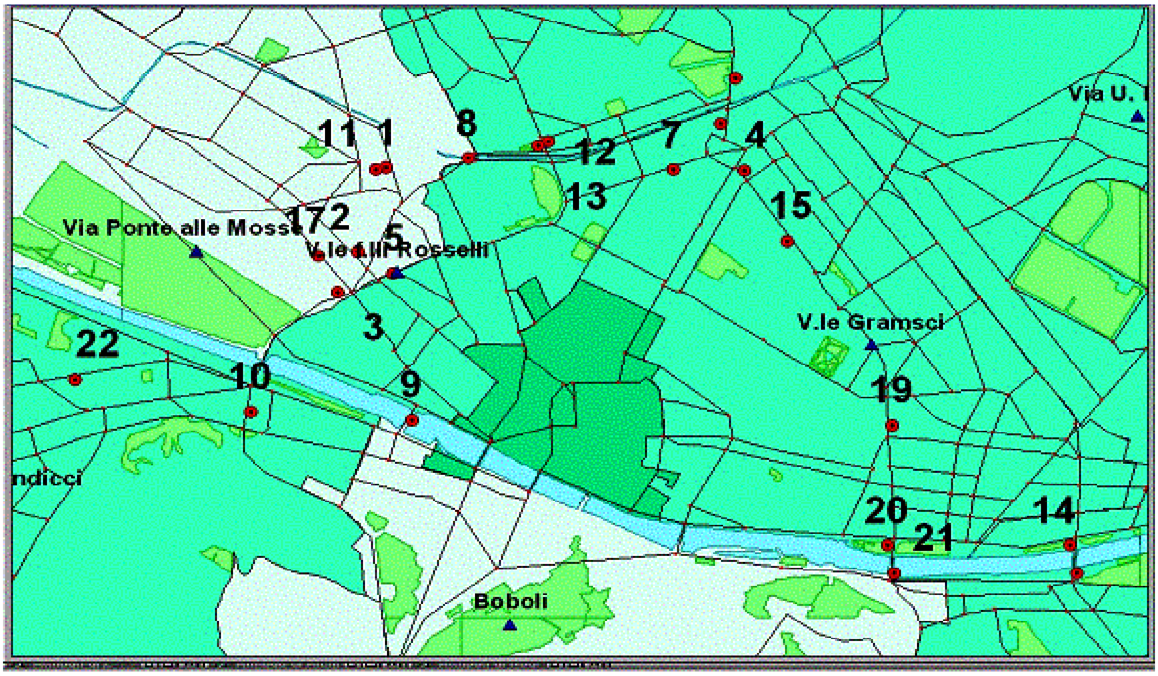
The monitoring stations classified with B and C indicate urban zones with intense traffic volume, in particular, the stations classified with class C associate both high traffic volume and population density, while the stations classified as "B" indicates high population density.

The monitoring station classified with "D" indicates an extra-urban zone.

With reference to the traffic flows, an urban network of 22 sensors allows analysing real data for two years (1995 and 1996). Considering data from all the sensors, a monthly average for each daily hour has been calculated with the purpose of estimating a representative average measure of traffic volume in the city of Florence.

It has to be considered, in fact, that the localization of sensors in the urban area (see figure below) being able to calculate a unique average value of traffic volume. The sensors are situated in a contiguous area approximately around the urban area, so that the average value represents could be assumed as the typical traffic volume of the overall city of Florence.

Figure 3: Localization of sensors in the city of Florence for traffic flow analysis



3.1.2 Correlation analysis between pollutants emissions and concentration levels

A preliminary step before implementing the correlation analysis between emissions and concentration levels is, on one side, the choice of pollutant –for emissions analysis- and, on the other, the selection of monitoring station, for the analysis of the concentration levels.

The pollutant selected for the implementation of correlation analysis between emissions and concentration level is the carbon monoxide (CO), due to its characteristic to be strongly linked to vehicles emissions.

The monitoring stations selected for the implementation of correlation analysis are those classified with "C", due to their proximity to urban zones characterised both by high traffic volume and population density.

In particular, the selected monitoring stations are "Gramsci" (up to 3,000 vehicle/hour) and "Mosse" (up to 1,000 vehicle/hour). The other monitoring station, "Rosselli", has been left out from the analysis due to its abnormal higher traffic volume, up to 5,000 vehicle/hour.

In order to perform the correlation analysis, the following three sets of data have been analysed (ENEA-ISIS, 2001) – all expressed as monthly average for each daily hour[19] -:

1. CO concentration levels from monitoring station type "C"

[19] As result, approximately 800 observations have been considered

2. Average of traffic flows data from the network of sensor surrounding Florence urban area

3. Meteorological data gathered by Florence meteorological observatory, i.e. wind speed, temperature and solar radiation

The function to be analysed is the following:

$$[CO] = f\,(Flux, T, Rad, V) \qquad (3.1)$$

where:

[CO] is the CO concentration level (mg/m^3);

Flux is the average hourly traffic volume (vehicle/hour);

T is the temperature value;

V is the wind speed (m/s);

Rad is solar radiation (W/m^2)
The examined correlation function has a linear trend, according to the following parameters:

$$[CO] = a*(Z) + b$$

where:

a is equal to the slope of the function

b is equal to the interception with CO axes

Z is the variable characterizing the monitoring station, where:

