Air pollution and road transport in Europe. A cluster and a regression analysis among countries and cities

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Abstract

Based on data on pollution ambient concentration levels downloaded from AIRBASE, a European air quality database available on the internet from the European Environmental Agency (EEA), the paper firstly performs a descriptive analysis – mainly ranking and clustering - on four pollutants strongly related to transport activities such as particular matter, ozone, nitrogen dioxide and benzene. Secondly, the paper studies the empirical statistical correlation between air pollution and the characteristics of the economic and transport system at country and city level making use of the available indicators. No clear cut spatial aggregations could be detected, though the northern countries are generally cleaner (more certainly for ozone due to its photochemical nature) than southern countries and western countries are less polluted than eastern countries. Regression analysis resulted in an overall statistically-poor explanatory model. However, some interesting hints could be derived. Per capita income resulted in many instance as the most important explanatory variable. Density is also an important determinant. Car ownership is positively linked to pollution, though its relative importance is minor. The price of petrol proved to be significantly inversely correlated to air pollution. Geographical and meteorological factors play the expected role, especially for ozone pollution, but also for nitrogen dioxide and particulate matter (with data at city level).

1. Introduction

Finding a better balance between air quality and accessibility needs is a goal for many national or city authorities. Yet, how to reach it and what transport policies are more likely to deliver results is an open question.

The aim of the paper is to evaluate the empirical evidence on the relationship between air pollution and the functioning of the transport system across Europe. How large are the differences in air pollution across European countries and cities? Is there a spatial pattern in air pollution? How is air pollution correlated to the characteristics of the transport system such as the number of private cars per inhabitant, the price of petrol or to the socio-economic characteristics of a city such as density or wealth? How do different transport institutional settings and policies affect pollution concentration levels? These are some of the issue the paper will deal with. Though some literature exists at local level (e.g., Haefeli, 2005), to the best of my knowledge, these questions have not received yet much attention at European level.

The task is a difficult one because of a mismatch in the spatial dimension. Air pollution is a local phenomena. Ambient concentration levels can be very diversified within a city or even within a street. For instance, pollutants concentration is higher at junctions where stop-and-go manoeuvres take place. On the contrary, transport systems have a wider spatial dimension. Some characteristics of the transport system vary by city (i.e., the provision of public transport, traffic regulations, etc.) while other have a national dimension (i.e., the price of petrol, the fiscal burden on cars, etc.). The choice of the level of aggregation at which to study the relationship between air pollution and the functioning of the transport system is consequently a difficult and a discretionary one. Because of our interest in comparing European countries, in this paper a choice was made to use indicators of air pollution and of transport mainly at a national level, tough some analysis at city level is also performed.

A second difficulty, as in most empirical studies, is related to data availability and comparability. Both air pollution and transport data tend to be collected at national level with different methodologies and levels of detail. Luckily, much progress has been made in the last years in collecting comparable data thanks to various European institutions and programmes. Urban environmental quality indicators are collected and made available by the European Environmental Agency. Transport statistics are reported by the European Commission.

The paper will firstly, in Section 2, perform some descriptive analysis on air quality describing the country results, ranking and clustering countries according to the various pollutants indicators (annual mean, maximum value, occurrence of exceedance). Four pollutants strongly related to transport activities in urban areas will be taken into consideration: particular matter (PM_{10}), ozone (O_3), nitrogen dioxide (NO_2) and benzene (C_6H_6). It will be possible to evaluate how big is the difference across Europe in average ambient concentration levels in urban areas and identify possible spatial patterns using cluster analysis, for instance, between western and eastern countries or northern and southern countries.

Finally, in Section 3, the paper will explore the empirical statistical correlation between air pollution and the characteristics of the economic and transport system at country and city level making use of the available indicators.

2. Air pollution in Europe

There is a large body of evidence suggesting that exposure to air pollution, even at the levels commonly achieved nowadays in European countries, leads to adverse health effects. In particular, exposure to pollutants such as particulate matter, ozone and nitrogen dioxide has been found to be

associated with increases in hospital admissions for cardiovascular and respiratory disease and mortality in many cities in Europe and other continents.
Various EEA studies document that air pollution remains a problem in most European cities. The *State of the Environment 2005* (EEA, 2005) reports that large fractions of the urban population are exposed to concentrations of air pollutants in excess of the health-related limits or target values defined in the air quality directives.
PM_{10} appears to be a pan-European air quality issue. The limit values are exceeded at urban measuring stations for background concentrations in nearly all countries. It appears that a significant proportion of the urban population (25–55 %) is exposed to concentrations of particulate matter in excess of the EU limit values set for the protection of human health.
Ozone is also a widespread problem, although the health-related target values are less frequently exceeded in north-western than in southern, central and eastern Europe. About 30 % of the urban population was exposed to concentrations above the 120 μg O^3/m^3 level during more than 25 days in 2002.
Nitrogen dioxide limit values are exceeded in the densely populated areas. It is roughly estimated that about 30% of the urban population live in cities with urban background concentrations in excess of the annual limit value of 40 $\mu g/m^3$ of nitrogen dioxide.
On the contrary, sulphur dioxide (SO_2) is not a problem anymore. Exceedances of SO_2 limit values are observed only in a few eastern European countries. The percentage of the urban population exposed to concentrations above the EU limit value has been reduced to less than 1 %. The reason is that since the 1960s, the combustion of sulphur-containing fuels has largely been removed from urban and other populated areas, first in western Europe and now also increasingly in most central and eastern European countries.
This paper will focus on 4 pollutants, recognized as directly or indirectly associated with adverse health effects[1], for which there exists a reasonable number of monitoring stations: PM_{10}, O_3, NO_2 and benzene.
The most comprehensive collection of data of air quality is provided by the European Air Quality database system, AIRBASE, a European AIR quality database managed by the European Topic Centre on Air Quality and Climate Change (ETC/ACC), under contract to the European Environmental Agency (EEA). The information stored in AIRBASE is available to the public via the Internet (http://air-climate.eionet.eu.int/databases/airbase/index_html). A total of 32 countries, including 24 EU Member States, provided air quality data for 2003. The database covers geographically all countries from the European Union, the EEA member countries and some EEA candidate countries[2].

2.2 Types of monitoring stations

The source of the environmental data which will be used are the urban monitoring stations stored in AIRBASE. Therefore it is important to look carefully into their characteristics. They are classified according to the type of area in which the station is located and to the type of sources that dominate the air quality at the station (Mol and van Hooydonk, 2005). According to location, they are classified into:
- *Urban*: station located in a city.
- *Suburban*: station located on the outskirts (fringe) of a city, or in small residential areas outside a main city.
- *Rural*: station located outside a city.

[1] Air pollution exists as a complex mixture and the effects attributed to single pollutants may be influenced by the underlying toxicity of the full mixture of all air pollutants.
[2] The EU countries are bound to report under the Council Decision 97/101/EC, a reciprocal exchange of information on ambient air quality, while the EEA member countries committed themselves to report to the EEA following this EU-legislation or develop the appropriate measuring and reporting infrastructure following EEA's EuroAirnet programme criteria. All data reported within EuroAirnet context are included in the database.

According to the type of source, they are distinguished into:

- *Traffic station:* located such that its pollution level can be determined predominantly by the emissions from nearby traffic (roads, motorways).
- *Industrial:* located such that its pollution level is influenced predominantly by emissions from nearby single industrial sources or industrial areas with many sources.
- *Background:* located such that its pollution level is not influenced significantly by any single source or street, but by the integrated contribution from all sources upwind of the station. These stations can be located both inside (*urban background*) and outside cities.

