The sustainable city and air pollution

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Abstract

The present paper deals with the integrated approach typically adopted to improve the air quality in a European urbanized area. A case study is selected and analyzed in order to find out the viable criteria for the correct management of the problem, aimed at a sustainable city and the decrease of human health effects. The role of conventional and unconventional pollutants (e.g. PM_{10} and ultrafine particles) is discussed. The available measurement strategies are analyzed in order to point out the trend of the sector and the gap to be covered for guaranteeing a homogeneous protection of the territory (every citizen has the right to inhale air of the same quality). The importance of not limiting the analysis to the implementation of emission inventories is demonstrable through simple examples: indeed data of global balances can mislead decision makers; they must guarantee an acceptable human exposure that depends on the amount of pollutant that effectively reaches each inhabitant. Location criteria for urban planning are proposed to prevent unacceptable human exposure cases (e.g. kindergarten should not be authorized near an urban freeway; construction of street canyons should be avoided). Zooming out the urban area helps to demonstrate that the coordination among cities is compulsory. To this concern, the transport of air pollutants from region to region must be taken into account. Unconventional emerging solutions for improving the air quality in urban areas are presented and discussed in the paper together with cost-related viability aspects.

Keywords: air quality, human exposure, NO_x, PM, SO_2, transport, urban planning.

1 Introduction

Air quality management is rarely connected with the urban sustainability, even if it is one of the most critical topics in many urbanized areas worldwide. The problem is faced with through different strategies depending on the city location,

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the local economic and legislative context and the ability of the local authority's organization [1–3]. The applied strategies must be based on the decrease of pollution and its decrease on the impact on human health [4, 5].

In the European Union (EU), a relevant legislation that established quality standards, generally in the form of threshold levels relative to both the long and short term exposure for avoiding troubles to the human population and ecosystems, was the 1996/62/CE Directive. During the years other directives setting limits for ambient air quality were issued: dir. 1999/30/CE (sulphur dioxide, nitrogen oxides, lead particles, particulate matter), dir. 2000/69/CE, (benzene and carbon monoxide), dir. 2008/50/CE (ambient air quality and cleaner air for Europe), etc. Thanks to these directives a mutual exchange of information and data from networks and individual stations measuring ambient air pollution within the Member States is required. At Italian level the Framework Directive 1996/62/CE has been transposed by Legislative Decree 351/1999, with the objective of defining the basic principles for the maintenance and improvement of air quality, while setting the criteria for the preparation of plans and programs in the area in question. These directive was then adjusted by the Ministerial Decree 261/2002. Presently the reference regulation in Italy is the Legislative Decree 155/2010 that transposed the European dir. 2008/50/CE. The tables below show the overview of the limits for each type of pollutant, acute exposure (Table 1) or chronic one (Table 2) and based on the object of protection, depending on whether it is the protection of the health human, vegetation or ecosystems (Table 3).

Table 1: Acute exposure limits established by law (EU).

Pollutant	Type of limit	Value
SO_2	Alert threshold (three consecutive hours in the territory)	500 μg/m^3
SO_2	Hourly limit not to be exceeded more than 24 times a calendar year	350 μg/m^3
SO_2	Daily limit not to be exceeded more than 3 times a calendar year	125 μg/m^3
NO_2	Alert threshold (three consecutive hours in the territory)	400 μg/m^3
NO_2	Hourly limit not to be exceeded more than 18 times a calendar year	200 μg/m^3
PM_{10}	Daily limit not to be exceeded more than 35 times a calendar year	50 μg/m^3
CO	Maximum daily 8 hour mean (consecutive hours)	10 mg/m^3
O_3	Information threshold: 1 h mean	180 μg/m^3
O_3	Alert threshold : 1 h mean	240 μg/m^3

Table 2: Chronic exposure limits established by law (EU).

Pollutant	Type of limit	Value
NO_2	98° percentile of the hourly average concentrations (calendar year)	200 μg/m^3
NO_2	Mean yearly value for the human health protection	40 μg/m^3
O_3	Long-term target for the protection of health: daily maximum 8 h mean (maximum 25 times per year)	120 μg/m^3
PM_{10}	yearly limit value	40 μg/m^3
$PM_{2.5}$	Yearly limit value	25 μg/m^3
Lead	Mean yearly value for the human health protection	0.5 μg/m^3
Benzene	Mean yearly value for the human health protection	5 μg/m^3
Benzo(a)pyrene	Calendar year average (target value)	1 ng/m^3

Table 3: Limits established by for the protection of ecosystems (EU).