LN is equal to Log_e

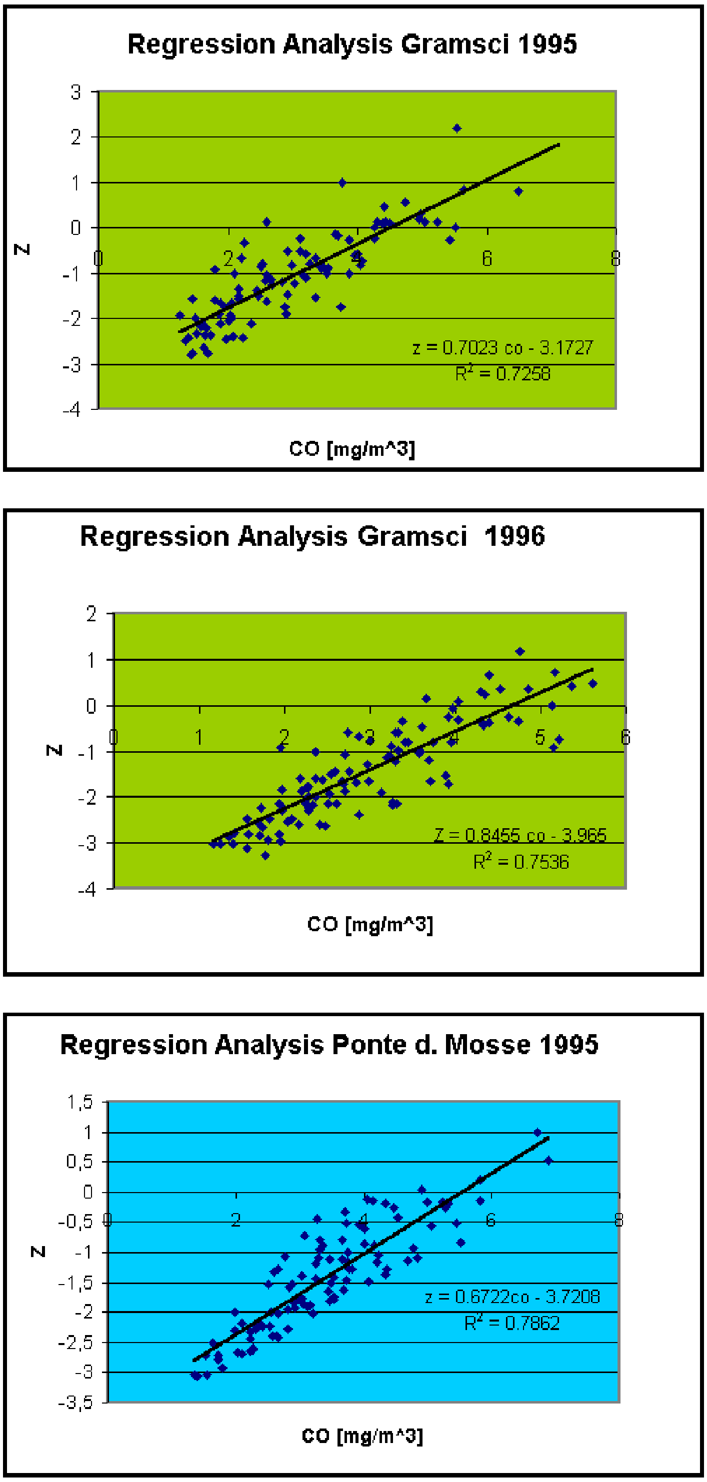
$$Z = LN\left(\frac{Flux}{(Rad)^\wedge(1.2) * (V)^\wedge 2 * EXP\left(\frac{T}{1000}\right)}\right) = LN(X)$$

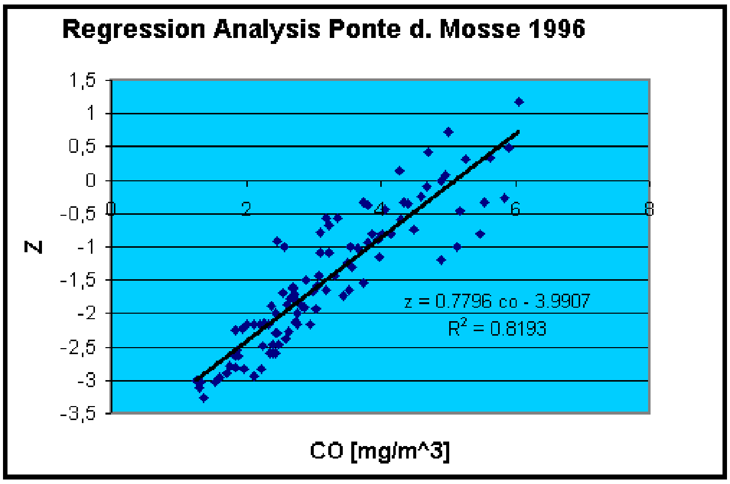
The analysis of correlation function shows that (X) variable is:

- directly proportional with traffic volume;
- inversely proportional to the power of solar radiation, of wind speed and the exponential of temperature.

The variable Z has been calculated for the monitoring stations of “Gramsci” and “P. di Mosse”. The correlation functions between Z and CO are the following:

Figure 4: Regression lines between Z variable and CO concentration levels

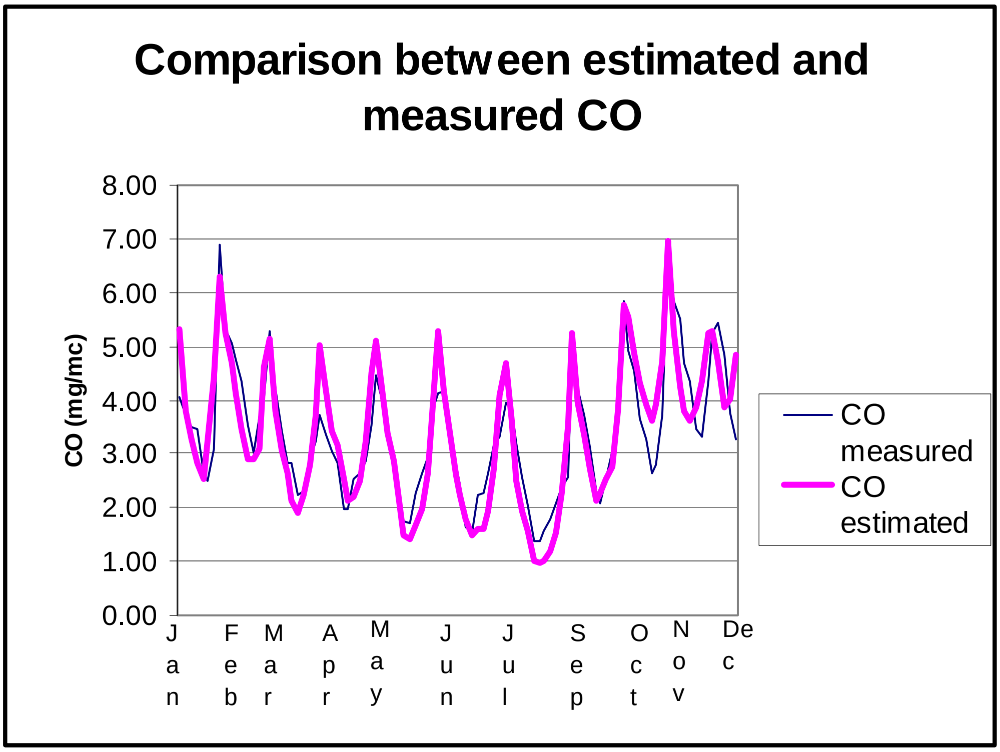




The above regression functions are calculated for two years with reference to the daily hour when the solar radiation is positive (approximately during the day time) and for each month less than August.

They show a good value of coefficient of determination R^2 meaning that, on average, approximately 80% of CO concentration is explained by the Z variable, linking traffic flows and meteorological variables.

The comparison between the monthly CO concentrations levels observed and calculated, applying the above regression lines for the 1995 year (Ponte delle Mosse monitory station), shows the capability of estimated value to follow the observed trends.