Several issues still exist in order to assure comparability among the readings of different monitoring stations. For a summary of the debate on the comparability issue one can look at the document produced by the World Health Organization (WHO, 2005) which stressed the importance of

- using of appropriate correction factors if different automatic methods for PM_{10} monitoring were used;
- standardising the siting criteria for the sampling locations;
- comparing and exchanging information/data between the diverse AQ monitoring networks operating in the country.

Because the objective of this study is to investigate the relationship between urban air quality and the functioning of the urban transport system, it seemed appropriate to restrict attention only to the data deriving from monitoring stations classified in the AIRBASE database as “urban” and “traffic”, that is located in an urban area and measuring pollution levels determined predominantly by nearby traffic.

From the AIRBASE database the information has been extracted on monitoring stations which reported data on particulate matter with a diameter equal to or less than 10 µm (PM_{10}), nitrogen dioxide, ozone, benzene within the period January 2003-December 2003. Data was downloaded in the period November, 18^{th}-21^{st}, 2005. Sulphur dioxide has not been investigated because of its well-documented decreasing relevance as a traffic-related pollutant.

2.3 Particulate Matter

Airborne particle (particulate matter, PM) levels that may be relevant to human health are commonly expressed in terms of the mass concentration of inhalable particles with an equivalent aerodynamic diameter equal to or less than 10 µm (PM_{10}) or equal to or less than 2.5 µm ($PM_{2.5}$).

PM in the atmosphere can result from direct emissions (primary PM) or emissions of particulate precursors (nitrogen oxides, sulphur dioxide, ammonia and organic compounds) which are partly transformed into particles by chemical reactions in the atmosphere (secondary PM).

Epidemiological studies have reported statistically significant associations between short-term, and especially long-term, exposure to increased ambient PM concentrations and increased morbidity - such as increased symptoms for asthmatics, respiratory symptoms, reduced lung capacity - and (premature) mortality. It is thought that the finer the particles the more dangerous are for the human health. Although the body of evidence concerning the health effects of PM is increasing rapidly, according to WHO (2003) it is not possible to identify a concentration threshold below which health effects are not detectable. However, the EU with the Directive 1999/30/EC, Annex III has set the limit values for concentrations of PM_{10} reported in Table 1.

Table 1 - LIMIT VALUES FOR PARTICULATE MATTER (PM10)

	Averaging period	Limit value	Date by which limit value is to be met
1. 24-hour limit value for the protection of human health	24 hours	50 µg/m^3 PM_{10}, not to be exceeded more than 35 times a calendar year	1 January 2005

2. Annual limit value for the protection of human health	Calendar year	40 µg/m³ PM_{10}	1 January 2005

A general, essential information to correctly interpret the results of the tables illustrated below concerns the number and the location of the monitoring stations reported in the AIRBASE database. The number of stations measuring pollution concentration, though rapidly growing, is still quite limited and varies by pollutant. While in some western European states the number of stations is large enough to assure statistical representitiveness, in other western European and, especially, eastern European states the number of monitoring stations is so small to be of little of no representitiveness. It needs to be stressed that we have information on the monitoring stations reported in the database under various European Community obligations or commitments. Such number might differ from the number of working monitoring stations actually in operation in each country.

Table 2 – Average countries indicators of PM_{10} concentration (January-December 2003)

Rank	Country	Stations	Inhab. per station	Annual daily Mean	Maximum	Occurrence
1	Finland	17	308	19.1	120.0	11.1
2	Iceland	1	293	19.4	102.9	16.0
3	France	22	2,736	27.7	78.3	19.6
4	Ireland	6	49	28.4	131.2	34.5
5	Switzerland	7	1,045	29.8	115.4	32.7
6	Norway	5	915	30.7	167.7	44.0
7	Great Britain	11	5,191	31.6	98.1	49.5
8	Denmark	4	1,353	32.6	160.6	38.8
9	Austria	20	407	33.4	139.4	56.4
10	Germany	106	779	33.9	124.2	40.3
11	Slovakia	6	896	34.0	120.0	53.2
12	Hungary	5	2,028	35.4	153.3	92.0
13	Lithuania	7	489	35.6	142.9	60.3
14	Sweden	4	2,253	36.8	348.8	62.0
15	Spain	63	700	37.5	116.1	54.2
16	Netherlands	10	1,629	38.1	103.6	45.7
17	Estonia	1	1,356	38.3	147.0	78.0
18	Belgium	4	2,599	40.4	129.0	73.3
19	Romania	1	21,681	41.1	113.0	86.0
20	Italy	71	815	41.8	127.5	66.4
21	Czech Republic	10	1,021	42.3	172.7	86.6
22	Portugal	12	873	45.5	154.2	118.1
23	Greece	9	1,216	48.8	170.6	91.1
24	Slovenia	3	655	51.9	144.7	148.7
25	Latvia	1	2,346	55.7	156.4	105.0
26	Cyprus	1	749	57.3	664.9	176.0
27	Macedonia	1	2,023	65.3	211.0	185.0
28	Poland	2	19,087	67.2	308.0	184.0
	All Countries	410	2,696	36.1	129.8	54.3

Legenda:
Rank: country ranking on annual daily means
Stations: n° of stations with PM_{10} measurements
Inhab. per station: n° of inhabitants per monitoring station in thousands
Annual mean: average annual concentration mean across urban, traffic stations
Maximum: average maximum concentration value across urban, traffic stations
Occurrence: occurrence of exceedance average n° of days with a PM_{10} concentration > 50 ug/m³ across stations

Let us consider the data reported in Table 2. The first two columns concern the monitoring stations. It can be noticed that the number of monitoring stations reported in the AIRBASE database is quite different among countries, even relative to the country size in terms of inhabitants (column three). Ireland has a monitoring station for every 49 thousand inhabitants. Germany has the largest absolute number of stations, with a station for every 779 thousand inhabitants. France has a quite limited number of stations with a station for every 2,7 million inhabitants. The coverage is even poorer in Great Britain with a station for every 5,191 inhabitants. Some eastern European countries do not have a good coverage, with the more populated states (Romania and Poland) ranking lowest with a station for every 20 million inhabitants.
Three types of pollution indices are reported in Table 2: the annual daily mean, the maximum concentration value averaged across traffic stations, and the number of days with a concentration larger than 50 ug/m^3 weighted on the number of monitoring stations to assure comparability (termed in the literature "occurrence of exceedances"[3]). These data tend to be correlated. Countries are listed based on their rank (from the least polluted to the most polluted) relative to the annual mean.
Considering that annual limit value for the protection of human health set by UE at a annual concentration greater than 40 ug/m^3 for the year 2005 (Table 1), it can be noted that 11 countries were, at average national level, above that limit. In Poland, for instance, the daily average concentration level of 50 ug/m^3 is overcome 184 days a year, on average, in the monitoring stations. On the other side of the spectrum, the attention level in Finland is overcome, on average, 11 days in a year.
In order to come up with a summary spatial judgement a hierarchical cluster analysis using the complete linkage (furthest neighbour) method[4] has been performed on the data on annual mean and on occurrences at the same time. Only these two variables have been used in the cluster analysis because they have been judged more interesting and representative whereas the information on maximum values can be easily distorted by local factors. Note that the two indices have been considered at the same level of importance since any weighting appeared to be discretionary. 5 groupings have been identified (the dendograms for this and the next cluster analyses are reported in Danielis, 2006):

Tab. 2 – Results of the cluster analysis for PM_{10} indices

Cluster	*Countries*	*Average annual mean*	*Average occurance*
1	Finland, Iceland, France, Ireland, Switzerland	24.9	22.8
2	Norway, Great Britain, Denmark, Austria, Germany, Slovakia, Lithuania, Sweden, Netherlands. Spain	34.4	50.4
3	Hungary, Estonia, Belgium, Romania, Italy, Czech Republic	39.9	80.4
4	Portugal, Greece, Latvia	50.0	104.7
5	Slovenia, Cyprus, Macedonia, Poland	60.4	173.4

The northern European countries appear in the first two groups, with an average annual mean well below the European limit value. The Mediterranean countries are mostly in the third and forth group (apart from Spain and France). Eastern countries are spread in various groups. Slovenia and Poland - the countries with the highest income levels among the eastern European countries - are in the last group together with Macedonia and Cyprus.