Pollutant	Type of limit	Value
SO_2	Critical level for the vegetation protection (winter)	20 μg/m^3
NO_x	Critical level for the vegetation protection (year)	30 μg/m^3
O_3	Target value for the protection of the vegetation: AOT40* on hourly means from May to July, as mean on 5 years (otherwise on 3 years)	18000 μg m^{-3} h
O_3	Long-term target value for the protection of the vegetation: AOT40 on hourly means from May to July	6000 μg m^{-3} h

*Accumulated exposure over threshold of 40 ppb, in μg m^{-3} h. This parameter is the difference between the O3 hourly concentrations higher than 40 ppb (around 80 μg/m^3) and 40 ppb, in a specific period of time, using only hourly measured values, every day, between 8:00 and 20:00 Central Europe Time.

The pollutants are traditionally divided into two categories:

- primary pollutants that are emitted directly into the atmosphere from identifiable sources, natural and anthropogenic; they are present in both the gaseous and particulate phases (SO_2, NO, CO, total suspended particulate matter, volatile hydrocarbons, metals, etc.);
- secondary pollutants that are derived from chemical and photochemical reactions involving primary pollutants and atmospheric constituents (O_3, NO_2, nitrous and nitric acid, nitrates, sulfates and sulfuric acid, etc.).

A part of the listed pollutants can have carcinogenic effects. Another one is important mainly for acute effects. The impact of someone is underestimated (e.g. O_3). Thus the mitigation priorities are not easy to be defined correctly.

In this frame, the aim of this paper is to present an integrated analysis, concerning the air quality in a European urbanized area, pointing out viable criteria of air quality management for a sustainable city and potential trends of the enhanced monitoring. Indeed the continuous evolution of the technologies opens to unconventional approaches more oriented to the "personalised" protection of the inhabitant health.

2 Case study

Even if far from the most critical cases at international level (e.g. Beijing) many cities in the north of Italy are characterised by a low quality of air. This characteristics depends not only on the local human activities but also on the unfavourable climatology (affected by the local morphology of the territory). The climate in the chosen case study, although falling in the Mediterranean continental type, has its own peculiarities, being in a transition zone between the Adriatic and the Alps, which separates this area from the continental-European center [6]. The local production system began to develop in the late nineteenth century, affecting initially the centers of the foothills of medium size, where they built small industries related to agriculture, crafts and local work. From the eighties a large-scale distribution began to establish, and industrial areas began to mix with craft and trade. In recent decades there has been further growth of productive areas of the chosen case study. In Figure 1 the relative weight of the different sectors is reported for the North Italy city selected as case study [7].

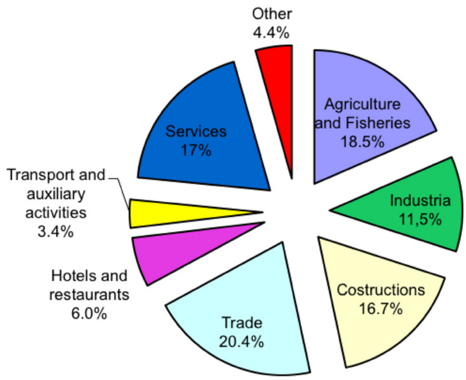

Figure 1: Activity sectors relevance in the area of the analysed case study.

The traffic is a significant component of urban air pollution even if it is caused by personal motor vehicles or from the industrial sector [8–10]. In Figure 2 the road types in the chosen case study are presented [11]. In the recent years, the volume of vehicular traffic has been growing in parallel with the number of cars on the road increasing the air pollution [12, 13]. The road network of the case study is responsible for a series of criticalities: highway and tangential road (by-pass) in the southern part of the city, for a total of 10 parallel lanes; street canyons; vehicle attractors like commercial centers and airport; commuters fluxes not compatible with the in-out roads; unoptimised school locations.

A positive aspect concerns the dynamics of the vehicular park. In Figure 3 the vehicle park evolution at Italian level taking into account the EURO class is reported. In Figure 4 a general view of the 2013 vehicle park composition in the case study is shown [6]. Generally the age of vehicles is higher for the gasoline engines in spite of the idea that diesel vehicles can operate longer; the median ages are 12 years for gasoline and 8 for diesel respectively [6], even if in the last decade the trend is towards buying of diesel cars [4, 7]. However that is not correlated with the vehicle mileage, typically higher for diesel vehicles.

