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8. Air Pollution: Mitigation and Adaptation Strategies

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Abstract. Air pollution is a major threat for human health and in general for environment, nevertheless, even if its effects are clear, the tasks to reduce its impacts are extremely difficult. Part of this difficulty relies on the fact that our knowledge of the topic is poor, but the main difficulty springs out from the direct connection existing between technology, progress, resources consumption and pollutants emissions. This study wants to propose a method to develop strategies devoted to face in a rational and quantitative way the topic of air pollution mitigation and adaptation, trying to show that it is possible to carry out actions devoted to contain the effects of pollution giving to Mankind some more time to find the road map toward a sustainable progress. This challenge is fascinating under the intellectual point of view but, at the same time, it is a crucial fight for our cultural model. The following work is a small contribution given to this ultimate cause.

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Introduction and historical overview

"As soon as I left the heavy Rome air and that smell of smoking kitchens which, once they are working, deliver with the dust all that pestilential steam they have absorbed, immediately I felt a change in my health conditions"

Seneca – Letter to Lucilio

A relatively diffuse way of thinking considers air pollution as typical problem of 20th Century. On the contrary, air pollution does not pertain to modern ages only; neither it is related uniquely to fossil fuels and industrial revolution, even if industrial revolution undoubtedly represents the major forward jump for the increase of pollution both in terms of episodes frequency and intensity. Another common thought is that , pollution as always related to combustion, while on the contrary it should be remembered that pollutants can be released even without combustion, as is the case of re-suspension (due to wind or vehicles) and the case of waste material dumps. These common and misleading ideas, far to be of interest only for Academia, can represent a dangerous mental trap for Policy Makers, which might focus their attention toward a wrong or incomplete vision of air pollution problem, then reducing the effectiveness of their governance. Because of air pollution manifold nature, no universal recipes are currently available and, probably, it might be wise do not trust too much in cash-and-carry approaches. However, past experiences and mistakes, in other words the historical overview, might surely help Decision Makers in finding their own strategy and tactics.

One of the first citations of atmospheric pollution in European Literature is that of Seneca, who wrote a letter to a friend mentioning the "gravioris caeli" (heavy sky) and "infamis aer" (infamous air) over Rome, at that time hosting more than one million of inhabitants, which had a negative impact on his health. Well before the first (1770 A.D.) and second (1850 A.D.) industrial revolutions, pollution episodes were reported in the historical chronicles. All these episodes are essentially related to productive activities (e.g., foundries, fish smoking houses, etc.) that, with their emissions, reduced the yields of neighbour farms. This conflict between opposite economical interests often brought to bloody riots that had to be managed by local authorities. The need to reduce these conflicts brought, around 1550, to the invention of the first known end-of-pipe mitigation device, the so called "dust chamber" shown in figure 0. The idea at the base of this device was that to release the emissions of furnaces not directly in the atmosphere, but inside a chamber, where emissions might reduce in temperature and particulate matter have more time to deposit on the floor and walls of that chamber.

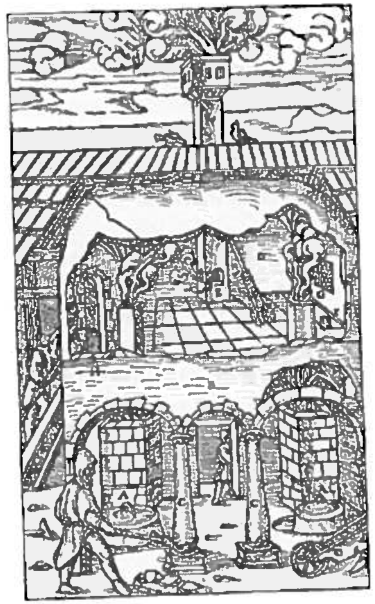


Figure 0. Representation of a "smoke chamber", the first known end-of-pipe mechanism adopted to reduce particulate matter emissions in furnaces [1].

The improvements of steam engine, in particular thanks to the efforts of James Watt (1769), supplied people a compact and portable source of power. In this way, productive activities might be installed wherever and whenever, increasing possible conflicts because of pollution episodes. This fact forced governments to regulate enterprise installations. In 1810, as an example, France released a list of nearly 60 activities that needed a formal approval before to be started up and that could not be installed within towns both for the fire hazard and for the effects of pollution. In 1823, French Government required a formal approval even for the installation of a single steam engine, while Germany did the same around 1845.

But these years were not characterized only by enterprise regulations but even by the first attempts to systematically study the causes and effects of air pollution. Stoeckhardt in Germany and Smith in England [2], in fact, underlined the importance of sulphur oxides (the expression "acid rain" was coined in this period), as well as of heavy metals, to explain the damages produced by pollution. Both Smith and Stoeckhardt proposed even adaptation strategies as, for example, the use of deciduous trees in place of conifers near to foundries because they suffered less during the winter time emissions. As often happens, researches and studies bring to the formation of schools for the diffusion of knowledge. In fact, in these years, schools for furnace-men appeared in several parts of Europe. These schools were mainly devoted to the development of techniques to increase factories efficiency, nevertheless a formal technical background of knowledge helped even the correct management of power plants, then a reduction of their impact on atmosphere.

Up to the mid of XIX century, apart from minor differences due to local peculiarities and timing, the leitmotiv beneath all the pollution episodes and attempts to deal with them reported in the chronicles, can be resumed in the following paradigm: pollution is a local phenomenon and it requires local solutions. Another common aspect between all these episodes, is that, in general, health was not a main concern, nor for inhabitants of the industrial areas, neither for workers. However, this paradigm was doomed to change roughly at the switch of the century with the London episodes: the new term adopted to identify these events was "smog". One of the first of this episode with a reported estimate of casualties ascribable to air pollution was that of 1880, when roughly 1000 people died for reasons related to a worsening of air quality. Since that time, increased awareness on the negative impacts of pollution on helath and the growing need to sustain industrial production, fostered technological innovation. The two main directions in which technology moved were that of chemistry (chemical deacidifying plants by way of dry absorption or scrubber towers) and fluid mechanics (dilution, cyclones and filters). Since that time stacks became taller and taller to increase dispersion of pollution, but in this way increasing the area of influence of emissions [1].