[3] "Since the number of stations differs widely from country to country, the absolute number of exceedance days does not offer a suitable comparison of the situation in different countries. Therefore, the concept of 'occurrence of exceedance' has been introduced. Occurrence of exceedance is defined as the average number of observed exceedances per country, i.e. the total number of exceedances for all stations divided by the total number of operational stations. Although this parameter is more comparable between countries, the differences in network, in particular, the ratio between different types of station, limits the comparability." (EEA, 2005).
[4] The cluster analysis has been performed with the SPSS package. The complete linkage (furthest neighbor) method has been chosen because it is the one which identifies cluster characterized by a higher degree of internal homogeneity and external difference. Since the two variables used (annual mean and occurrences) are not homogeneous they have been standardized with the *z* values.

2.4 Ozone

Ozone is the most important photochemical oxidant in the troposphere. It is formed by photochemical reactions in the presence of precursor pollutants such as NO_x and volatile organic compounds. In the vicinity of strong NO_x emission sources, where there is an abundance of NO, O_3 is "scavenged" and as a result its concentrations are often low in busy urban centers and higher in suburban and adjacent rural areas. On the other hand, O_3 is also subject to long-range atmospheric transport and is therefore considered as a trans-boundary problem. As a result of its photochemical origin, O_3 displays strong seasonal and diurnal patterns, with higher concentrations in summer and in the afternoon.

The main sectors that emit ozone precursors are road transport, power and heat generation plants, households (heating), industry and petrol storage and distribution.

In short-term studies of pulmonary function, lung inflammation, lung permeability, respiratory symptoms, increased medication usage, morbidity and mortality, O_3 appears to have independent effects (especially in the summer)[5]. For long-term effects the results are not entirely consistent.

The current WHO Air quality guidelines (AQG) (WHO, 2000) for O_3 provide a target value of 120µg/m3 (60 ppb), based on controlled human exposure studies, for a maximum 8-hour concentration. It is estimated that only 9% of the urban population experienced no exceedance of the 120 microgramme O_3/m^3 level, while about 30% of the urban population was exposed to concentrations above the 120 microgramme O_3/m^3 level during more than 25 days. The target level was exceeded over a wide area and by a large margin.

Table 3 – Ozone limits

	Level ($\mu g/m^3$)	Averaging time
Information threshold	180	1 hour
Alert threshold	240	1 hour
Long-term objective	120	8-hour average, daily maximum
Target value	120, not to be exceeded on more than 25 days per calendar year over three years	8-hour average, daily maximum

Because of the photochemical nature of the ozone reaction, ozone formation and ozone exceedance is a seasonal phenomenon. That is why some studies concentrate their attention only to the summer period. The year 2003 had an exceptionally hot summer with long spells of unusually high temperatures of about 35° Celsius even in the northern European countries, with the western countries showing higher temperatures than the eastern countries.

Table 4 – Average countries indicators of ozone concentration in the summer months (April to September 2003)

Rank	Country	Stations	Inhab. per station	Annual hourly Mean	Maximum	Occurrence
1	Great Britain	3	19,035	24.4	137.3	2.3
2	Lithuania	6	571	29.8	111.7	0.0
3	Estonia	1	1356	32.7	102.0	0.0
4	Denmark	2	2706	32.9	109.2	0.0
5	Netherlands	5	3,258	34.7	209.9	9.8
6	Belgium	2	5198	37.8	252.0	27.5

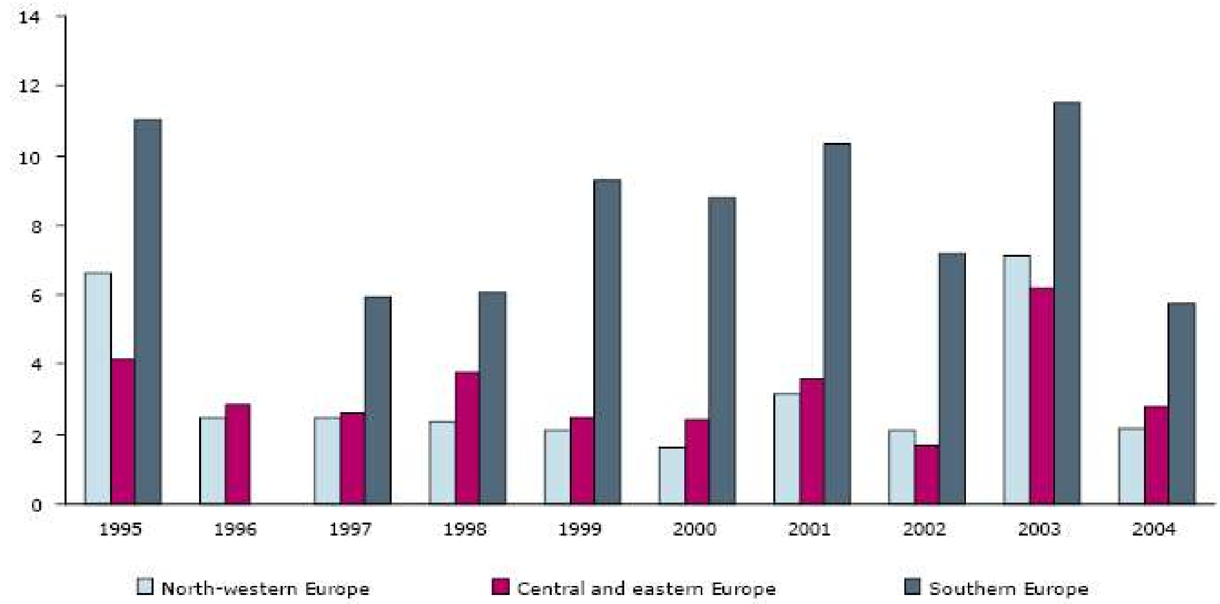
[5] Epidemiological studies show that short-term effects of O_3 can be enhanced by particulate matter and vice versa. Experimental evidence from studies at higher O_3 concentrations shows synergistic, additive or antagonistic effects, depending on the experimental design, but their relevance for ambient exposures is unclear. O_3 may act as a primer for allergen response.