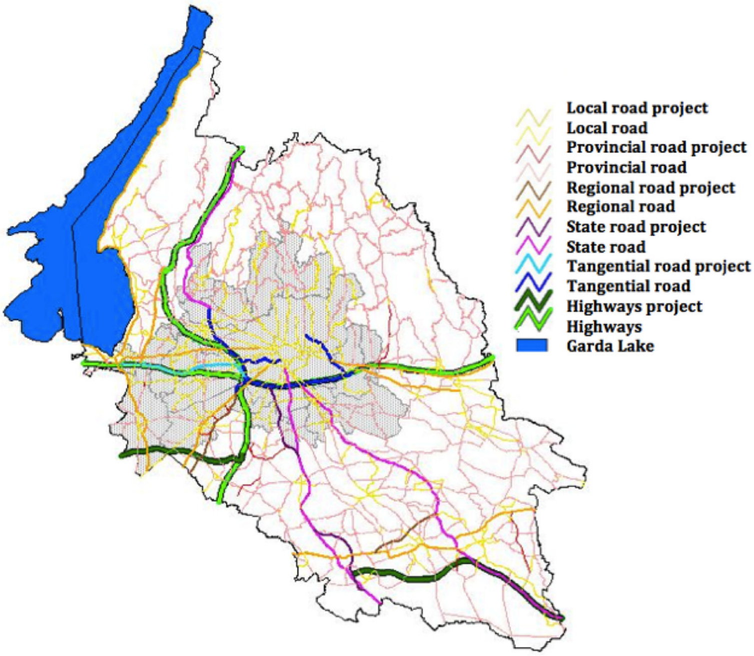

Figure 2: Road types in the case study area [11].

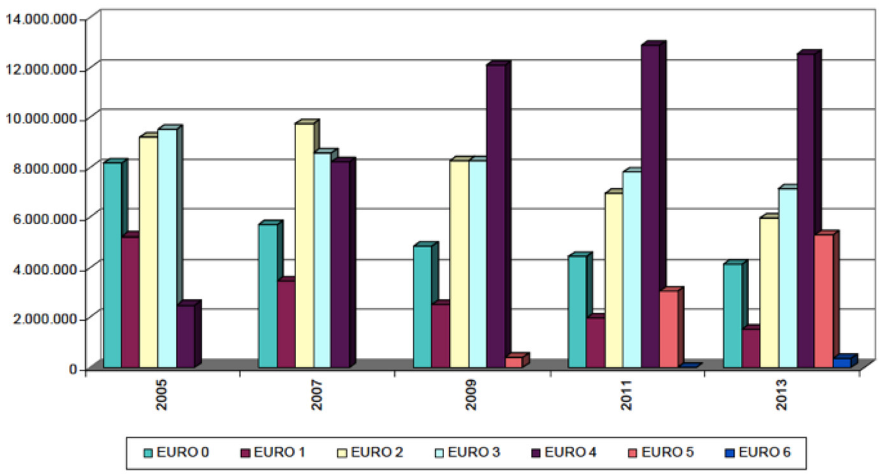

Figure 3: Evolution of the vehicular park at national level [12].

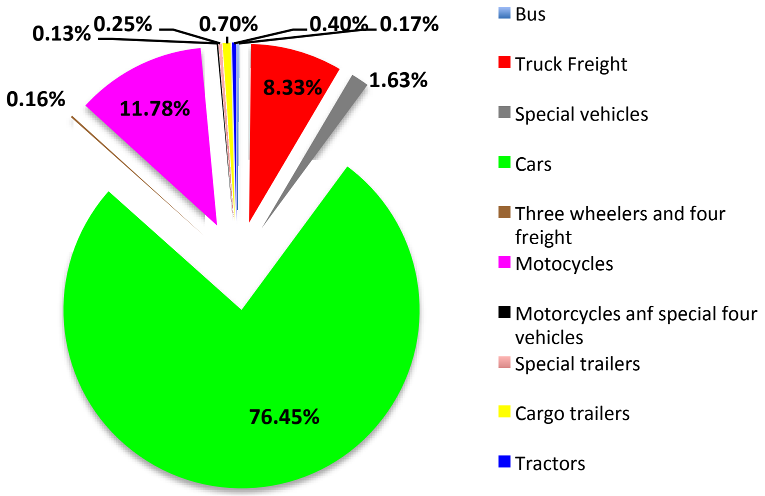

Figure 4: Vehicular park composition in the case study.

Of course, air quality is not only a matter of traffic pollution: also punctual sources play an important role. These emissions are located at a point (stack) and/or are related to other emissions from storage, handling and transfer of materials, or vents, drains, evaporation along the lines of the process. The emissions related to industrial sources refer to activities classified in different macro-sectors depending on the type of industrial process; the following ones are present locally:

- Energy production and conversion of fuels [14–16];
- Combustion in industry [17, 18];
- Production processes [19–21];
- Use of solvents [22];
- Waste treatment and disposal [8, 23, 25].