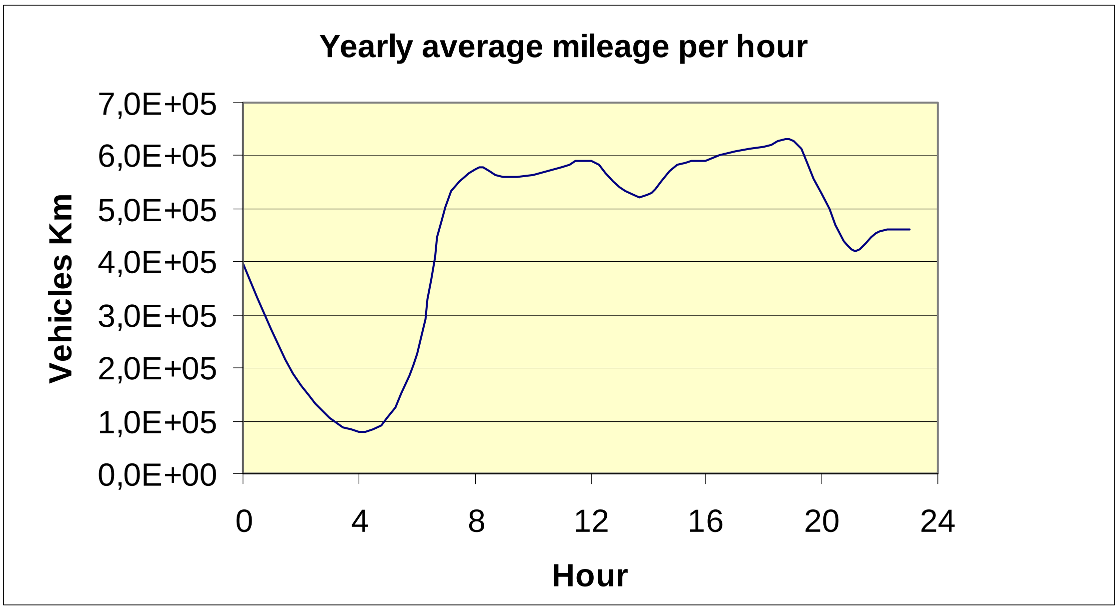


The implementation of the function 3.1 with reference to the yearly average of vehicle kilometres calculated for each hour (the trend of traffic vehicles mileage is considered similar to the functional form of average flows data recorded from the network) provide as result a measure of the relationship between the marginal CO concentration levels due to the variation of traffic flows.

The next graph shows the trend of traffic mileage, (yearly average of vehicle kilometres calculated for each hour) in the urban area delimitated by sensors.

The following remarks can be pointed out:

1. the peak-hour of about 600,000 vehicle kilometres is around the 19.00;
2. the lower traffic flow value, less than 100,000 is recorder during night-time;
3. with reference to the most significant range of time for traffic flows, i.e. 13 hours from 7.00 am to 19 pm, the difference between the peak and non-peak hour is about of 25%, indicating a regular trend which can be assumed as a representative value of traffic flow in the city of Florence.



The implementation of correlation function considering the traffic flows between 7.00 am to 19 pm has the following specification:

$$\frac{\partial(CO)}{\partial(Flux)} = \frac{1.38}{Flux}$$

The unitary variation of traffic flows determines a value of CO concentration level equal to a constant divided by the average traffic flows.

3.1.3 Estimation of other pollutants from transport activity

The estimation of the concentration of pollutants from transport activity represents an important step in order to estimate the environmental external costs. Apart from the CO emissions, the other two pollutants originating from traffic activity with a prominent impact on human health are particulate (PM_{10}) and Benzene.
With reference to the concentration of Benzene, starting from the CO concentration levels, a study of the Regional Agency for Environment[20] for the urban area of Florence has delivered the following function:

Benzene = K * (CO) **(3.1.1)**

Where:

Benzene = Benzene concentration level ($\mu g/m^3$);

CO = CO concentration level (mg/m^3);

K = coefficient for the estimation of Benzene.

The value of K is equal to 4.8 in the monitoring station classified with "C", while in the monitoring station classified as "B" and "A", K is respectively equal to 5.7 and 5.9.

With reference to PM_{10}, the estimation of concentration levels due to the urban transport activity follows the approach suggested from L.A. Cifuntes et al[21]. The basic assumptions are the following:

- A "box model" dispersion formula is considered as basic equation;
- The total PM_{10} emissions are expressed as linear combination of three factors: mobile sources, fixed sources, and other sources (sea aerosol, combustions, etc);
- The emissions stemming from mobile sources are considered proportional to the CO emissions;
- The emissions stemming from fixed sources are considered proportional to the SO_2 emissions;
- The emissions stemming from other sources are considered not correlated with mobile and fixed sources.

As result, the following equation is obtained:

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[20] ARPAT-Comune di Firenze, "Relazione annuale sulla qualità dell'aria nel Comune di Firenze", 1999
[21] "Ancillary Benefits and Cost of Greenhouse Gas Mitigation", OECD, 2000

$$[PM_{10}] = a[CO] + b[SO_2] + \frac{c}{u} + d\frac{P}{u} + e$$

Where:

$[PM_{10}]$ = average daily concentration of PM_{10} ($\mu g/m^3$)

$[CO]$ = average daily concentration of CO (mg/m^3)

$[SO_2]$ = average daily concentration of SO_2 ($\mu g/m^3$)

u = average daily wind speed (m/s)

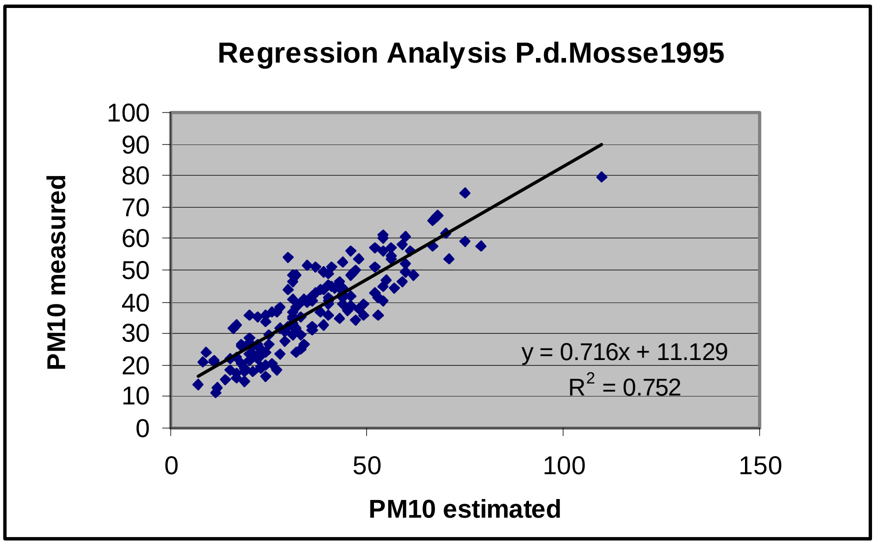
P = average daily height of rain (mm)

a,b,c,d,e = coefficient to be estimated through regression analysis.

The implementation of regression analysis applied for the monitoring station of “P. delle Mosse”[22], gives the following result:

$$[PM_{10}] = 5.83[CO] + 0.168[SO_2] + \frac{15.535}{u} - 24.734\frac{P}{u} + 5.43 \qquad \textbf{(3.1.2)}$$

As can be observed in the following chart, the regression analysis between observed and estimated PM_{10} concentration levels shows a good value of R^2 (0.75).