7	France	7	8600	38.9	187.1	19.6
8	Iceland	1	293	39.2	99.8	0.0
9	Finland	1	5237	39.8	123.0	0.0
10	Spain	104	424	39.8	164.0	10.2
11	Portugal	9	1,164	40.0	194.8	6.1
12	Greece	8	1367	40.9	181.1	33.3
13	Ireland	2	147	40.9	148.9	3.0
14	Germany	37	2231	41.7	195.3	30.1
15	Hungary	4	2536	41.9	176.7	22.0
16	Austria	7	1163	43.5	189.1	43.6
17	Sweden	1	9011	44.1	117.3	0.0
18	Slovenia	3	655	44.2	176.1	38.7
19	Switzerland	7	1,045	44.2	195.9	45.7
20	Czech Republic	3	3,404	44.3	175.7	24.7
21	Italy	47	1232	45.5	214.6	45.7
22	Cyprus	1	749	51.0	149.0	7.0
23	Macedonia	1	2,023	59.5	161.5	41.0
		262	3,191	41.0	178.0	20.4

Legenda:
Rank: country ranking on annual hourly means
Stations: n° of stations with O_3 measurements
Inhab. per station: n° of inhabitants per monitoring station in thousands
Annual mean: average annual hourly concentration mean across urban, traffic stations
Maximum: average maximum concentration value across urban, traffic stations
Occurrence: occurrence of exceedance average n° of days with a O_3 concentration > 120 ug/m^3 across stations

The number or urban, traffic monitoring sites is lower for ozone than for particulate matter (262 vs. 410) and they are unequally distributed between countries and also within countries (in Italy, e.g. the coverage in the North is much higher than in the South).
Because of the photochemical nature of ozone formation, one would expect the northern countries to exhibit higher ozone concentration level than southern countries. Fig. 3, extracted from a detailed study published by EEA (EEA, 2005), document that southern European countries had over the years consistently higher ozone exceedances in absolute terms.

Figure 4.1 Average occurrence (the number of exceedance per station) per region for stations, which reported at least one exceedance, observed during the year



Note:
North-western Europe: United Kingdom, Ireland, the Netherlands, Belgium, Luxembourg and France north of latitude 45 °.
Central and eastern Europe: Germany, Poland, the Czech Republic, Slovakia, Hungary, Austria and Switzerland.
Southern Europe: France south of latitude 45 °, Portugal, Spain, Italy, Slovenia, Greece, Cyprus and Malta.
Northern Europe has not been included in this figure because of the low number of exceedances.

Source: EEA, Air pollution by ozone in Europe in summer 2004 (2005, p. 27)

A similar classification to the one used in the EEA study[6] – but with the difference that it is performed on urban, traffic monitoring stations only, France is assigned to the north of Europe, and Macedonia substitutes Malta – produces for the summer 2003 the following results for the annual hourly mean, consistent with the EEA study: North-western Europe: 62; Central and eastern Europe: 166; and Southern Europe: 181. Our calculations therefore confirm that southern European have much higher ozone concentration levels than northern European countries, but not very different from the central and eastern European countries, at least in the summer 2003.
Furthermore, the cluster analysis conducted both on the annual mean and on the daily occurrences averaged across monitoring stations identifies 6 groupings. Ordered from the less to the more polluted they are:

Table 5 – Result of the cluster analysis for ozone indices

Cluster	Countries	Average annual mean	Average occurance
1	Great Britain, Lithuania, Estonia, Denmark, Netherlands	30.9	2.4
2	Iceland, Finland, Portugal, Ireland, Spain, Sweden	41.2	6.3
3	Belgium, France, Greece, Germany, Hungary, Czech Republic	40.2	26.5
4	Austria, Switzerland, Italy, Slovenia	44.4	43.4
5	Cyprus	51.0	7.0
6	Macedonia	59.5	41.0

[6] North-western Europe comprises: the United Kingdom, Ireland, the Netherlands, Belgium, Luxembourg and France north of 45° latitude, roughly corresponding to the line Bordeaux–Valence–Briançon. Central and eastern Europe includes: Germany, Poland, the Czech Republic, Slovakia, Hungary, Austria and Switzerland, and Southern Europe: France south of 45 ° latitude, Portugal, Spain, Italy, Slovenia, Greece, Cyprus and Malta.

It is interesting to note that in the exceptionally hot summer 2003 the spread in average annual (summer) means is not very large. Spain and Portugal belong to the second group comprising otherwise mostly northern countries. Austria and Switzerland share with Italy and Slovenia the fourth group with a quite large number of average occurrences. Macedonia stands apart with a very high average concentration value.

2.5 Nitrogen Dioxide

Nitrogen dioxide is formed in the environment from primary emissions of oxides of nitrogen. Although there are natural sources of NO_x (e.g., forest fires), the combustion of (fossil) fuels is the major contributor in European urban areas. In fact, vehicular traffic has largely replaced other sources (e.g., domestic heating, local industry) as the major outdoor source of NO_x from fossil fuel combustion (WHO, 2003).
NO_2 is also subject to extensive further atmospheric transformations that lead to the formation of O_3 and other strong oxidants that participate in the conversion of NO_2 to nitric acid and SO_2 to sulphuric acid and subsequent conversions to their ammonium neutralization salts. Thus, through the photochemical reaction sequence initiated by solar-radiation-induced activation of NO_2, the newly generated pollutants formed are an important source of nitrate, sulphate and organic aerosols that can contribute significantly to total PM_{10} or $PM_{2.5}$ mass. For these reasons, NO_2 is a key precursor for a range of secondary pollutants whose effects on human health are well documented.
Short-term exposure to nitrogen dioxide may result in airway and lung damage, decline in lung function, and increased responsiveness to allergens following acute exposure. Toxicology studies show that long-term exposure to nitrogen dioxide can induce irreversible changes in lung structure and function.
With regard to protection against acute health effects, either the peak-hour average or 24hr (daily) average NO_2 concentrations can be used as a measure of direct short-term exposure, since they are highly correlated in urban areas. The need for guideline value is supported by the evidence on possible direct effects of NO_2 and on its indirect consequences through the formation of secondary pollutants. The EU limit values are reported in Table 6.

Table 6 - Limit values for nitrogen dioxide

	Averaging period	Limit value	Date by which limit value is to be met
1. Hourly limit value for the protection of human health	1 hour	200 µg/m^3 NO_2, not to be exceeded more than 18 times a calendar year	1 January 2010
2. Annual limit value for the protection of human health	Calendar year	40 µg/m^3 NO_2	1 January 2010
3. Alert threshold for nitrogen dioxide		400 µg/m^3 measured over three consecutive hours	

It is estimated that about 30% of the urban population lives in cities with urban background concentrations in excess of the 40 micrograms NO_2/m^3 limit value. However, it is expected that also in cities where the urban background concentration is below the limit value, limit values are exceeded at hot spots, in particular in locations with high density of traffic. Peak nitrogen dioxide levels occur often in busy streets in cities where road traffic is the main source.

Table 7 – Average countries indicators of NO_2 concentration

Rank	Country	Stations	Inhab. per station	Annual Hourly Mean	Maximum	Occurrence	Annual Daily Mean

1	Ireland	4	73	23.7	155.9	0.3	23.7
2	Iceland	1	293	23.8	249.0	5.0	23.8
3	Slovakia	6	896	28.3	151.7	1.2	28.3
4	Macedonia	1	2,023	28.3	132.4	0.0	28.3
5	Finland	10	524	29.3	167.4	0.3	29.3
6	Lithuania	7	489	30.9	166.7	2.3	30.8
7	Slovenia	2	982	34.7	142.2	0.0	34.5
8	Sweden	3	3,004	36.3	186.4	0.3	36.2
9	Estonia	1	1,356	37.5	172.5	0.0	37.4
10	Spain	80	551	39.7	206.2	7.2	39.7
11	Portugal	14	748	40.3	188.6	2.9	40.3
12	Austria	29	281	40.5	165.8	0.6	40.4
13	Hungary	7	1,449	41.1	208.5	2.1	41.1
14	Cyprus	1	749	41.9	132.0	0.0	42.0
15	Switzerland	8	915	44.0	155.2	0.4	44.0
16	Denmark	5	1,082	44.5	196.9	0.8	44.5
17	Germany	114	724	45.1	181.1	2.6	45.1
18	Norway	4	1,144	45.9	334.6	14.3	45.9
19	Czech Republic	11	928	n.d.	n.d.	n.d.	46.9
20	Netherlands	10	1,629	48.0	203.8	1.5	48.0
21	Belgium	6	1,733	50.1	199.7	6.7	50.1
22	Greece	10	1,094	51.6	217.1	9.6	51.6
23	France	35	1,720	52.0	211.9	8.4	52.0
24	Italy	132	439	53.6	227.5	11.9	53.6
25	Great Britain	23	2,483	55.9	216.3	24.9	55.9
26	Poland	2	19,087	59.7	202.0	4.0	59.8
		532		39.5	183.5	4.1	39.3