Around forties, a new dimension in the universe of pollution became significant, starting from the United States (where industries were less affected by the two World Wars) and only after a few decades even in Europe: the automotive pollution. Thanks to the widespread diffusion of cars, in fact, carbon monoxide and nitrogen oxides concentrations grew constantly and, in periods of significant solar radiation, these high concentrations brought to the overproduction of ozone. The new term used to identify these episodes, related to sunshine differently from the London ones, mainly related to inversions and cloudiness, was that of "photo-smog". Second part of XX century was characterized by the rebuilding of World after the devastating effects of the wars that characterize the first part of that century as well as by the growing competition between USA and USSR even within their areas of influence. This fostered the diffusion of industries as well as the demand and consumption of energy without particular care to

technological improvements. In this way, emission of pollutants grew worldwide, without any compensating effect related to technological progress. These are the years hosting the London Great Smog (5-9 December 1952 with 4000 estimated casualties) and the Los Angeles photo-smog events. In these years, most sensitive nations developed administrative tools to face pollution episodes. In 1955 United States issued the "Clean Air Preservation Act", while Great Britain in 1956 released the "Clean Air Act". Both these legislative tools proved to be effective, in particular, when in 1962 London suffered for another smog episode similar to the 1953 event[1], thanks to the "Clean Air Act" the number of casualties was reduced down to 700, i.e., roughly by one order of magnitude. Thanks to the feed-backs received by these positive legislations, the United States in 1963 released what is nowadays considered the first modern legislation on air pollution mitigation and adaptation: the "Clean Air Act". What makes the "Clean Air Act" a modern tool of governance can be resumed in two points:

1. it defines precise limits for the pollutants concentration that have to be respected in order to keep pollution impacts on health and environment within a level of acceptance;
2. it defines a plan of actions with a clear timing as well as a clear set of indicators devoted to monitor the effects of actions against air pollution.

This strategy is still adopted in current legislation, for this reason, pollution management and air quality plans can be considered as synonyms and, dealing with pollution management, all the efforts are devoted to single out sustainable limits for pollutants concentrations and the most effective set of sustainable actions for the compliance with these thresholds.

Under the historical point of view, the last major step was formally achieved in 1979, with the institution of the Convention on Long Range Transboundary Air Pollution (CLRTAP). Up to that year, in fact, air pollution was considered as a local problem and its widest range was that represented by political borders. With the institution of CLRTAP, Nations recognized that a successful pollution management can be obtained only through transnational agreements and with an efficient and continuous exchange of information both on pollutants concentrations and emissions. As often happens in the history of Mankind, even the CLRTAP institution sprung out from a very specific problem, the acid rain phenomenon, when

1 The 1952 London smoke episode had peaks of average SO2 daily concentrations of roughly 3.8 mg/m3, while that of 1962 had peaks of SO2 daily concentration of 3.2 mg/m3.

scientists realized that sulphur emissions might cause damages to forests and in general to ecosystems and stone monuments even if they were sited very far from the emitting Country. Then, the CLRTAP represented the governance tool that Nations decided to build to face this transnational problem. As often happens in Mankind history, even the CLRTAP demonstrated to be a very effective instrument and it made possible the formalization of several protocols related to different kind of pollutants.

8.1. A general scheme for mitigation strategies

The chess-board is the world, the pieces are the phenomena of the universe, the rules of the game are what we call the laws of Nature. The player on the other side is hidden from us. We know that his play is always fair, just and patient. But also we know, to our cost, that he never overlooks a mistake, or makes the smallest allowance for ignorance.

"Science and Education, T. H. Huxley (1963)"

It is currently believed that the most effective approach for the management or air quality problems is that figured out for the first time in the US Clear Air Act, with the definition or adoption of thresholds for the concentration or exposition and the preparation of air quality plans which encompass, as well, the set of indexes for the monitoring of actions effectiveness. The definition of pollutants thresholds is far beyond the scope of this contribution; for this reason attention will be now on focused toward the preparation of air quality plans.

The approach proposed for the preparation of air quality plans follows a modified version of the DPSIR scheme, see figure 1, currently adopted by the European Environmental Agency [3, 4, 5]. This modified version of the DPSIR approach adopts a perspective which is more centered on environment, differently from the original one which is instead Society oriented.

8.1.1. Determinants

In detail, following the scheme depicted in figure 1, air quality plans should be developed starting from the careful analysis of the air quality determinants, i.e., of all the elements that trigger pollutants dispersion and transformation in the system we are interested in. Topography (height and distribution of relieves, urban canyons, etc.) and geography (distance from the sea or watersheds, land use, etc.) are clearly among these determinants even if the main player in the realm of drivers is surely represented by meteorology. In fact, as shown by the scheme depicted in figure 2, atmosphere

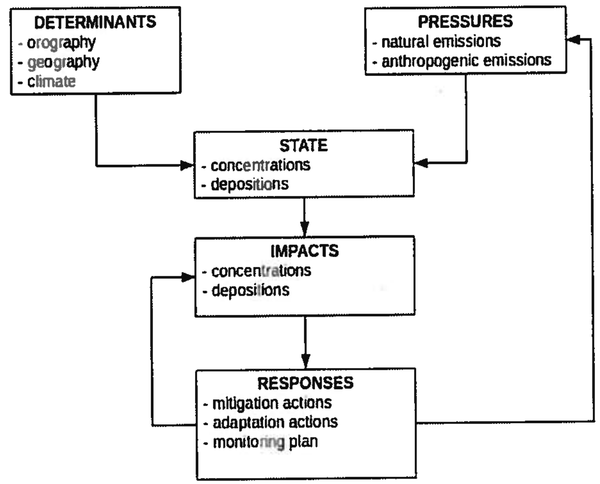


Figure 1. Scheme adopted for the development of air quality plans (DPSIR). Determinants and Pressures, concur to the definition of the observed State. Once the State is defined, impacts of single pressures have to be singled out for the definition of the best set of Responses, i.e., of the most suited set of actions and of their monitoring plan.