[22] The monitoring station of “P. delle Mosse” has been evaluated by a recent WHO study, as the most representative station in order to estimate the impacts of pollutants on resident population, in particular for PM_{10}. The reason lies on its localisation, i.e. a residential area with an average traffic volume. WHO,” Impact evaluation of air pollution on health in the 8 major Italian cities”, 2001

With reference to the concentration levels of PM_{10} and Benzene, the implementation of the above equations 3.1.1 and 3.1.2 provides the following results:

$$\frac{\partial(PM_{10})}{\partial(Flux)} = \frac{5.755}{Flux}$$

$$\frac{\partial(Benzene)}{\partial(Flux)} = \frac{6.624}{Flux}$$

The variables PM_{10} and Benzene are expressed in $\mu g/m^3$.
(inserisci commento sul trend)

3.1.4 The impacts evaluation of emissions from transport activities

The impacts on health have been estimated through the use of dose-response functions with the following specification (with reference to morbidity):

$$S = b*\Delta C*N_e$$

Where:

b = slope of the function, i.e. cases/(person*year* $\mu g/m^3$);

ΔC = increase of the yearly concentration due to transport activity ($\mu g/m^3$);

N_e = population exposed;

S = number of cases

With reference to the mortality (acute and chronic), it's important to stress that the slope of dose-response function means the % change in annual mortality rate due to $\mu g/m^3$ of pollutant.

The exposure response slopes (f_{er}), related to Western Europe[23], are shown in Annex I.

In order to obtain a monetary evaluation of impacts, a monetary value is assigned to physical impacts. For health impacts evaluation, the steps to be undertaken are the following:

- estimation of years of life lost (YOLL), from dose-response functions. With reference to acute mortality the YOLL estimation is equal to $YOLL_a$ = Mortality

[23] ExternE, "Externalities of Energy", Vol. 7, 1999

cases * 0.75, with reference to chronic mortality, the YOLL estimation is equal to $YOLL_c$ = Mortality cases * 5[24];

- both $YOLL_a$ and $YOLL_c$ have then to be multiplied by the monetary "value of a life year lost" (VLYL).

Reference values for estimating VLYL acute and chronic (1998) are the following[25]:

VLYL (acute) **euro**	129 700
VLYL (chronic) **euro**	75 400

In the Florence case study the health impacts evaluation has been considered a discount rate equal to 3%.

3.1.5 Marginal costs of air pollution

The calculation of marginal costs of air pollution for the Florence urban area leads to the following three steps:

1. The identification of urban zone. It includes an area approximately situated around the city centre, which yearly average traffic flows can be considered representative of the overall urban traffic conditions. In such an area, the localisation of monitoring stations, i.e. in particular the station class "C", "P. delle Mosse", is suitable for the analysis of the concentration levels.

2. The estimation of concentration levels. Through the implementation of the regression analysis, e.g. the application of the functions (3.1), (3.1.1) and (3.1.2), the correlation functions between traffic flows and concentrations of pollutants (Benzene, CO, PM_{10}) have been found out.

3. The impacts evaluation. The application of dose-response functions available from literature survey, together with the monetary evaluation of impacts has been assumed as the general criteria for the estimation of impacts evaluations.

The following table displays the calculation of marginal costs for PM10 impacts on human health for the whole urban area, its downtown and suburban areas. The marginal

[24] ExternE, "Externalities of Energy", Vol. 7, 1999

[25] Nellthorp, J. ae alt. (2001)

costs presented in tables below have been calculated considering the central value of daytime vehicles' hourly mileage. Therefore, the calculation of the extreme values requires an adjustment according to the function showed at page 35 (equation related to PM_{10}).

For the sake of comparativeness, the marginal costs of Florence case study are compared to marginal costs stemmed from disaggregated marginal values for vehicle category - as reported in INFRAS/IWW 2000, based on ExternE results for German case study – and applied to Florence vehicles fleet.

Table 9: Marginal costs of air pollution in the city of Florence

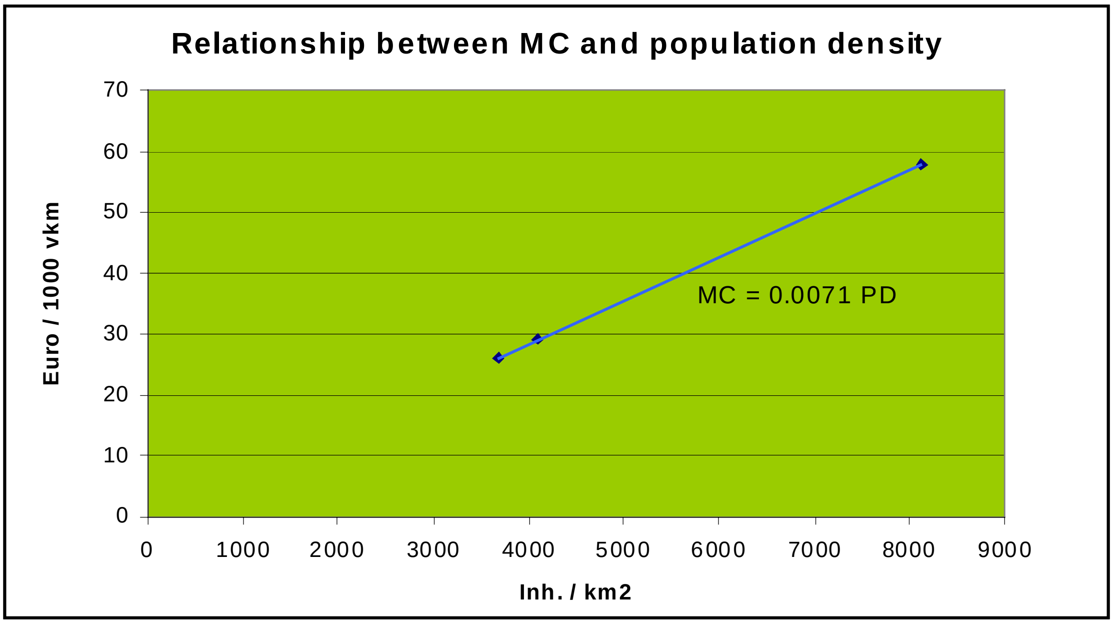
	Marginal costs of air pollution (PM_{10})	
	Florence MC case study	INFRAS/IWW 2000
PM_{10} MC (€/1000 v Km) Urban area	29.2	28.8
PM_{10} MC (€/1000 v Km) Central area	57.8	57.0
PM_{10} MC (€/1000 v Km) Peripheral area	26.2	25.8

The marginal costs for the downtown and suburban areas have been calculated by means of the distribution of the population density. A multiplying factor – taking into account the ratio between population density of the downtown area (or suburban one) and the average population density of the whole Municipality – has been applied to the marginal costs referred to the whole Municipality. Data on 1996 population density shown on the table below were estimated from 1998 official data to the City of Florence.

	Central area	Peripheral area	Urban area
Population density (Inh./Km^2)	8121.6	3679	4101
Area (Km^2)	8.89	84.64	93.53

The MC's trend according to population density is shown in the graph below.

Figure 5: Relationship between marginal costs and population density



The definitive linear function is the following:

$$MC = PD * 0.0071$$

MC in €/veh.*Km
PD in Inh./Km^2.