Legenda:
Rank: country ranking on annual hourly means
Stations: n° of stations with NO_2 measurements
Inhab. per station: n° of inhabitants per monitoring station in thousands
Annual mean: average annual hourly concentration mean across urban, traffic stations
Maximum: average maximum concentration value across urban, traffic stations
Occurrence: occurrence of exceedance average n° of days with a NO_2 concentration > 200 ug/m^3 across stations

Information drawn from the AIRBASE database shows that the total number of monitoring stations is larger than for PM_{10} but it is highly concentrated in few countries. Two countries, Italy and Germany, make up almost half of the total monitoring stations while others, such as Sweden and Great Britain, are represented by a very limited number of stations.
The annual means is scattered from the low levels of Ireland and Iceland to the twice as high levels of France, Italy, Great Britain and Poland. At country level, more than half of the countries have an annual mean superior to the annual limit value for the protection of human health set by the EU (see Table 6). Abiding to the EU directive is not going to be an easy task.
Note that the ranking over the annual mean is quite different from the ranking over the average occurrences, proving that NO_2 concentration is determined by a variety of local factors such as meteorology and wind factors.
The cluster analysis conducted both on the annual mean and on the occurrences identifies 5 groupings ordered from the less to the more polluted:

Table 8 – Result of the cluster analysis for NO_2 indices

Cluster	Countries	Average annual mean	Average occurance
1	Ireland, Iceland, Slovakia, Macedonia, Finland, Lithuania	27.4	1.5
2	Slovenia, Sweden, Estonia, Spain, Portugal, Austria, Hungary, Cyprus, Switzerland, Denmark, Germany, Netherlands	41.1	1.5
3	Belgium, Greece, France, Poland	53.4	7.2

4	Norway, Italy, Great Britain	51.8	17.0

Within the first group it is surprising to find, together with the traditionally low polluted, small northern European countries such as Ireland, Iceland and Finland, eastern countries such as Slovakia and Lithuania (Macedonia has only was stations). The second group is quite heterogeneous as well, comprising northern and southern countries, countries with a reputation of having low pollution levels and countries with a reputation of being highly polluted. The third and fourth group comprise as well a varied group of countries with different size and geographical location. Nitrogen dioxide, hence, does not appear to have a easily identified spatial pattern.

2.6 Benzene

At normal ambient temperatures benzene (C_6H_6) is a liquid, but it readily evaporates and small amounts are detectable in the atmosphere. Almost all of the benzene found at ground level is likely to have resulted from human activities, in particular the combustion of petroleum fuels by motor vehicle engines. Cigarette smoking is another major contributor to the exposure of individuals.

Studies of workers exposed to benzene in industrial workplaces have shown that they have run a small, but definite, increase in risk of developing certain types of leukaemia. Studies in laboratory animals have shown similar effects, and have suggested moreover that benzene is a genotoxic carcinogen.
It is thought impossible to determine a concentration to which people might be exposed at which there is no risk detectable. But for practical purposes the EU Directive 2000/69/EC recommended an Air Quality Standard for benzene of 5 ppb as a running annual average.

Table 9 - Limit values for benzene

	Averaging period	Limit value	Date by which limit value is to be met
Limit value for the protection of human health	Calendar year	5 μg/m^3	1 January 2010

Table 10 – Average countries indicators of benzene concentration

Rank	Country	Stations	Inhab. per station	Annual Mean	Maximum
1	Ireland	2	147	0.6	2.0
2	Iceland	1	293	1.1	3.3
3	Denmark	1	5,411	1.2	3.3
4	Belgium	1	10,396	1.3	7.3
5	Lithuania	1	3,425	1.7	12.7
6	Portugal	3	3,492	1.9	10.0
7	Netherlands	1	16,292	2.1	5.1
8	Spain	18	2,450	2.4	9.7
9	Czech Republic	3	3,404	2.5	10.8
10	Germany	54	1,528	2.6	8.3
11	Great Britain	10	5,710	2.8	6.4
12	Slovakia	3	1,793	4.1	11.7
13	Italy	33	1,754	4.3	13.0
14	France	4	15,050	5.1	12.3
		135		3.0	9.6

Legenda:
Rank: country ranking on annual hourly means
Stations: n° of stations with benzene measurements
Inhab. per station: n° of inhabitants per monitoring station in thousands
Annual mean: average annual hourly concentration mean across urban, traffic stations
Maximum: average maximum concentration value across urban, traffic stations

The number of monitoring station operating in the year 2003 is much smaller than for other pollutants. Again, Germany and Italy alone comprise for more than half of the total monitoring stations. The representativeness of the data reported in Table 10 is consequently quite limited. Keeping this in mind, Ireland and Iceland continue to rank among the "cleanest" countries, whereas Slovakia, Italy and France show quite high concentration values. France has a national average above the limit value for the protection of human health set by the EU (see Table 9).
The cluster analysis conducted both on the annual mean and on the maximum value averaged across monitoring stations identifies 4 groupings. Ordered from the less to the more polluted they are:

Table 11 – Result of the cluster analysis for NO_2 indices

Cluster	Countries	Average annual mean	Average occurance
1	Ireland, Iceland, Denmark	0.9	2.9
2	Belgium, Netherlands, Great Britain, Germany	2.2	6.8
3	Lithuania, Portugal, Czech Republic, Spain	2.1	10.8
4	Slovakia, Italy, France	4.5	12.3

In the first group the traditionally clean countries of northern Europe can be found. Germany is well positioned in the second group, Spain in the third and Italy is lagging in the fourth group, together with Slovakia and France (with a much lower number of monitoring points). Because of the poor representitiveness of the data no spatial conclusion can be drawn.

2.7 Country clusters considering pollutants jointly

So far we have analysed countries considering each pollutant separately. Let us consider all pollutants jointly, that is, PM_{10}, O_3, NO_2 and benzene. How do countries group and rank?
12 countries only reported information on all 4 pollutants. Considering as a pollution indicator the annual mean there appear to be the groupings reported in Table 12.

Table 12 – Result of the cluster analysis for all four pollution indices

Cluster	Countries	Benzene	O_3	NO_2	PM_{10}
1	Ireland, Iceland	0.8	40.1	23.7	23.9
2	Denmark, Lithuania, Netherlands	1.6	32.5	41.1	35.4
3	Belgium, Germany, Spain	2.1	39.8	45.0	37.3
4	Portugal	1.9	40.0	40.3	45.5
5	Great Britain	2.8	24.4	55.9	31.6
6	France	5.1	38.9	52.0	27.7
7	Italy	4.3	45.5	53.6	41.8

Ireland and Iceland group together with the lowest levels of most pollutants, apart from ozone. The second cleanest grouping comprises the northern countries of Denmark, Lithuania, Netherlands. Belgium, Germany, Spain group together, whereas Portugal, Great Britain, France are in a group of their own. Notice that these countries cannot be univocally ranked since they score high in some pollutants and low in others. On the contrary Italy is on a group of his own with worse annual mean concentration levels for all pollutants, apart for benzene relative to France.
Excluding benzene, 22 countries report data on PM_{10}, NO_2 and O_3. 5 groupings can be traced out as reported in Table 13.