steer all the five elements M_{in} , M_{out} , M_{em} , M_{rem} and M_{tra} which, starting from an initial pollutant concentration C(t), bring after a time Δt to the concentration $C(t+\Delta t)$ mathematically expressed here below

$$C(t+\Delta t)=\frac{1}{V(t+\Delta t)}\left[M(t)+M_{in}(\Delta t)-M_{out}(\Delta t)+M_{em}(\Delta t)-M_{rem}(\Delta t)+M_{tra}(\Delta t)\right]$$

An example of the existing relationship between emissions and meteorological determinants, which is probably the less intuitive effect, is shown in figure 3a, where the link between the yearly value of heating-degrees-day and methane consumption in the plain of Friuli Venezia Giulia (Northern Italy). Moreover, because heat conduction, according to the Fourier law, depends from the thermal gradient, a 1 °C increase of outdoor temperature is equivalent to a 1 °C decrease of indoor temperature. In this way, the existing relationship between average outdoor temperature and methane consumption shown in figure 3b mimics the existing relationship between the thermal reduction of indoor temperature and methane consumption, which is proportionally related to the CO2 and other pollutants emissions. As shown in figure 3b, a strict control of indoor temperature can bring to relevant benefits in energetic budgets and pollutants emissions.

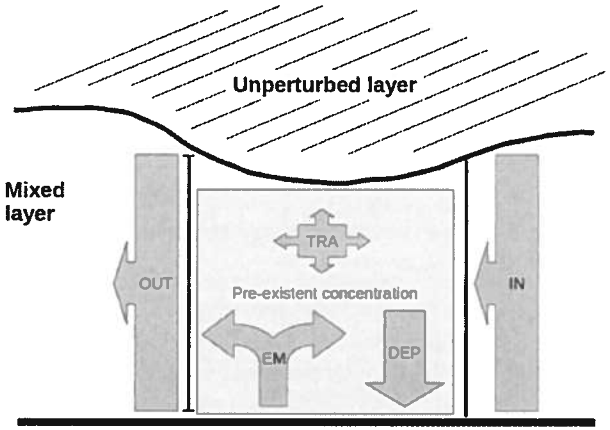


Figure 2. Schematic description of the elements which concur to the formation of the observed pollutants concentrations. M_{out}, and M_{dep} represent respectively the pollutant outcomes and deposition, while M_{in}, M_{em} and M_{tra} represent respectively pollutants incomes, emissions and transformations.

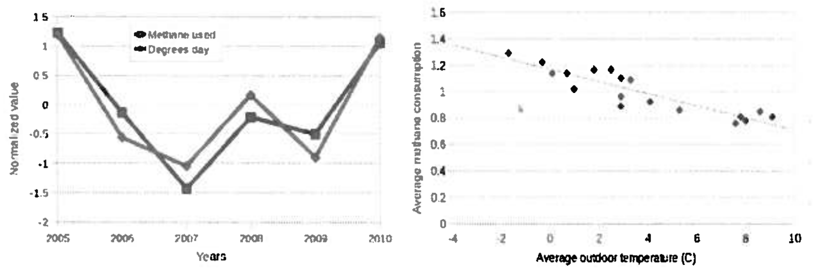


Figure 3ab. Left panel shows the methane consumption versus degrees-day, a measure of thermal energy requirement, in the years from 2005 up to 2010 over the plain of Friuli Venezia Giulia (Northern Italy). Normalized values are used for both the variables. Right panel shows the daily methane consumption (rescaled to the sample average) as a function of the average outdoor temperature. Because the Fourier law of heat conduction depends from the thermal gradient, it is clear that a 1 °C increase of average outdoor temperature has the same effect of a 1 °C decrease of indoor average temperature.

Other relationships between meteorological determinants and emissions can rely hidden in the increased use of private vehicles in spite of public transport systems in rainy days or in the particulate matter emissions from roads after sanding or salting in case of snow events. Because of this strong

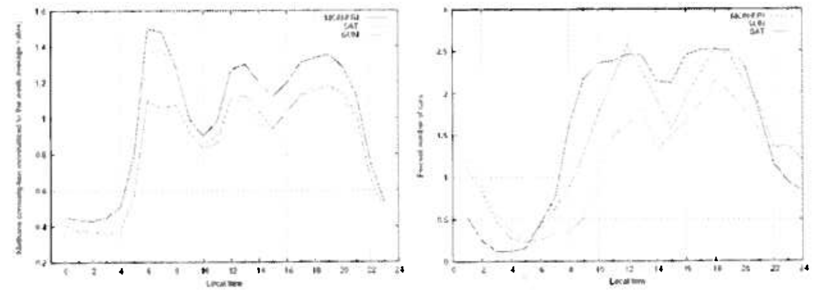


Figure 4ab. Left panel shows the diurnal cycle of methane consumption (values rescaled to the weekly mean) for the different days of the week (Monday to Friday clustered together) in Trieste (Friuli Venezia Giulia). Right panel shows the diurnal percent cycle of car transits in the different days of the week (Monday to Friday clustered together) in Udine (Friuli Venezia Giulia).

connection between meteorology and air quality, all the climatic aspects relevant for the area should be carefully analyzed, starting from the most evident parameters like the average wind speed and direction or mixing height and ending with the number of sunny days, e.g., days with an amount of total solar radiation larger than 15 MJ/m3 which are related to the peaks of concentration [6].

8.1.2 Pressures

After the definition of the meteorological determinants, an exhaustive analysis of the pressures acting on the system we are interested with should be taken into account. Dealing with air quality, pressures are represented by both natural and anthropogenic emissions in atmosphere. Emissions should be analyzed even under the point of view of their diurnal and weekly modulation. The aspect of emissions modulations is particularly relevant in the frame of air quality plans, because these modulations can mimic the effects of potential measures, as is the case for the weekly cycle of traffic and industrial production (e.g., week-end decrease in Western Countries).