For the generalisation of this value to other urban areas, we suggest the following procedure:

1. Estimating a first marginal cost rough value by means the PD to the urban area;
2. Adjusting this value by the following formula:

$$K = I_{Florence} / I_{urban\ area}$$

Where :
$I_{urban\ area}$ = total mileage per year in the city (veh. * Km) / urban area (Km2)
$I_{Florence}$ = total mileage per year in Florence (veh. * Km) / urban area (Km2)

This factor is then used to highlight the fact that the marginal function for concentration has an inversely proportional trend with the traffic flows.

Therefore, the resulting generalisation formula is:

$$MC = K * PD * 0.0071$$

3.1.6 Disaggregation of marginal costs for pollutant and vehicle type

The following table shows the disaggregation of marginal costs for type of pollutant, i.e. CO and Benzene and vehicle type.

The municipality of Florence, in collaboration with the Regional Agency for Environmental Protection[26] has delivered the measured levels of the CO and Benzene related to the fleet vehicle circulating in the Florence urban area.

Table 10: Disaggregation of air pollution marginal costs for type of pollutant and vehicle type

	CO	Benzene
	MC (€/ 1000 vehKm)	MC (€ / 1000 vehKm)
Petrol kat	0.003	0.145
Petrol car no kat	0.043	0.681
LPG car NO kat	0.056	0.000
METANO No Kat	0.006	0.000
Diesel Car	0.001	0.000
LGV diesel	0.004	0.000
HGV+Bus Diesel	0.007	0.000
Moped	0.021	2.449

It has to be mentioned the relevant external costs of moped, deriving from Benzene emissions. This information is valuable considering the growing trend in the use of such a type of vehicle in the various urban contexts.

The disaggregation of PM_{10} marginal costs by vehicle category has been performed through the emissions factors of exhaust and not exhausts PM_{10}.

Emission's factors for not exhaust PM_{10} have been taken from INFRAS/IWW (2000) study, those ones for exhaust emissions have been taken from the Italian Environmental Protection Agency (ANPA 2000), which estimated these factors through COPERT II model.

In the following table are showed emission's factors used in Florence case study.

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[26] Report on the air quality of the Florence Municipality, 1999

Table 11: Emission's factors for vehicle type

	Non-exhaust PM10	Exhaust PM10	TOTAL
	[g/vkm]	[g/vkm]	[g/vkm]
Petrol Car	0.12	0.00	0.12
Diesel Car (Florence fleet)	0.12	0.43	0.55
Bus	1.20	0.90	2.10
LDV	0.21	0.46	0.67
Diesel Car (conventional not cat.)	0.12	0.48	0.60
Diesel Car (Euro 1)	0.12	0.11	0.23
Diesel Car (Euro 2)	0.12	0.05	0.17

Marginal external costs for vehicle category are listed in the table below.

Table 12: Disaggregation of PM_{10} air pollution marginal costs for vehicle type

	PM_{10}
	MC Euro / 1000 veh Km
Petrol (cat)	6.1
Petrol car (not cat., LPG, Met.)	6.1
Diesel Car (Florence fleet)	27.9
LGV diesel	34.3
HGV+Bus Diesel	106.9

Motorcycles and mopeds are not taken into account because of lack of reliable data about emission's factors.

Marginal external costs of diesel cars were disaggregated for vehicle's technology in the following table.

Table 13: Disaggregation of PM_{10} air pollution marginal costs for vehicle type

	PM_{10}
	MC (€/ 1000 veh Km)
Diesel Car (conventional not cat.)	30.4
Diesel Car (Euro 1)	11.7
Diesel Car (Euro 2)	8.7

The external marginal cost for gram of PM_{10} (exhaust and not) emitted is equal to: **0.05 € / g.**

The relationships between MC (€ / 1000vkm) and population density (PD) (Inh. / km^2) for vehicle category and technology is listed below:

1. Petrol Car (cat. & not cat.): MC = 0.0014 PD
2. Diesel Car (conventional not cat.): MC = 0.0069 PD
3. Diesel Car (Euro 1): MC = 0.0027 PD
4. Diesel Car (Euro 2): MC = 0.0020 PD
5. Diesel Car (Florence fleet): MC = 0.0063 PD
6. LGV diesel (Florence fleet) : MC = 0.0078 PD
7. HGV & BUS (diesel Florence fleet) : MC = 0.0242 PD

The proposed generalization formula proposed in the previous section can be now estimated for vehicle category:

$$MC = K * (VCF) * PD$$

K = $I_{Florence} / I_{urban\ area}$
VCF = vehicle category factor (e.g. 0.0014 for petrol car)
PD = Population density (Inh. / km^2)

3.2 NOISE

As generally known[27], the calculation of noise impacts and the related monetary evaluations is very difficult, owing to the great number of variables to account for, i.e. source type, characteristics of the noise, background noise levels, etc.

In the Florence case study, a step towards the partially overcoming of such difficulties has been made by the Florence municipality, in collaboration with the Regional Agency for Environmental Protection that, between 1987 and 1996, has conducted an extensively urban campaign for the noise measurement.

More than 300 noise measurement campaigns have been conducted over 170 urban sites involving more than 1,300 days of measurement. All measurements have been performed through the adoption of homogeneous technical criteria.

3.2.1 The classification of urban roads

The main result of the data elaboration is the provision of a noise urban model for the city of Florence. The model allows estimating with the help of statistical tools the following variables:

- the noise levels according to road types;
- the contribution of vehicle types to the noise levels.

The examination of noise levels has been effected through a classification of a set of factors associated with the measured noise emissions. The typology of factors has been diversified as follows:

- Factors related to technical characteristics of pavements, i.e. type of asphalt, etc
- Seasonal effects;
- Day of the week, i.e. working day;
- Topographic characteristics of the road, i.e. flat, flanked by a row of building, with high traffic volume, dedicated to local traffic, etc
- Transit of bus, proximity to the ZTL, limited traffic zones.

Each measurement has been classified with reference to the presence of such factors and a regression analysis has estimated the correlation between noise emissions and group of factors.

[27] ExternE, 1998, vol. 7, pag.456

Some of them resulted not correlated with noise emissions:

- Type of pavement, due to the insignificant presence of type of pavements other than asphalt;
- Type of day (working day or not);
- Seasonal effects

Significant statistical correlations have been found for the following factors:

- road types, in particular the primary roads with high traffic volume; (class A)
- the secondary roads, in proximity or feeding the main roads; (class B)
- the local roads, with frequent bus transits and flanked by rows of buildings. (class L)

The following table shows the contribution in L_Aeq of each factor, differentiated by daytime and night-time.

FACTOR	L_Aeq DAYTIME	L_Aeq NIGHTIME
Urban road (A)	8.5	9.5
Urban road (B)	6.5	7.5
Urban road (L) with bus transits	3.0	3.0
Urban road (L) in proximity of ZTL	2.0	3.0
Constant	58.0	54.5

The factor “constant” indicates the background noise without the impacts of other factors; so that, for instance, the contribution to the noise emissions of urban road (L) in daytime is equal to the background level of 58 L_Aeq adding the proximity to the ZTL (2.0 L_Aeq), and the transit of bus (3.0 L_Aeq).