Table 12 – Result of the cluster analysis for three pollution indices

Cluster	Countries	O_3	NO_2	PM_{10}
1	Finland, Iceland, Ireland	40.4	26.5	23.7
2	Great Britain	24.4	55.9	31.6
3	Spain, Hungary, Sweden, Portugal, Denmark, Netherlands, Estonia, Lithuania	37.0	39.8	37.5
4	Austria, Switzerland, Germany, France, Belgium, Greece, Italy	41.5	45.1	34.4
5	Slovenia, Cyprus, Macedonia	51.5	34.9	58.2

Finland, Iceland, Ireland are in the grouping of the clean countries with the exception of ozone. Great Britain is in an individual group with low levels of O_3 and PM_{10}, but high levels of NO_2. Spain, Hungary, Sweden, Portugal, Denmark, Netherlands, Estonia, Lithuania are a moderately clean group of countries. Austria, Switzerland, Germany, France, Belgium, Greece, Italy are, on the contrary, a moderately polluted group of countries. And Slovenia, Cyprus, Macedonia are the countries that rank worse among the 22 countries which have reported monitoring stations for the three pollutants.

2.8 City clusters

A further cluster analysis has been performed considering the annual mean and the occurrence of exceedances of PM_{10} at city level. Given the large number of cities (304), the K-means cluster method has been used pre-fixing the number of clusters to 10. The results are reported in Appendix A. Clusters are listed from the least polluted to the most pullulated, averaging (somewhat arbitrarily) the annual mean and the occurrence indicators.
It is not easy to characterise each cluster since it would requires further data and analysis, which is left to future work. A short comment is as follows.
Cluster 1 comprises many Finnish cities, including the capital city. The remaining cities are of relatively average or small size. Cluster 2 is very large and includes many German cities and two capital cities (Copenhagen and Dublin). Cluster 3 is relatively small and includes the city of München. Cluster 4, 5 and 6 are characterised by an annual average mean within the information limits but with a large number of occurrence of exceedances. They include a variety of cities, both small and large including very large capital cities such as London, Madrid, Athens, Paris and Budapest. Cluster 7 and 8 comprise various Spanish and Italian cities (including Rome) together with eastern European cities. Cluster 9 and 10 group cities with both very high annual means and very large number of occurrence of exceedances. They include Torino, an average size Italian city, various southern European cities such as Tessaloniki, Nicosia, Cordoba and Lisboa and a eastern city such as Krakow.

3. Air pollution and the system: a tentative regression analysis

The descriptive and cluster analysis is complemented by a regression analysis using the available data at national and city level. A detailed description and illustration of the data and data sources is available in Danielis (2006).

3.1 Data at national level

How is urban air pollution related to the characteristics of the transport system? The answer empirically to this question would require many specific technical and socio-economic data regarding the geography and the climate of the cities and countries, the technical characteristics of the vehicles used, their relative use (e.g., type and share of public transport vs. car transport), the vehicle and traffic regulation (e.g., pollution abatement requirements for vehicles, heavy vehicles permission to enter the city area, the type of bus engines in use, city distribution rules for goods, etc.). Unfortunately no such data was available for the majority of countries. Four interesting indicators were available (a detailed description of the data and of the data sources is in Danielis, 2006):

- a motorization index: the number of cars per 1000 persons
- a wealth index: the gross domestic product per capita
- a cost index: the price of unleaded petrol
- and a density index: the population per square-kilometre
- a latitude measure: the latitude of the capital city.
- a temperature index: the average annual temperature of the capital city.

Data for the average age of cars and the modal share were available and homogenous only for some country (mainly for the UE15).
Regressing these indices on the above pollutant indices gives the results listed in Table 13. The best models for each pollutant are reported.

Table 13 – Regression results

		Constant	Cars per 1000 person	GDP Per capita	Unleaded petrol price/ GDP per capita	Density	Latitude	Adjusted R^2	N° of obs.
PM_{10} annual mean	Coeff.	94.810	-0.003	-0.402	-1,837.930	0.033		0.35	27
	P-value	0.003	0.911	0.007	0.139	0.105			
PM_{10} occurances	Coeff.	297.976	-0.006	-1.594	-7,154.800	0.072		0.31	27
	P-value	0.021	0.960	0.009	0.166	0.383			
		Constant	Cars per 1000 person	GDP Per capita	Unleaded petrol price/ GDP per capita	Density	Latitude		
O_3 annual mean	Coeff.	67.273	0.025	-0.103	-1,087.550	-0.026	-0.267	0.41	22
	P-value	0.003	0.163	0.372	0.299	0.136	0.123		
O_3 occurances	Coeff.	67.674	0.091	-0.503	-3,561.150	0.055	-0.171	0.37	22
	P-value	0.250	0.085	0.147	0.252	0.273	0.729		
		Constant	Cars per 1000 person	GDP Per capita	Unleaded petrol price/ GDP per capita	Density	Temperature		
NO_2 annual mean	Coeff.	-7.261	0.005	0.160	1528.630	0.040	0.910	0.24	24
	P-value	0.851	0.859	0.367	0.326	0.076	0.117		
NO_2 occurances	Coeff.	-41.54	0.01	0.20	1507.63	0.00	0.55	0.00	24
	P-value	0.13	0.56	0.12	0.17	0.89	0.17		

The ability of the transportation indices to explain the variability of the pollution indices is generally quite low (see the adjusted R^2 index), also because of the very low number of observations.
The best results are achieved, relative to the pollutants, for the O_3, followed by PM_{10} and by NO_2. Including the latitude variable improved the model only in the case of the O_3 pollutant, proving the geographical nature of the pollutant. For NO_2, latitude is substituted by temperature.
Note that the model estimate is statistically superior when the indicator of annual mean is used rather than the indicator of occurrences, the reasons being that an occurrence have a local determinant which cannot be capture in a general model and the fact that there is nonlinear threshold factor in the endogenous data. Let us then focus the discussion only on the models where the annual mean is used as an exogenous variable.
As regards to the PM_{10} annual mean - apart from the large role played by the constant (which indicates that many important determinants of the data variability are not present in the model) - per capita GDP appears to be the variable which is more strongly (inversely) statistically correlated with PM_{10} pollution: the richer the country the lower is PM_{10} pollution. Of course, wealth is not a direct determinant of pollution but it can affect, for instance, car age, engine technology, road maintenance and the quality of public transportation via the taxes on petrol and on parking. Unfortunately, there is not enough data to prove this point (there is only partial evidence for the age of cars), therefore the ways in which wealth affect pollution could not the explored further.
Density is the second most significant determinant: the denser the country the more polluted. Density is likely to affect pollution via congestion and, hence, an increase in emissions per kilometre driven.
The price of unleaded petrol adjusted by the wealth difference appears mildly inversely correlated with pollution, whereas the number of cars per inhabitant is not. This results are confirmed for PM_{10} occurrences of exceedances tough with lower significance.
In the case of O_3 pollution (and occurrence of exceedances), the model with the addition of the latitude variable performs statistically better but none of the variables is significant at 10% value (apart from the constant). Latitude is the variable with the largest significance, proving the geographical nature of the formation of O_3 (the more to the north the geographical position of the country the lower the average O_3 annual mean). GDP per capita and the real price of unleaded petrol loses some of their explicative power, while the number of cars per inhabitant gains some power. Note that density, though not significant, even reverses its sign: O_3 pollution is not correlated with the density of an urban area as the physics of O_3 pollution suggests.
NO_2 proves to be the lest predictable pollutant (unpredictable for NO_2 occurrence of exceedances). The model explicative capacity is very poor. The constant is statistically significant, that is there is no common unexplained value shared among countries. Density is the only significant variable below 10% and only with the annual mean formulation. A possible explanation is that the meteorological factors play and important. The introduction of a temperature index, measuring the average annual temperature of the capital city improved the statistical significance of the model and showed a positive sign.
Comparing across equations and pollutants, it can be noted that
a) the number of passenger cars appears to be generally not correlated with pollution. The vehicle ownership, highly differentiated among countries (from 591 in Italy to 140 in Macedonia), does not imply a direct effect on air quality.
b) on the contrary, the wealth index (GDP per capita) is generally strongly negatively correlated: poor country have more air pollution.
c) the price of the unleaded petrol relative to the per capita GDP (to control for the differing purchasing power) represents an index of the disincentive to private mobility. It is generally inversely related to air quality, though its explanatory power is quite low.
d) the density index controls for the population number and the size of the country, which is quite diversified in the sample (the lowest being Iceland with 2.7 people per square-km, the highest the