8.1.3. State

Once pressures are defined and analyzed, the next suggested step is that to determine the state of the system we are interested. Dealing with air quality, this means the determination of pollution levels according to the current legislation and, whenever possible, with the recommendations of

World Health Organization which, quite often are stricter than those of local legislation. In general, even if usually not prescribed by legislation, it is useful, as done for pressures, to analyze even the diurnal and weekly cycles of pollutants. These cycles, as happened for emissions, can supply useful information on potential effects of mitigation or adaptation measures. As an example, in figure 5abcd are reported the winter (December, January and February) average diurnal and weekly cycle of NO2 and PM10 concentrations (normalized values) for a Town with more than 100 000 inhabitants (Udine and Trieste, in the Northeastern part of Italy). Differences in the behavior of these pollutants clearly emerge from the figures; in particular it is clear that the weekly decrease observed during week-end is stronger for NO2 than PM10. This is an experimental evidence of a possible difference in the sources of these two pollutants, since the meteorological determinants should be the same for both of them.

Before to conclude the short discussion on the determination of the state of the system, a few words should be spent dealing with numerical models. In fact, it is nowadays considered fundamental define the levels of pollution not only through in situ measurements, but even with the aid of numerical modeling. In other words, numerical models and in situ measurements have to be jointly used to sustain each other weaknesses through each other strengths. Numerical models, in particular, are particularly useful to supply spatial and homogeneous information even if, sometimes, they suffer from systematic or scale errors (homogeneous overestimation or underestimation). On the contrary, in situ measurements can be extremely precise but strongly affect by local sources at worst and without a precise spatial representativeness at best. For this reason the joint use of in situ measurements and numerical models, that can be carried out or through an a priori data-assimilation technique or a posteriori spatial interpolation[2], probably represents the best available evaluation we can hope to have on air quality in a specific area.

8.1.4. Impacts

The state represents the best available description of the system at a defined time, impacts, on the contrary, represent the contribution given by different pressures to the constitution of the current state. A precise definition of impacts, then, is the crucial point for any mitigation activity. Knowing all the

[2] e.g., information supplied on a regular grid by a numerical simulation can be used to spatially interpolate the local values retrieved by air quality monitoring stations.

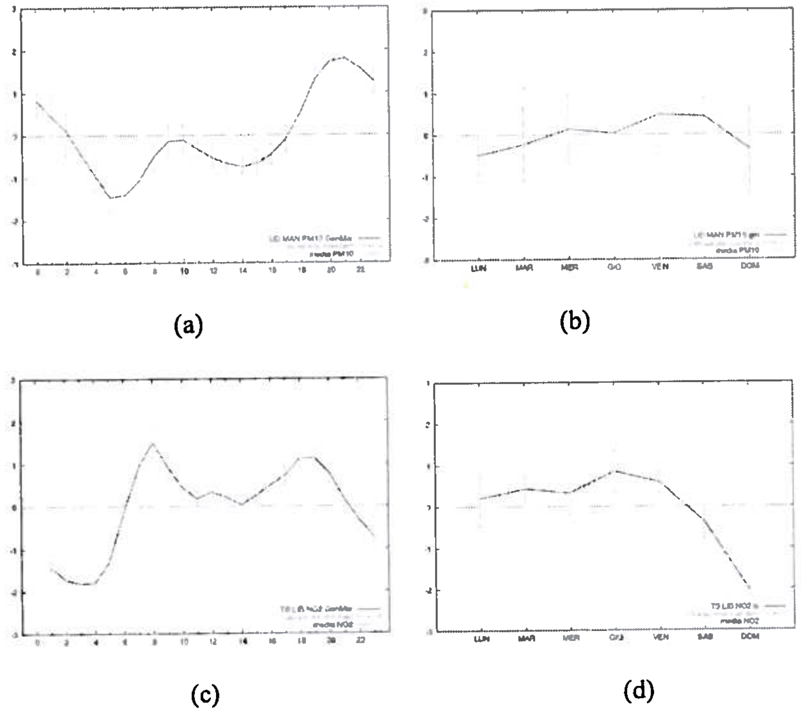


Figure 5 abcd. Upper left panel shows the winter diurnal cycle, while the upper right panel shows the weekly cycle of PM10 concentration (normalized values). Bottom left panel shows the winter diurnal cycle, while the bottom right panel shows the weekly cycle of NO_2 concentration (normalized values). Error bars are represented as well. The monitoring stations are representative of urban traffic conditions [6].

impacts, in fact, we would know which is the relevance of each pressure, then we would know which pressure or set of pressures has to be taken into account for the definition of the set of mitigation measures, avoiding the waste of resources and minimizing as well the time needed to achieve the fixed goals. Because of the complex equations which steer atmospheric chemistry, the definition of impacts is not an easy task and, if we are dealing with several concurrent pressures, this step is not possible without the aid of numerical modeling. The great advantage of numerical models, in fact, is that they can (try to) reproduce the state of the system we are interested in, and reproduce the state of the system neglecting single pressures. In this way, *via negationis*, we can estimate the relative weight of each single pressure reproducing the final state of the system without the contribution of that single pressure. Under the technical point of view, there are two ways in which this apportionment of sources can be done: i) removing completely each single pollution emission (pressure); ii) diminishing by a small percentage (e.g., 10 % or 20 %) each single pollution emission. In the first case, the impact is described by the following formula

$$\Delta C_i = C(E_1, \ldots, E_{i-1}, E_i, E_{i+1}, \ldots, E_n) - C(E_1, \ldots, E_{i-1}, E_{i+1}, \ldots, E_n)$$

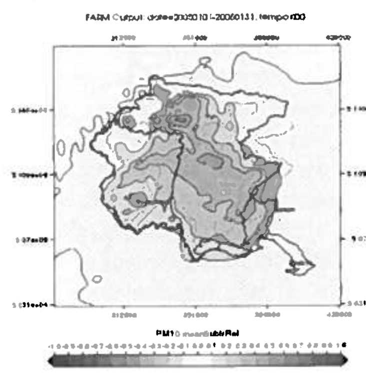
In the latter case, the impact is described by the following Taylor's approximation

$$\Delta C_i = \Delta E_i \cdot \frac{\partial}{\partial E_i} C(E_1, \ldots, E_{i-1}, E_i, E_{i+1}, \ldots, E_n)$$

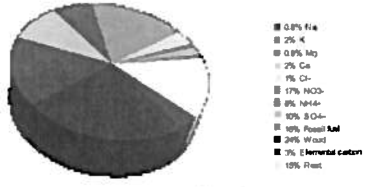
where ΔC_i is the variation in concentration due to the i^{th} emission source or class E_i