The urban roads with the most relevant contribution to urban noise levels can be summarised as follows:

URBAN ROAD	L_Aeq DAYTIME	L_Aeq NIGHTIME
A	74.5	69.0
B	72.5	67.0
L	66.0	56.5

It’s interesting to note that the urban roads A and B, with the higher contribution to noise emissions, are also important in terms of diffusion over the urban area.

3.2.2 The noise contribution for vehicle type

The data gathering from the urban noise measurement campaign have been used also for the determination of the contribution to noise emissions by vehicle type.

The measured data concerning the contribution of vehicle types to noise emissions have been elaborated and expressed with reference to the "average car" noise emissions, assumed equal to 1 dB(A) in the table below.

An examples of results, based on measurements in 9 important roads, is the following:

Measurement points	Car	Motorcycle	Heavy Vehicle	Bus
P.zza Vettori	1	1.0	2.8	45.0
Via Cavour	1	1.0	1.0	10.0
Via Nazionale (ZTL)	1	3.0	8.8	8.8
Via Nazionale (no ZTL)	1	1.7	8.8	8.8
Via Orsini	1	1.0	9.4	9.4
Via Salutati	1	1.0	6.6	6.6
Via Bande Nere	1	1.0	6.5	6.5
Via Mosse	1	1.0	9.0	9.0
Via Pira	1	1.0	7.1	7.1

It can be observed that the noise emissions of heavy vehicles on average scale up to a factor from 1 to 10 dB(A) with reference to cars noises.

3.2.3 Marginal costs for noise emissions

The methodology for the appraisal of the marginal costs related to noise impacts borne by road transport, includes the following basic steps:

1. Ranking of roads in three classes (A, B and L);
2. Each class of road is given a Leq(A), by means data regression on measured Leq(A)'s;
3. Use of WTP values – already taken into account by INFRAS/IWW 2000 – (a 0.11% of per capita income increase for each dB(A);
4. Threshold level (L0) have been fixed to 55 dB(A) both for day and 45 dB(A) for night.

For the appraisal of marginal costs per vehicle*hour for reducing 1 dB(A), the following formula has been implemented:

$$LAeq = 44.2 + 10*\log10(car+1.7*moped+8.8*(HGV+bus)$$[28]

This formula corresponds to the noise measurement carried out through regression analysis between measured LAeq and traffic flows by vehicle type over Via Nazionale, an important route of class B.

The graph below shows the trend of marginal external costs compared with flows of equivalent vehicles, where equivalent flows represent the value of flows expressed like flows of cars. The expression used for the graph is:

$$d(L_{eq}) / d(Flow_{eq}) = constant / (Flow_{eq})$$

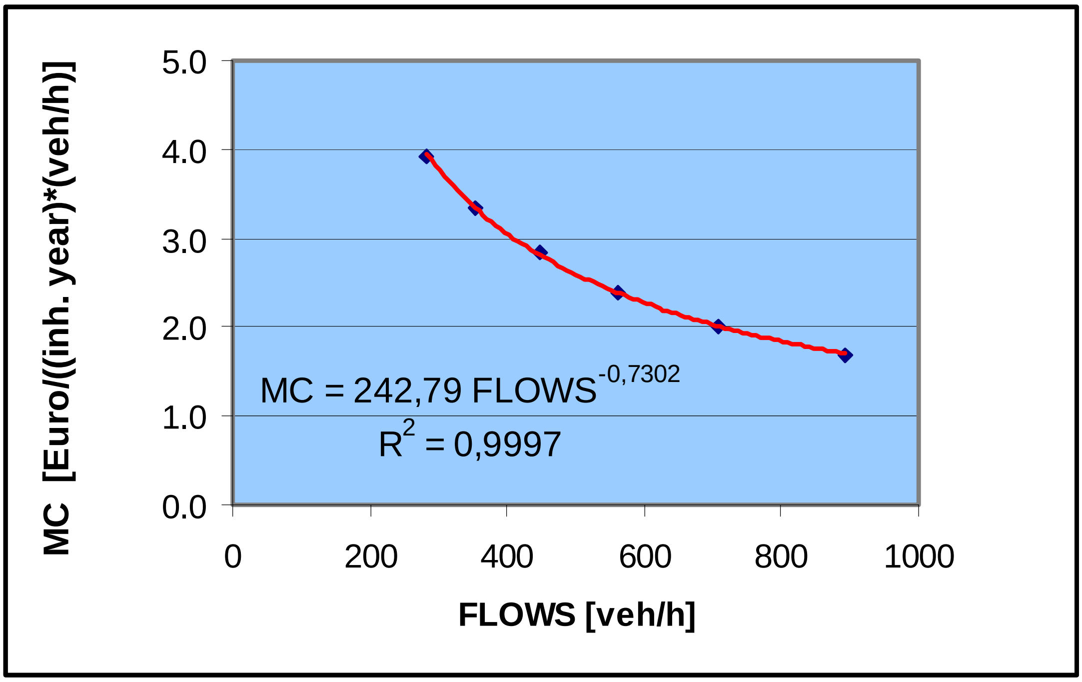
So that:

$$MC = d(WTP * L_{eq}) / d(Flow_{eq})$$

Where:

WTP = Euro/(inh.*year*dB(A))
L_{eq} = equivalent level dB(A)
$Flow_{eq}$= vehicle/hour
MC = marginal costs [€/(inh *year * (veh /h))]

Figure 6: MC trend function of equivalent flows



[28] If traffic flow – vehicle/hour – is over 200, it has to be added 2.4, if traffic flow is less than 300 it has to be added 1.5

This functional form has been carried out through these data and assumptions:

- Per capita income in Florence (1996) = 15082 €
- LA_{eq} = 73.7 dB(A)
- Hours of day : 7:30 – 18:30
- L_0 = 55dB(A)

The results in terms of marginal costs for reducing 1 dB(A) according to the variation of traffic flows are the following:

Vehicle / h	MC [€/((inh. year)*(veh/h))]
891	1.7
708	2.0
562	2.4
447	2.8
355	3.3
282	3.9

These results, and the corresponding functions, are reliable only for the street examined, so that their generalisation to other streets of urban area is not applicable. Different considerations can be drawn for urban streets with similar characteristics (class B), same average speed and fleet composition, where the MC trend found out through the above function could be generalised.

3. 3 GLOBAL WARMING

The methodology underlying the estimation of global warming impacts in the city of Florence is based on the following assumptions:

- economic unit value per tonne of Carbon equivalent provided by literature

- emission rates from the average vehicle fleet composition

Due to the unavailability of case studies concerning the average emissions during particular traffic circumstances, e.g. peak/off peak period, the average emissions are related to the average vehicle fleet composition of the city of Florence.

That is to say that the marginal external cost of global warming does not differ by the average external costs.

The table below shows the marginal cost of Global Warming.