Netherlands with 393). It correctly affects pollution negatively, though not always with high statistical significance.
e) the geographical index such as latitude or, inversely, temperature has some explicative power in the case of ozone and, to a lesser degree, NO2.
Overall, the model produces reasonable results tough its explanatory power is statistically low. However, considering the macro level of the analysis, its performance is quite interesting. Using the model to predict the PM_{10} annual mean concentration values give the results reported in Table 14.

Table 14 - Actual and predicted PM_{10} annual mean, and residuals

Country	Actual	Predicted	Residual
Slovakia	34.0	45.5	-11.4
Finland	19.1	30.0	-10.9
Lithuania	35.6	46.0	-10.4
Estonia	38.3	48.1	-9.9
Iceland	19.4	27.4	-8.0
Hungary	35.4	43.4	-8.0
France	27.7	34.3	-6.5
Czech Republic	42.3	47.2	-4.9
Great Britain	31.6	35.4	-3.9
Germany	33.9	37.7	-3.8
Switzerland	29.8	32.1	-2.4
Spain	37.5	39.4	-1.9
Netherlands	38.1	39.1	-1.0
Romania	41.1	41.7	-0.6
Ireland	28.4	28.3	0.1
Denmark	32.6	32.0	0.5
Belgium	40.4	39.6	0.8
Austria	33.4	32.5	0.9
Greece	48.8	45.2	3.6
Portugal	45.5	41.2	4.3
Italy	41.8	35.9	5.9
Sweden	36.8	30.1	6.7
Slovenia	51.9	44.7	7.2
Latria	55.7	47.3	8.4
Norway	30.7	20.1	10.6
Cyprus	57.3	45.0	12.3
Poland	67.2	44.7	22.4

A negative value in the residuals column (the difference between the actual value and the value predicted by the model) could be interpreted as the country efficiency in keeping pollution low relative to the average aggregate efficiency. On the contrary a positive values implies an efficiency lower than the aggregate average. The two groups are geographically mixed, though southern countries appear mostly in the second group (apart from Spain).

3.2 Data at city level

As opposed to the analysis of the relationship between pollution indicators averaged at a national level and national system indicators, one can perform the analysis at city level. 292 PM_{10} annual mean indices are available, averaged at city level. Cities vary from a population of 6,589 to a 8,278,251 inhabitants, with an average of 307,149 inhabitants. The only other data available at city level are the latitude and altitude. Data on the characteristics of the transport system such as the number of cars per 1000 inhabitants, GDP per capita at city level or modal share at city level is available only for a small subset of the cities considered. Consequently, the data at national level was tentatively applied to all cities of each country. The best model estimate is reported in Table 15.

Table 15 – Regression results for the PM_{10} annual mean at city level

	Coefficient	t-ratio
Constant	70.770	11.925
Cars per 1000 person at national level	0.016	1.889
GDP per capita at national level	-0.180	-4.618
Latitude at city level	-0.521	-5.023
Inhabitants at city level (in thousands)	0.002	2.227

Adjusted R^2: 0.2051410
Number of observations: 292

The explanatory power of the model is pretty poor and inferior to the one at national level. The constant is the most statistically significant variable showing a common base value not explained by the model's variable. Latitude, a geographical variable, is the second most significant variable (altitude prove of no significance). It has a negative sign. The interpretation could be merely geographical and meteorological or it can be extended to include cultural and organizational aspects. With the existing data, nothing can be said about the latter.
The variable concerning the city population can be thought as a proxy of the density (since population size and density are usually correlated). It is confirmed that the larger (denser) the city, the higher pollution levels.
Regarding the data available at national level only, applied to each city of a country, GDP per capita confirmed its negative correlation with pollution. Its interpretations is the same as above. The number of cars per inhabitant show also a statistically almost significant correlation with PM_{10} pollution, whereas it was not so at national level.

4. Conclusions

The paper is based on the data available from the AIRBASE database. Both the quantity and the quality of the data is not homogenous among countries, therefore, the results of the data analysis reported in the paper are obviously affected by such heterogeneity. However, the AIRBASE database is arguably the best database on air pollution available and is gradually becoming richer and more consistent. It is therefore a useful tool for data analysis on the relationship between air pollution and the functioning of the transport system. To the best of my knowledge, AIRBASE data has been used so far only to evaluate pollution trends in EEA reports, but not for comparing among countries and for studying the structural (economic, organizational and political) determinants of pollution.
The data analysis presented in the paper allowed us:

- to compare among countries both in terms of their success in monitoring pollution and filling information on the database and in terms of the concentration of air pollutants in their cities;
- to group countries in clusters according to the various air pollution indicators to try and see if there is a general or specific spatial pattern in air pollution levels;
- to try and establish a statistical link between air pollution concentration and the some properties of the transport and economic system.

European countries present quite diversified annual pollution means. In order to statistically compare countries' annual pollution means cluster analysis has been performed on single pollutants and on specific sets of pollutants. No clear cut spatial aggregations could be detected tough it is fair to say the Northern countries are generally cleaner (more certainly for ozone due to its photochemical nature) than southern countries and western countries are less polluted than eastern countries.

In order to appreciated the determinants of pollution level a simple regression analysis have been performed to search for the statistical correlations between the transport system characteristics and the pollution level.
It should be admitted that the overall performance of the estimated statistical model is poor. It did not prove possible neither at the national level of aggregation nor at the city level explain more than 40% of the pollution variation. The results should be of no surprise: it reflects both the inaccuracies and poor statistical representativeness of the available data on pollution concentration (on average with a monitoring station per 2.5 million inhabitants and in some extreme case with a monitoring station per 20 million inhabitants) and the many local and technical determinants of the pollution which can only be roughly captured by the indicators available presently for the transportation system. In fact, no enough and comparable data exists on the vehicles in use by fuel or by type of engine for the UE25 countries or on the prevailing congestions levels in cities, both factors widely acknowledged as important determinants of air pollution.
Consequently, air pollution remains a largely unexplained and unpredictable phenomenon. However, the general hints derived from the statistical analysis are interesting and informative.
Density appeared to be an important determinant, proving that pollution is linked to the density of car trips and, hence, to congestion.
Car ownership is positively linked to pollution, though its relative importance is not to be over-estimated. The interpretation could be that the availability of cars spurs owners to use it, but the opposite might be true: a low investment and reliance on public transport spurs people to own and use a car.
Per capita income resulted in many instances as the most important explanatory variable. Wealth allows to keep pollution levels down. The availability of a better engine technology and newer cars come first to the mind, but a larger availability of funds to promote public transport derived from parking charges or ownership taxes could also explain the finding. Unfortunately, the data so far available do not allow to accurately analyse the issue further.
The price of petrol acts as an disincentive to private mobility resulted also as inversely correlated to air pollution.
Geographical and meteorological factors play a role as expected, especially for ozone pollution, but also somewhat for nitrogen dioxide and for particulate matter (with data at city level). It is unclear whether this could be attributed to the climate factors only or whether cultural, organizational or policy factors play a role: an issue to be further explored.