Just to make an example, trying to evaluate the impacts of road transport on NO2 concentrations, we can reproduce the NO2 concentration by completely removing the NOx emissions due to road transport or we can diminish by 10% the NOx emissions due to road transport. In the latter case we will have a percent variation in the NO2 concentrations that we might put in relationship with the NOx variation. In the former case, we will have the total effect of road transport on NO2 concentrations. Both these approaches have their advantages and disadvantages. In fact, even if the complete neglecting of a class of emissions is an easy task and supplies information on the total impact of that class, the current state of the system could not be written as the sum of each single class of pressures because of the non linearity of atmospheric chemistry [7]. This is particularly true for secondary pollutants (e.g., ozone) or mainly secondary pollutants (e.g., nitrogen dioxide or particulate matter) . On the contrary, the variational approach can supply an estimate of the impact which is probably nearer to what should happen thanks to the adopted measures which, in general, do not reduce completely a class of emissions but only reduce them. However, through both these approaches, if carefully done, the result achieved is that of a matrix of impacts, which will be the base for the preparation of mitigation measures.

Even if numerical modeling is probably the easiest and cheapest way to evaluate impacts, it is not the only option, because source apportionment can be carried out even through chemical analysis, in particular for particulate matter. In fact, thanks to complex analysis, it is possible to estimate the fingerprints



(a)



(b)

Figure 6ab. Left panel shows the reduction in the mean PM10 concentration over Friuli Venezia Giulia (Northeasterrn Italy) obtained trough photochemical numerical simulations neglecting the contribution of domestic wood combustion. Right panel the source apportionment carried out on the middle of this region during the months of January and February 2011.

of different classes of sources on the collected amount of aerosols. The description of these laboratory methods are beyond the scope of this chapter, nevertheless an example of mass-closure for particulate matter collected during winter on Friuli Venezia Giulia is shown in figure 6ab.

8.1.5. Responses

Once the impacts matrix is defined with the appropriated level of detail in emission classes, the responses, i.e., the mitigation measures, should spring out naturally facing first the sources with a greater impact, since these should produce the most effective effect. However, even if the greatest impacts should be the first to be taken into account, whenever possible technological measures should be proposed firstly and measures based on restrictions (e.g., sectoral driving ban) should be taken into account only when technological measures had already been adopted. Once a potential set of measures had been figured out, it should be important to try to evaluate their effects *in silico* by way of numerical simulations (see figure 7). Moreover, every action encompassed on a measure, should have an indicator devoted not only to evaluate its effectiveness, but even its degree of application. Just to make an example, adopting a speed limit to reduce NOx emissions and NO2 concentrations we should: i) simulate the expected improvement due to the proposed speed reduction; ii) measure the effective

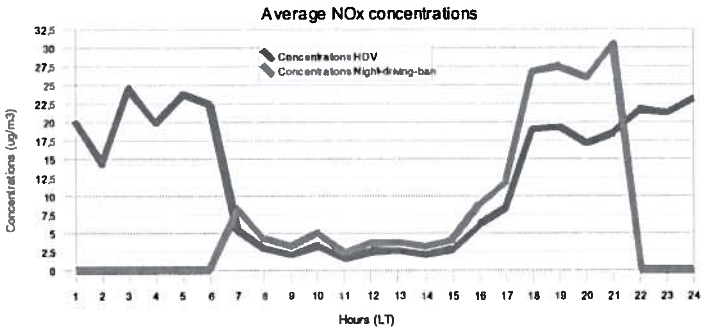


Figure 7. Simulation of the effects of night driving ban on NOx concentrations at 50 m from the road border over the Tarvisio Corridor (EU Baltic Adriatic Corridor) through a Gaussian dispersion model. It can be shown that the effects of the vehicles shift from night-time to day-time produces a clear improvement of air quality.

speed reduction through monitoring campaigns or by way of fix devices; iii) measure the NO2 concentrations during the application of speed reduction. Only through this monitoring plan we might have all the elements to evaluate the effectiveness and efficiency of our measures.

8.2. Technical and non technical measures

"The last thing that every Government desires to have is a set of precise numbers"

J. M. Keynes

Every science has its own classification scheme, whose aim is that to reduce complexity, increasing awareness and management capability. Even dealing with mitigation strategies we can classify measures but using two orthogonal archetypical concepts which are that of technical and non technical measurements. Technical measurements are here considered those organized set of actions that are merely related to technological improvement and do not depend from end users behaviour or sensitivity. On the contrary, non technical measurements are those set of organized sect of actions which depend only on end users behaviour and sensitivity. From these definitions, it is clear that every measure presents both these aspects, nevertheless this decomposition is not merely academical and, as will be hopefully clear in a while, it is worth to spend some efforts in evidencing how much and in which part a measure is technical and non technical both to improve its effectiveness and to adopt the suited monitoring criteria. Just to

make an example, a typical technical measurement is that related to the emission concepts of vehicles, while a typical non technical measure is that of bicycle tracks.

In general technical measures are much easier to adopt because they do not change people habits and, to some extent, technical measures can be almost completely transparent for end users. Adopting low emission cars people does not have to change its own habits or reduce its mobility. On the contrary, bicycle paths imply a change in the current people habits and, probably, people's mobility should vary to maximize the positive effects of these infrastructures. But the easy and soft adoption of technical measures is not the only advantage they have in spite of non technical ones, in fact technical measures are even quite easy to monitor, then it is easy to evaluate their impact on air quality. It is in principle easy to achieve information on how many low emission vehicles are sold in an area, then to evaluate the net reduction in pollutant emissions due to their penetration in Society. On the contrary, non technical measures are quite difficult to monitor. It is in fact hard, but not impossible, try to evaluate how much is the reduction in pollutants emissions due to a bike path. Nevertheless, even if non technical measures are difficult to implement as well as to be monitored, their positive impact on environment is not negligible and in some cases even larger than technical measures. Moreover, non technical measures are usually quite cheap to adopt, then the amount of pollutants not released for a fixed amount of money is larger for non technical measurements than for technical ones.