	Displacement (cm^3)	g (CO_2) / vkm	€ /1000 vkm
Petrol car conventional	< 1,400	150.9	3.0
Petrol car conventional	1,400 - 2,000	288.7	5.8
Petrol car Euro I and II	< 1,400	250.3	5.0
Petrol car Euro I and II	1,400 - 2,000	346.1	6.9
Diesel Car conventional	all	291.1	5.8
Diesel Car Euro I and II	all	216.1	4.3
LGV diesel conventional	all	334.8	6.7
LGV diesel Euro I and II	all	416.4	8.3
HGV conventinal	all	879	17.6
HGV Euro I and II	all	1000	20.0
Moped	< 50	75.4	1.5
Motorcycles	> 50	125.4	2.5

Emission factors (based on COPERT II) for urban context are taken from National Environmental Protection Agency (ANPA 2000).
A shadow value of € 20 per tonne of CO_2 emitted, was used for valuing CO_2 emissions.[29]

[29]Link, H. et al., *The Pilot Accounts for Germany, UNITE Deliverable 5.*

9G 4. GENERALISATION OF RESULTS

The generalisation of results represents a crucial issue for the environmental marginal costs studies. In fact, owing to their deep relationship with specific conditions, i.e. traffic situations, geographic context, and meteorological factors, a full exploitation of results can be hampered, if procedures and methods facilitating the transferability in other context are not provided.

The generalisation of specific results to other cities addresses at least two different aspects:

- generalising the methodology, providing that the required input data are available and the methodology is clearly explained

- generalising the results, through a direct transferability of values, providing that the key variables have been identified and adjusted accordingly.

To a great extent the choice depends on the particular type of environmental costs we are dealing with.

The generalisation of marginal costs of noise, for instance, should be mainly based on the methodological aspects. The complexity of urban context, e.g. the extreme variability of morphological conditions, the irregular distribution of receptors, does not allow a direct transferability of the results.

The generalisation of the methodology adopted for the assessment of marginal external costs for noise lies on the following assumptions:

- the availability of a reliable base of empirical data, derived, as in the Florence case study, from an urban campaign of noise measurement over a period of ten years (1987-1996);

- the provision of a "urban noise model" that correlates a set of urban factors, i.e. road type, working day, traffic characteristics, with measured noise levels.

Through the multiple regression analysis, the specification of the most significant factors linked to the noise emissions is found.

- the disaggregation of noise emissions per vehicles type, e.g. cars, buses, motorcycles, heavy vehicles, in order to differentiate the impacts according to the urban fleet.

As result, the urban noise model should lead to the classification of the overall urban roads with reference both to the measured db (A) levels (during daytime and nigh-time) and to specific characteristics. In the Florence case study, the following three types of roads have been identified:

- main urban roads with reference to traffic flow;
- secondary urban roads linked to the main roads;
- roads characterised by local traffic flow

Marginal costs for reducing 1 dB(A) with the variation of traffic flows have been assessed through regression analysis based on measured noise level over a particular road with specific fleet composition (class B). Given the same average speed and traffic conditions, the application of regression analysis for estimating marginal costs can be generalised to other similar roads (class B). The generalisation to other roads can't be carried out without specific measurements.

The monetary evaluation of noise disturbances has been implemented through a WTP approach based on a survey of studies[30].

On the other hand, in the case of marginal costs of air pollution, the generalisation of results can be carried out, provided that the key variables of population density, traffic flows and fleet composition have been taken in account. A standardised measure of the intensity of emission, i.e. the vehicle/hour per km^2, according to the specific city-contexts, should be also included in order to refine the generalisation of results in other context.

If data are available, the generalisation of methodology for air pollution external costs in other contexts involves the following steps:

1. Providing the delimitation of urban areas in urban zones according to specific characteristics, i.e. socio-economic context and traffic situation

2. Estimating a functional relationship between emissions from traffic flows and concentration levels

3. Estimating the incidence of primary pollutants, as PM_{10} and Benzene, directly related to traffic flows and significant from the point of view of health impacts;

[30] INFRAS/IWW, "External cost of Transport", 2000

4. Applying the dose-response functions and monetary unit values as defined by European research projects[31] for impact evaluation

5. Adjusting the marginal external costs with factors accounting for the specific population density and traffic flows.

The delimitation of urban zones is a necessary step in order to define the level of disaggregation for the calculation of marginal costs. Following the Italian national legislation concerning the localisation of air quality monitoring station, at least four typologies of urban zones can be theoretically identified:

- Urban zones "A", not directly interested by emissions from traffic flows, like parks or pedestrian areas, suitable for the analysis of the concentration of "background emissions", both primary and secondary;

- Urban zones "B", situated in highly densely populated areas, suitable for the analysis of the concentration of significant pollutants, both primary and secondary;

- Urban zones "C", with high traffic flows, suitable for the analysis of the concentration of pollutants directly linked to the traffic activities;

- Urban zones "D", situated in peripheral or sub-urban areas.

The practical delimitation of urban zones should be made on "case by case" basis, depending on the site-specific characteristics.

In general, as main criteria, it would be suggested to concentrate the analysis on the monitoring station situated in urban zones "B" and "C", with the exclusion of the monitoring station with too high or too low traffic flows values or situated in areas with particular morphological structure, e.g. canyon with low-building.

In the Florence case study, for example, a single monitoring station, "P.delle Mosse", has been selected as representative of the urban zone "C", as densely populated areas with an average value of traffic flow (vehicle/hour), which could be considered as representative of the average traffic exposure for resident population. Such a choice has also been favoured by the conformation of the city of Florence, quite self-contained around its historical centre, without extended outskirts. In such a way it has been possible to identify a typical concentration level for the overall urban area.

The integration of traffic flows data with the urban zones identified by the monitoring stations should complete the delimitations of urban zones. Traffic flows data, necessary for the emissions analysis are provided by the urban network of sensors. As general rule, the urban areas, which include the traffic flows delimitated by sensors, should overlap with the urban zones delimitated by monitoring stations. An alternative solution

[31] This is the case when there is no availability of local studies concerning dose-response functions or willingness to pay surveys.

would associate two or more micro-areas delimitate by the sensors to one urban zone delimitated by monitoring stations. Again, the choice depends on the distribution of the sensors throughout the urban area.

In the Florence case study, the contiguous localisation of the urban network of sensors, approximately located in the urban zones “B” and “C” (high population density and high traffic level), has led to the choice of considering an average traffic flow related to all sensors as a representative traffic volume of the urban area.

Once the delimitation of urban area in homogeneous urban zones has been performed, the crucial step of the functional analysis between emissions and concentration levels has to be undertaken.

The final result would be a regression line to estimate relationships between traffic flows and concentration level of pollutants for each urban zone. The appropriate set up of data represents a basic requirement for the significance of results. The following issues can be underlined:

- It’s important to gather the meteorological data in a consistent way: solar radiation, wind speed, temperature should be available as monthly average daily hour, in order to account for the seasonal effects on concentration levels. In the Florence case study, the regression analysis has been implemented only for daily hours (solar radiation > 50 W/m^2 or > 0). In other cities, where necessary, the estimation of CO concentration during night-time can be expressed as follows:

  - $$\frac{CO_n}{CO_g} = K$$

  where CO_n is equal to the average night-time CO concentration and CO_g represent average day-time CO concentration.

- It should be suggested to test the regression line with a sufficient number of observations, at least two years, as in the Florence case study.