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Appendix A: Clusters at city level

Rank	City	Annual mean PM_{10}	Exceed. PM_{10}
1	Kufstein (At), St. Pölten (At), Helsinki (Fi), Jakobstad (Fi), Joensuu (Fi), Jyväskylä (Fi), Kajaani (Fi), Kokkola (Fi), Kuovola (Fi), Lahti (Fi), Mikkeli (Fi), Oulu (Fi), Turku (Fi), Vaasa (Fi), Aix En Province (Fr), Belfort (Fr), Brest (Fr), Lyon (Fr), Clermont-Ferrand (Fr), Orleans (Fr), Boulogne-Sur-Mer (Fr), Tours (Fr), Amiens (Fr), Besancon (Fr), Nimes (Fr), St Etienne (Fr), Perpignan (Fr), Nantes (Fr), Nauen (Fr), Suhl F. (De), Coburg (De), Hanau (De), Heidelberg (De), Potsdam (De), Grensas (Is), La Spezia (It), Udine (It), Gorizia (It), Arezzo (It), Viterbo (It), Latina (It), Caserta (It), Salerno (It), Potenza (It), Mazeikiai (Lt), Senica (Sk), Murcia (Es), Alcoi (Es), Badajoz (Es), Getxo (Es), Huelva (Es), Llodio (Es), Malaga (Es), Ponferrada (Es), Zamora (Es), Basel (Ch), St. Gallen (Ch), Inverness (Gb)	22.8	8.2
2	Lienz (At), Salzburg (At), Villach (At), Brno (Cz), Plzen (Cz), Aalborg (Dk), Århus (Dk), Copenhagen (Dk), Lappeenranta (Fi), Calais (Fr), Lehavre (Fr), Dunkerque (Fr), Strasbourg (Fr), Marseilles (Fr), Karlsruhe (De), Schwerin (De), Düsseldorf (De), Pirmasens (De), Chemnitz (De), Wolmirstedt (De), Gotha (De), Jena (De), Altenburg (De), Borna (De), Düsseldorf (De), Essen (De), Flensburg (De), Freiberg (De), Friedrichshafen (De), Fulda (De), Hagen (De), Karlsruhe (De), Kiel (De), Koblenz (De), Lübeck (De), Münster (De), Neubrandenburg (De), Nordhausen (De), Plauen (De), Rostock (De), Speyer (De), Ulm (De), Weißenfels (De), Wiesbaden (De), Wuppertal Fr. (De), Zwickau (De), Papa (Hu), Dublin (Ie), Cork (Ie), Galway (Ie), Trieste (It), Pisa (It), Benevento (It), Avellino (It), Pordenone (It), Klaipeda (Lt), Haarlem (Nl), Groningen (Nl), Nijmegen (Nl), Bergen (No), Faro (Pt), Presov (Sk), Bilbao (Es), San Sebastian (Es), Granada (Es), Reus (Es), Sarriá De Ter (Es), Tolosa (Es), Vitoria (Es), Zaragoza (Es), Ávila (Es), Uppsala (Se), Lausanne (Ch), Luzern (Ch), Zürich (Ch), Brighton (Gb), Dumfries (Gb), Wrexham (Gb)	30.1	30.7
3	Ansbach (De), Augsburg (De), Bayreuth (De), Frankfurt An Der Oder (De), Landshut (De), Lindau (Bodensee) (De), München (De), Nürnberg (De), Fürth (De), Passau (De), Regensburg (De), Schweinfurt (De), Weiden I.D.Opf. (De), Würzburg (De), Vicenza (It), Rovigo (It), Merate (It), Valencia (Es), Tarragona (Es)	40.5	2.8
4	Eisenstadt (At), Hallein (At), Innsbruck (At), Linz (At), Karlovy Vary (Cz), Odense (Dk), Aachen (De), Mönchengladbach (De), Itzehoe (De), Bremen (De), Dessau (De), Dresden (De), Glauchau (De), Görlitz (De), Hamburg (De), Magdeburg (De), Mannheim (De), Stralsund (De), Stuttgart (De), Trier (De), Weimar (De), Atene (Gr), S.Giorgio (It), Crema (It), Rovereto (It), Trento (It), Vigarano Mainarda (It), Napoli (It), Aosta (It), Kaunas (Lt), Panevezys (Lt), Eindhoven (Nl), Utrecht (Nl), Rotterdam (Nl), Oslo (No), Trondheim (No), Bratislava (Sk), Igualada (Es), Logrono (Es), Tenerife (Es), Santander (Es), Bern (Ch), Manchester (Gb), Glasgow (Gb), Middlesbrough (Gb)	35.1	50.0
5	Feldkirch (At), Klagenfurt (At), Wien (At), Wolfsberg (At), Antwerpen (Be), Borgerhout (Be), Charleroi (Be), Mechelen (Be), Beroun (Cz), Viru (Ee), Paris (Fr), Duisburg (De), Leipzig (De), Wittenberg (De), Aschersleben (De), Berlin (De), Brandenburg (De), Erfurt (De), Frankfurt (De), Kassel (De), Mainz (De), Nyíregyháza (Hu), Como (It), Firenze (It), Palermo (It), Lecco (It), Siauliai (Lt), Trnava (Sk), Kosice (Sk), Zilina (Sk), Durango (Es), Mataro (Es), Mieres (Es), Puertollano (Es), Eugeni D'ors (Es), Sevilla (Es), Stockholm (Se), London (Gb)	39.2	71.4
6	Hagen (De), Cottbus (De), Darmstadt (De), Halle (De), Ludwigshafen (De), Wetzlar (De), Volos (Gr), Budapest (Hu), Sondrio (It), Verziere (It), Vimercate (It), Pavia (It), Parma (It), Reggio Emilia (It), Ravenna (It), Ancona (It), Senigallia (It), Lodi (It), Riga (Lv), Vilnius (Lt), Apeldoorn (Nl), Aveiro (Pt), Matosinhos (Pt), Quebedo (Pt), Galati (Ro), Madrid (Es), Terrassa (Es),	43.1	94.7
7	Larissa (Gr), Genova (It), Verona (It), Ferrara (It), Den Haag (Nl), Barcelona (Es), Lleida (Es), Sabadell (Es), Sant Cugat Del Valles (Es)	56.0	52.0
8	Graz (At), Praha (Cz), Hannover (De), Braunschweig (De), Patra (Gr), Miskolc Búza Tér (Hu), Szeged (Hu), Mestre (It), Bologna (It), Faenza (It), Perugia (It), Roma (It), Pescara (It), Sosnowiec (Pl), Coimbra (Pt), Porto (Pt), Trbovlje (Sk), Zagorje (Sk), Aviles (Es), Castellón Del La Plana (Es)	49.3	134.6
9	Nicosia (Cy), Torino (It), Kocani (Mk), Cascais (Pt), Lisboa (Pt), Maribor (Sk)	56.5	170.9
10	Tessaloniki (Gr), Krakow (Pl), Cordoba (Es),	68.7	223.7