As stated above, classical technical measures are those related to the emission concepts of cars. It is clear, from table 1, that a significant potential improvement on air quality spring out from the reduction in emissions due, as an example, to the different Euro categories of vehicles. It has to be stated that, even if the particulate matter emissions of vehicles dramatically improved, nevertheless the emission factors do not take into account secondary pollutants, i.e., those formed through the complex chemical reactions that occur in atmosphere. As an example, in the emission factors of table 1, particulate matter constituted by ammonium nitrate, formed through the chemical reaction of nitrogen oxides released, among others, by car engines, with ammonium already present in atmosphere coming, among other sources, from agriculture. This amount of particulate matter is not negligible and the it has to be taken into account when evaluating the most suited set of measures for a specific area. These emission factors, moreover, do not include nor fugitive emissions (those escaping from the engine or from the fuel tank) neither those to resuspension of particulate matter, which can be extremely relevant during dry spells or in sandy areas.

Table 1. Emissions in g/km of CO, NOx , PM10 and hydrocarbons (HC) for different emissions concepts (Euro classes) as obtained through HBEFA 3.1 database [8]. Emission factors are referring at the end-of-pipe in a free flow traffic situation with speed limit of 70 km/h for gasoline (G) and Diesel (D) fuel. Emission factors are experimentally determined up to E4 class, derived from laboratory tests for higher Euro classes.

Fuel	Pollutant	E 0	E1	E2	E3	E4	E5	E6
G	CO	7.21	1.30	0.63	0.37	0.20	0.18	0.16
G	NOx	0.99	0.49	0.25	0.04	0.04	0.04	0.04
G	PM10	0.03	0.02	0.03	0.01	0.01	0.01	0.00
G	HC	0.81	0.11	0.04	0.01	0.00	0.00	0.00
D	CO	0.51	0.30	0.13	0.04	0.02	0.01	0.02
D	NOx	0.51	0.43	0.46	0.46	0.35	0.34	0.12
D	PM10	0.07	0.08	0.06	0.03	0.03	0.01	0.01
D	HC	0.11	0.06	0.03	0.02	0.01	0.01	0.01

Before to conclude it is important to underline the fact that emission factors can vary dramatically from a driving condition to another one, in general emission factors are almost constant for low speeds, say from 30 to 60 km/h, and increase sharply with increasing velocity. However, the worst driving condition is that represented by the so called "stop-and-go". In this driving condition, just to make an example, a Euro 4 Diesel engine can emit more than twice NOx amounts per kilometer than those released at 70 km/h. For this reason the low speed areas (sometimes called "low emission zones") adopted in the major towns even if in theory are not particularly relevant under the reduction of emissions just in terms of speed, nevertheless they can be useful because they contribute to make more fluid the flow of vehicles, reducing the stop-and-go regime, then abating emissions.

But vehicles are not the only devices that have to be taken into account under the point of view of technical measurements. In fact even domestic heating can play a major role in the achievement of observed pollutants concentrations, specially in terms of pollutant matter an in particular for the finest dimensions of aerosols (i.e., with an aerodynamic diameter lower than 2.5 μm). Table 2, in fact, reports the emission factors as revealed through a warm (i.e., measuring the particulate matter concentration in the hot exhausts of combustion) and cold (i.e., after the cooling of exhausts) evaluation method.

Table 2. Emissions in mg/GJ of PM10 for different domestic heating devices and for different estimation methods [9].

Combustion device	Warm method estimate	Cold method estimate
Open fireplaces	500	860
Traditional stove	250	810
Closed fireplace	250	450
High efficiency stove	150	260
Pellet	70	76

The huge differences in the amount of particulate matter (PM) emission derives from the fact that, if the combustion is not optimized, then during the first and second phase of solid combustion, i.e., that of pyrolysis and volatile organic compounds oxidation (VOC), the unburned VOC can escape in the free atmosphere as a vapor phase, then condensing because of the low outdoor temperatures. This component of PM, moreover, often is composed by carcinogenic compounds, like benzo[a]pyrene, then represents a significant risk for people health. Just to make an example, a kg of wood burned in a traditional stove and a kg of Diesel fuel can release respectively 25 and less than 3 mg of benzo[a]pyrene [9]. This is the reason why an effective set of measures devoted to the reduction of PM has to consider even actions on domestic heating devices and in the near future even end-of-pipe systems will surely be adopted in domestic heating devices to reduce the amount of condensable organic matter, i.e., the unburned VOC compounds [10].

Even if non technical measures are difficult to monitor, nevertheless it is fundamental try to evaluate their impacts. One of the most diffuse non technical measures, at least in western Countries, is that of bicycle tracks because it is relatively easy to implement, cheap and it can produce non negligible benefits even under the life style and health point of view. It can be shown (see Appendix A.) that the emission reduction Q_x for a generic pollutant ascribable to a bicycle track system is described by this formula

$$Q_x = \langle N_c \rangle \cdot L \cdot \Delta T \cdot EF_x$$

where L is the total length of the bicycle track system, $\langle N_c \rangle$ is the average bikers flow (number of bikers in a time unit), ΔT is the amount of time in which the bicycle path is used and EF_x is the average emission factor of the vehicles in the area in which the bicycle path is sited and which are ideally substituted by a bicycle. With this formula, is is estimated that every year the Udine municipality (roughly 100 000 inhabitants), through a system of roughly 17 km of bicycle tracks can reduce by roughly 4.5 Mg the emissions of NOx over its whole territory when the total amount of NOx emissions ascribable to transports (and the territory of Udine municipality is even crossed by the EU Baltic-Adriatic Corridor) is of the order of 340 Mg.

8. 3. Social aspects of adaptation and mitigation strategies

Blindly the Pythtia augured away, and since she was believed with equal blindness, no one was bothered by the fact that her predictions rarely came true, and that when they did, it couldn't have happened any other wayay

"The dying of the Pythia" F. Durrenmatt (1976)

In the evaluation of the possible actions devoted to the reduction of pollution, it is important not to forget that their effectiveness always has a component related to the response of society. This component would be, obviously, larger for the non technical measurements, but even the "hardest" technical actions, like those related to automotive efficiency or *end-of-pipe* emissions reduction can be more or less effective according to their penetration into the social texture. In other words, we might even have extremely low emission in new vehicles but if people does not purchase them renewing the fleet, the benefit would be negligible. For this reason, every action should be tailored according to the Society and culture in which it has to be adopted.