In this frame, it must be pointed out that a criticality can come from the way of authorizing industrial activities in urban areas: the regulation of the sector is mainly based on the concept of compliance of stack emission limits without a verification of the contribution to the local air pollution of the area affected. Moreover, some problems can come from old authorizations to the construction of potentially critical plants in urban areas: in the case study a steel making plant was authorized in the urban territory. In this case the presence of diffused emissions (in addition to the punctual ones) could cause a significant risk for the population.

Finally, domestic heating is also considered as an important source of urban air pollution. The emissions from domestic heating depends mainly on the used fuel: methane, diesel, liquefied petroleum gas or biomass [14, 25, 26]. In the case study methane is dominant, but a typical use of wood at domestic level cannot be neglected, at least as integrated heating system. This is a typical characteristics of domestic heating in the Alps [14]. This combustion can potentially contribute to a significant part of the primary particulate matter emission of an urban area.

3 Mitigation criteria

Mitigation strategies can be developed on a short and long time perspective. Taking into account that the traffic is the most polluting sector, some possible short-term actions that can be undertaken in the area of private transport in order to reduce emissions can be proposed in order to decrease the emission of nitrogen oxides, PM_{10} and benzene. However the topic must be viewed from a wider perspective, as reported in Table 4.

Table 4: List of the short term actions.

General action	Objectives
Sustainable urban transport: impact reduction from private vehicles	Switching from private to public transport
	Up-grade of local public transport
	Aeration and control of the circulation
	Definition of lanes
	Fleet renewal
	Increase of traffic limited zones
	Increase of pedestrian areas
	Increase of bicycle and pedestrian paths
Impact reduction from commercial vehicles	Regulated access
	Transformation or replacement of commercial vehicles
	Transit limitation of heavy vehicles in urban areas
Impact reduction of the civil plants	Transformation and replacement of plants
	Improvement of energy efficiency
	Compliance with rules of energy conservation
	Encouraging use of clean renewable energy
Impact reduction of production activities	Conversion and processing means of transport
	Forums for the exchange of goods
	Adoption of best available technologies in production facilities
Application of planned measures to limit traffic	Restricting the movement of polluting vehicles
	Blocks of total traffic (Ecological Sundays)
Spatial planning	Adoption of standards or territorial management plans contributing to air pollution reduction
	Completion and updating of the databases with respect to environmental compartments and emissivity

Concerning the long-term actions, they can be seen from the point of view of the pollutant reduction. In Table 5 a list of the possible actions, as output of the case study analysis, are reported, taking into account also the role of plants in the surroundings of the urban area and the need of generalizing the contents.

Table 5: Long-term actions.

	SO_2	NO_x	PM
Conversion sector (involving plants in the surroundings of the case study city)	Low sulfur in fuel oil: < 1% sulfur	Combustion changes + selective non-catalytic reduction(SNCR)	High efficiency dust collectors in refinery processes
	Refinery process emission control	Selective catalytic reduction (SCR)	Fuel oil boilers: good maintenance
	Desulfurization (deS) of flue gas from boilers/furnaces	Refineries process control	
Domestic sector	Low sulfur in heavy fuel oil (< 1% sulfur)	Heavy fuel oil boilers and gas: primary measures	Dust collectors for commercial boilers
	Coal with a low sulfur content	Controls on boilers liquefied petroleum gas	New boilers in the residential. sector (biomass)
			Passive filters on chimneys and stoves
Industry (also mixed with residential areas in the city of the case study)	Low sulfur fuel	Combustion changes + SNCR	High efficiency dust collectors
	Control measures of sulfur inside boilers/furnaces	SCR	Boilers: good maintenance
	DeS of flue gases		
Electricity generation	DeS of flus gases in all the existing plants	Changes in the combustion of all existing plants where selective catalytic reduction is not expected	High efficiency dust collectors for all new solid fuels plants
	High efficiency deS in new plants by clean fuels	Selective catalytic reduction of all new oil/coal plants	Fuel oil boilers: good maintenance
Industrial processes	Controls of emissions from industrial processes	Additional controls of emissions from industrial processes	High-efficiency scrubbers to control chimneys emissions
			Fugitive emission cont.
Waste	Good practices		
	Prohibition of diffused emissions		
Transport	Further reduction of the sulfur content (in addition to current regulations) in the fuels used in domestic activity	Additional measures on light commercial vehicles: catalyst and particulate filter	Additional measures on diesel light commercial vehicles
		Additional measures to heavy goods vehicles: urea catalyst	Additional measures on diesel heavy commercial vehicles