- The primary pollutant to be adopted for the concentration analysis should be the carbon monoxide (CO), due to its strong linkage with vehicle emissions. The CO concentration level has allowed, in the context of the city of Florence, the study of the correlation with other primary pollutants, e.g. PM_{10} and Benzene, essential for the health impacts evaluation. The correlation analysis between CO concentration and hydrocarbons pollutants could be also assessed for other pollutants, provided that such kind of data have been collected in other cities.

The health impact of air pollution has been assessed through dose-response functions resulting from epidemiological studies. The transferability of such functions in other contexts is commonly accepted, when local studies are not available[32].

[32] See, for example, ExternE, “Externalities of Energy”, 1999, pag.337

On the other hand, the distribution of receptors (population density) represents a highly site-specific data, which should be analysed, as first best solution, on the base of urban surveys of origin-destination movement for each urban zone identified.

In the Florence case study, due to the unavailability of recent survey[33], the population density has been considered for two zones (downtown and peripheral) taking as reference the census, i.e. the resident population.

In summary, the following table shows the proposed methodologies of generalisation, associated with the corresponding data requirements and main uncertainties.

Table 14: Generalising the methodology: data requirements and uncertainties

EXTERNALITIES	METHODOLOGY	DATA REQUIREMENTS	UNCERTAINTIES
AIR POLLUTION	▪ Delimitation of urban area in homogeneous urban zones; combining traffic flows values and concentration levels	▪ Urban network of monitoring station and traffic sensors (*)	▪ Correspondence of urban zones delimitated by monitoring station with traffic flows data.
	▪ Set up of statistical tools for correlation analysis between concentration levels and traffic flows (emissions)	▪ Meteorological data, traffic flows and primary pollutants concentration levels (monthly average daily hour) (*)	▪ Availability of data for at least two years in order to test the results
	▪ Assessing the impact evaluation through dose-response functions	▪ Dose-response functions for mortality and morbidity effects (**)	▪ Transferability of dose-response functions in specific contexts
	▪ Assessing the population density and traffic flows for each urban areas	▪ Origin-destinations matrixes, resident population, traffic flows (*)	▪ Uncertainties of the correlation function for the nigh-time period
	▪ Delimitation of urban area in homogeneous urban zones from the point of view of noise	▪ Urban campaign of noise measurement (*)	▪ Availability and reliability of detailed data on urban noise emissions

33 With reference to the area of Florence, a partial updating of the information concerning the origin/destination matrix has been conducted between April and May 1998, but not released.

EXTERNALITIES	METHODOLOGY	DATA REQUIREMENTS	UNCERTAINTIES
NOISE	emissions ▪ Set up of statistical tools for correlation analysis between noise emissions and road types ▪ Assessing the impact evaluation through WTP surveys	▪ Urban road classification, e.g. type of asphalt, traffic flow, daytime (*) ▪ Population exposed, WTP surveys (**)	▪ Availability of sufficient data for testing the results ▪ Estimation of the population exposed and transferability of WTP values
(*) Site dependent data (**) Data drawn from literature			

ANNEX I: EXPOSURE RESPONSE FUNCTIONS

Receptor	Impact Category	Reference	Pollutant	f_{er}
ASTHMATICS (3.5% of population)				
Adults	Bronchodilator usage	Dusseldorp et al, 1995	PM10, Nitrates, PM2.5, Sulphates	0.163 0.163 0.272 0.272
	Cough	Dusseldorp et al, 1995	PM10, Nitrates, PM2.5, Sulphates	0.168 0.168 0.280 0.280
	Lower respiratory symptoms (wheeze)	Dusseldorp et al, 1995	PM10, Nitrates, PM2.5, Sulphates	0.061 0.061 0.101 0.101
Children	Bronchodilator usage	Roemer et al, 1993	PM10, Nitrates, PM2.5, Sulphates	0.078 0.078 0.129 0.129
	Cough	Pope and Dockery, 1992	PM10, Nitrates, PM2.5, Sulphates	0.133 0.133 0.223 0.223
	Lower respiratory symptoms (wheeze)	Roemer et al, 1993	PM10, Nitrates, PM2.5, Sulphates	0.103 0.103 0.172 0.172
All	Asthma attacks (AA)	Whittemore and Korn, 1980	O3	4.29E-3

Receptor	Impact Category	Reference	Pollutant	f_{er}
ELDERLY 65+ (14% of population)				
	Congestive heart failure	Schwartz and Morris, 1995	PM10, Nitrates, PM2.5, Sulphates, CO	1.85E-5 1.85E-5 3.09E-5 3.09E-5 5.55E-7
CHILDREN (20% of population)				
	Chronic cough	Dockery et al, 1989	PM10, Nitrates, PM2.5, Sulphates	2.07E-3 2.07E-3 3.46E-3 3.46E-3

Receptor	Impact Category	Reference	Pollutant	f_{er}
ADULTS (80% of population)				
	Restricted activity days (RAD)[1]	Ostro, 1987	PM10,	0.025
			Nitrates,	0.025
			PM2.5,	0.042
	Minor restricted activity day (MRAD)[2]	Ostro and Rothschild, 1989	Sulphates	0.042
			O3	9.76E-3
	Chronic bronchitis	Abbey et al, 1995 (after scaling down: see text)	PM10,	2.45E-5
			Nitrates,	2.45E-5
			PM2.5,	3.9E-5
			Sulphates	3.9E-5
ENTIRE POPULATION				
	Chronic Mortality (CM)	Pope et al, 1995 (after scaling down: see text)	PM10,	0.129%
			Nitrates,	0.129%
			PM2.5,	0.214%
			Sulphates	0.214%
	Respiratory hospital admissions (RHA)	Dab et al, 1996	PM10,	2.07E-6
			Nitrates,	2.07E-6
			PM2.5,	3.46E-6
			Sulphates	3.46E-6
		Ponce de Leon, 1996	SO2	2.04E-6
			O3	3.54E-6
	Cerebrovascular hospital admissions	Wordley et al, 1997	PM10,	5.04E-6
			Nitrates,	5.04E-6
			PM2.5,	8.42E-6
			Sulphates	8.42E-6
	Symptom days	Krupnick et al,	O3	0.033
	Cancer risk estimates	Pilkington et al, 1997; based on US EPA evaluations	Benzene	1.14E-7
			Benzo-[a]-Pyrene	1.43E-3
			1,3 butadiene	4.29E-6
			Diesel particles	4.86E-7
	Acute Mortality (AM)	Spix et al / Verhoeff et al, 1996	PM10,	0.040%
			Nitrates,	0.040%
			PM2.5,	0.068%
			Sulphates	0.068%
		Anderson et al / Touloumi et al, 1996	SO2	0.072%
		Sunyer et al, 1996	O3	0.059%

1 Assuming that all days in hospital for respiratory admissions (RHA), congestive heart failure (CHF) and cerebrovascular conditions (CVA) are also restricted activity days (RAD). Also assume that the average stay for each is 10, 7 and 45 days respectively. Thus, net RAD = RAD - (RHA*10) - (CHF*7) - (CVA*45).

2 Assuming asthma attacks (AA) are also minor restricted activity days (MRAD), and that 3.5% of the adult population (80% of the total population) are asthmatic. Thus, net MRAD = MRAD - (AA*0.8*0.035).

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