Behind the ocean of differences existing among Societies and Cultures, there are a few simple mechanisms that can be considered as universal. Our attention will be then devoted to present these mechanisms with the aim that awareness might at least reduce their potentially negative impact on our actions, with the secret hope that you might somehow find the way to use them even to foster policies.

8.3.1. Principle[3] of social evidence

The first, and probably most evident and known, social mechanism that might influence the effectiveness of our actions is that of "social evidence". This principle can be summarized in two simple rules: i) a person behaves like majority of people behaves and ii) people behaves like notable people

3 In this chapter, the term "principle" will be used with a meaning which is different from that usually known among analytical sciences. In detail, with the noun "principle" we will indicate a behavior of the system, i.e., Society, which is considered statistically true because the majority of people behaves in that way in normal conditions.

behaves. The second rule is that often adopted by commercial advertisements with testimonials taken from the world of sport, cinema and fashion. The first rule, on the contrary, is less used by commercial advertisements and it is the potentially most dangerous for environmental actions. Just to make an example, if a policy is applied to Society mentioning that it has to be adopted because the majority of people does not care about the specific aspects object of that policy, then a person would be discouraged to adopt or even to accept it, this because the message that is implicitly vectored to people is that all the "other" people would probably not adopt that policy, then making it senseless. The automatic reaction that the majority of people would probably have is "why should I do that if al the others would not do the same". This aspect was clearly underlined in the Friuli Venezia Giulia Air Quality Plan [11] during the evaluation of the effectiveness of Municipal Air Quality Plans. In that document, the ineffectiveness of municipal actions was attributed not to their technical weakness, but to the so called "nocebo effect" that, similarly but oppositely to the "placebo effect", reduces the power of policies reducing the number of people that adopt them.

There is of course no magic recipe to avoid the negative effects of the "social evidence". A general suggestion is that to take particular care in the verbal formulation and even more attention in the promotion of an action. Noticeable testimonials, somehow, might enhance the penetration of that action in Society [12].

8.3.2. Principle of lost

The principle of lost is based on a curious psychological mechanism that makes people aware of something only when it is lost. The most famous episode ascribable to the "principle of lost" occurred in 80es and is that related to the issuing of the new recipe of a famous soft drink with the withdrawal of the old one. This marketing strategy caused literally a riot of consumers with severe economical damages that pushed the company to produce and sell again the "old recipe" even if blind tests showed that consumers clearly liked the new recipe in spite of the old one.

Almost all the policies devoted to the reduction of pollutants involve a small or large lost for people, a clear example in that sense is that of traffic restrictions. It is then fundamental to pay extreme attention in presenting any restriction, even because it has been shown that even revealing to people that negative feeling toward a policy might partially be due only to the sense of lost does not reduce the intensity of those negative feelings, in other words a car. In general, every environmental measure will bring long term benefits in spite of current small losses, for this reason it is always effective figure out push and pull couple of measures that to be jointly implemented. The principle of asymmetry is even the reason why all the policies devoted to the improvement of cars or household appliances efficiency has to be sustained by an economical incentive policy because the amount of money saved, even if large, will never overcome the resistance to the initial expenditure because the latter is current while the former is long term. Even if they are extremely effective, economical incentives policies have to be adopted with extreme care because they might result in a dangerous doping of market if not, even worst, in a distortion of the measure itself. An example in this sense is represented by the economical incentives adopted for the promotion of biofuels, a renewable source of energy, to reduce the dependency from fossil fuels. In Countries where the economical incentives are tightly connected with the production and use of heat released by biofuels, only small and local power plants are build because heating networks are efficient only at short distances. On the contrary, in Countries where the economical incentives are connected with the production of electricity, huge power plants are the most appealing infrastructures in a free economy, with a serious risk of long-chain networks to supply biofuels which, in turn, might delete of even worsen the dependence from fossil fuels. Both these kind of economical incentives are in principle usable, but the sustain given to the production of electricity by way of biofuels has to be put in relationship with other steering instruments (e.g., thresholds in thermal or electrical power produced, requirement to use all the produced heat, etc.) to avoid the above mentioned draw back [15].

8.3.5. The rebounding mechanism and monitoring plans

A dangerous and unwanted feed-back that has to be kept into account dealing with environmental measures devoted to the pollution reduction is the so called "rebounding mechanism". In fact, if the measures adopted are effective or at least perceived as effective, people might be pushed toward an increased usage of resources. An example in that sense is that of low emission vehicles (both in terms of $CO2$ or of other trace pollutants); a person that has just purchased such a vehicle, might be pushed toward an extensive usage of that car because of its high performances, in this way the benefit represented by such a car might be deleted or even worsen by its intense usage. Similar detrimental effects can be hidden beneath solar power as well as other renewable forms of energy. It is not easy to foresee similar effects, but it is possible to achieve a prompt awareness of their onset

through a careful monitoring plan and the adoption of useful indicators. In general Society is a complex and chaotic system and it is not possible to foresee all the possible effects of our measures, for this reason monitoring plans are mandatory steering instruments because they close the connection between environmental targets and expected results. Every measure should be put in relationship with its foreseen impact and this foreseen impact should be put in relationship with a measurable indicator (e.g., the renew of the vehicle fleet should be monitored by the number of cars substituted), only in this way we will be able to realize if our measure is moving the system toward the right direction and in the right timing.

8.4. Conclusion

It is hard to find a meaningful conclusion in a topic which, to some extent, is endless. Even if it is possible to suggest general schemes or propose theoretical approaches and measures, every mitigation strategy is somehow unique and peculiar because it spring outs from the peculiarities of each different context. Nevertheless, mitigation and adaptation strategies to face atmospheric pollution are a fundamental topic which will determine our capability to sustain our social model of life waiting for a full sustainability, hoping that it might exist. The very general suggestion is that to try to quantify almost everything, we are not sure if the phrase ascribed to the Nobel Price for Economy by P. Krugman "what we can measure we can control" is true, but we are almost sure that what we can measure we can check if it is wrong, then correct it. And this is an important starting point.