In addition to that, some less technical aspects must be taken into account:

- Communication actions to business owners, craftsmen, managers of condominiums, farmers, truck drivers, etc.
  - good transport with more eco-friendly vehicles (e.g. natural gas, liquefied petroleum gas, hybrid or electric) thanks to agreements to facilitate the access of financing for the purchase of vehicles with low environmental impact;
  - a logistics platform (Logistic-City) for the reorganization of goods distribution, support services organization and optimization paths.
- Communication actions to citizenship
  - sensitization by increasing energy efficiency and the diffusion of energy saving;
  - sensitization for the reduction of the use of private means of transport, for its use shared, for the use of collective means and the bicycle;
  - specific training to raise awareness through information material (paper, computer, etc.) for the use of domestic products at low solvent content;
  - action to raise awareness of citizenship for compliance with the maximum ambient temperature in domestic homes in winter [27];
  - citizen information about the risks to health arising from the main pollutants (PM_{10}, $PM_{2.5}$, PAH, NO_x, etc.);
  - public information about air quality: updated picture of its state and the daily data values within legal limits.

The role of unconventional pollutants such as ultrafine particles (UFP, diameter less than 0.1 μm) is presently deeply discusses in the scientific sector. An adoption of UFP limits at real scale is expected, but not in the short term because of the high cost of measurement. What is clear today is the negative role of diesel engines and domestic wood combustion. In order to take care of this problem the Autonomous Province of Trento (Italy) promoted the co-financing of domestic electrofilters for existing stoves/boilers/fireplaces fed by wood. The removal efficiency is higher than 70% for PM_{10} and higher than 90% for UFP.

However the problem is not only related to mass of pollutants emitted, as the human exposure depends also on the dilution of the emissions into the atmosphere. Thus, location criteria for urban planning must be adopted to prevent unacceptable human exposure cases: e.g. kindergarten should not be authorized near an urban freeway; construction of street canyons should be avoided.

More generally, a gap to be covered concerns the guarantee of a homogeneous protection of the territory, because every citizen has the right to inhale air of the same quality. To this concern, the evolution of low-medium cost environmental sensors is opening important perspectives [28–30]. One interesting option refers to the possibility of creating an additional network of sensors acting as an alert system integrated with the conventional one. The topic is of clear interest as demonstrated by some pilot experiences that can be seen also in Italy (e.g. in Trento and Bozen). The economic viability can take advantage from the recent decrease of cost for this kind of sensors.

The smartphone availability is an opportunity too. Recent demonstration projects are trying to collect data integrating the conventional apparatus with environmental wireless sensors that can allow the creation of a real time detailed mapping of the air quality that the citizens can inhale. The cost of the initiative can take advantage from the availability of smartphones already bought.

The importance of not limiting the analysis to the implementation of emission inventories can be demonstrated through a simple example: suppose the traffic sector (linear emissions) emits the same amount of the pollutant X than the industrial sector (punctual emissions with diluting stacks); the higher proximity to the inhabitants of the first "activity" is clear; thus it is clear that, in this example, traffic will cause a higher human exposure even if the amount of pollutant released is the same. The importance of this example is not secondary: data of global balances can mislead decision makers; they must guarantee an acceptable human exposure that depends on the amount of pollutants that effectively reaches each inhabitant.

Zooming out the urban area is important because the coordination among cities in the same (wide) region is compulsory. Indeed the air pollutants transport from region to region must be taken into account.

4 Conclusions

Air quality management is a key factor that contributes to the sustainable city concept. On a worldwide view, the non-homogeneous attention to this problem has caused highly critical situations in a few cities. Moreover, at local level, an homogeneous protection of the territory is often not guaranteed: every citizen has the right to inhale air of the same quality. The European Union, thanks to the evolution of its regulation on this topic, can be a good reference for decision makers, that can take also advantage of the effort made for the generation of the necessary environmental information (measurements, survey, etc.). The presented case study was useful for pointing out a few specific actions that must be taken into account for whatever city, but the sector have not yet reached a steady approach: an unconventional parameter is expected to grow its relevance in the official strategies; this is the case of ultrafine particles, that has shown critical emission factors in the sectors of domestic wood combustion and diesel engine circulation. Moreover, additional efforts should be made in terms of use of land in urban areas (school location compatibility with pollutant emitters) and, more in general, human exposure assessment (through modelling and enhanced monitoring).

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