Appendix A. Analytical evaluation of the impacts of non technical measures

Non technical measurements are those set of actions proposed by Policy Makers to achieve a predetermined goal and whose effectiveness is essentially determined by the way in which Society adopts them. According to this definition, the improvement of vehicles fleet or filters applied end-of-pipe to domestic heating devices are technical measures, while bicycles tracks or a bike sharing service are non technical measure. Evaluation of the impacts of the above mentioned non technical measures can be carried out in two steps:

1. estimate of the number of kilometres avoided through the non technical measure (km per year);
2. estimate of the amount of emissions avoided thanks to the reduction in km (kg per year).

Taking into account these two steps, it is clear that in principle the same non technical measure can have different effects in two different areas even if it penetrates in the same way into society. In fact, if the bike sharing measure is adopted in an area where the vehicles fleet is extremely efficient in terms of reduced emissions, the benefits would be reduced by the fact that the amount of reduced emissions would be small because of the small impacts on air quality of the vehicles in that area. For this reason, it is recommended, before of the adoption of every measure, to carry out a careful analysis following the general scheme proposed in this chapter.

A1. Bicycle tracks

The effectiveness of a bicycle track in reducing pollution is proportional to the number of people that use the bicycle instead of a car in a fixed period of time. It is here assumed that every person that uses a bicycle would have used a car and not another vehicle devoted to public transportation. Because it is not possible to know in advance the emission concept of the car which would be substituted by a bicycle, an average weighted emission factor for each pollutant has to be computed using the average emission factor of the fleet that characterizes that area as shown here

$$EF = \sum_i f_i EF_i$$

where f_i is the fraction of vehicles with emission concept i which have an emission factor (g/km) EF_i for a specific pollutant. An example of the determination of average emissions factor is shown in figure A1 and figure A2.

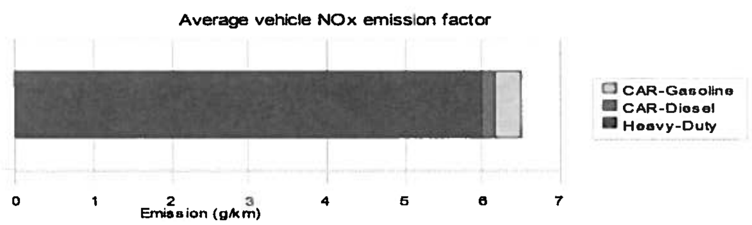
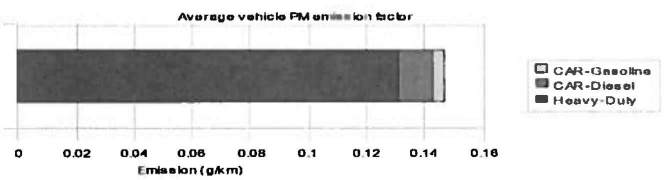


Figure A1. Upper panel shows the reduction in the mean PM10 concentration over Friuli.



Venezia Giulia (Northeastern Italy) obtained trough photochemical numerical simulations neglecting the contribution of domestic wood combustion. Right panel the source apportionment carried out on the middle of this region during the months of January and February 2011.

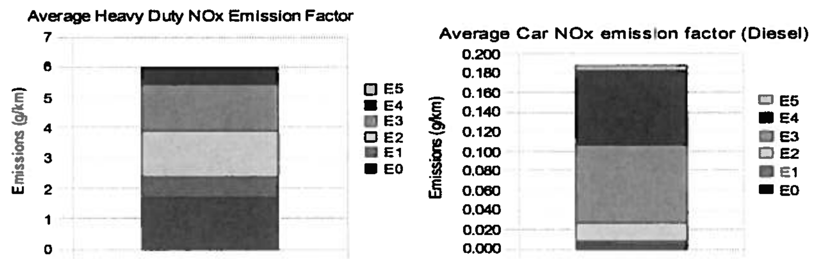


Figure A2. Left panel shows the weighted average emission factor for heavy duty vehicles while the right panel shows the weighted average emission factor for Diesel cars over the Tarvisio corridor (EU Baltic Adriatic Corridor). Emission factors are computed using the number of vehicles running over that corridor and the average vehicle fleet composition for year 2010 (Courtesy EU Alpine Space Project "iMONITRAF").

An indicator easy to monitor related to the usage of bicycle tracks is the flux of bikers (number of bicycles that cross a section in a fixed period of time) N_c then its average value $<N_c>$ for the whole track system. It is clear that this value changes from trunk to trunk of the track system and in the different periods of the year or day, for this reason it should be wise try to evaluate it in different conditions, times and trunk. This uncertainty might be solved by a numerical model of the track. Without such a modelling, an average flux, weighted for the different trunks of the track system $<N_c>_P$ might be used.

The average speed V of bikers in the bicycle path is another parameter of the track system; it can be measured experimentally, but in general it can be assumed without particular errors that the average speed is of the order of 15-20 km/h, while the average distance P ran by a person can be considered of the order of 2 km.

Knowing the flux of bikers in the track system and their average speed, it is possible to evaluate the bikers density D as

$$D=\frac{\langle N_c\rangle}{V}.$$

Then, knowing the total length L of the track system, the number of users N_o of the track system in a fixed instant of time will be

$$N_o = D \cdot L.$$

In the same way, the average time of usage $\langle T_u \rangle$ of the track system can be estimated as

$$\langle T_u\rangle=\frac{P}{V}.$$

Once these parameters are know, the number of kilometers K ran in a track system in an interval of time ΔT will be given by this relationship

$$K = N_o \cdot P \cdot \frac{\Delta T}{\langle T_u\rangle}$$

Which, expanding the parameters N_o and $\langle T_u \rangle$ according to their definition, becomes

$$K = D \cdot L \cdot P \cdot \frac{V}{P} \cdot \Delta T$$

then

$$K=\frac{\langle N_c\rangle}{V} \cdot L \cdot P \cdot \frac{V}{P} \cdot \Delta T$$

and at the end

$$K=\langle N_c\rangle \cdot L \cdot \Delta T$$

Where attention as to be payed to express $\langle N_c \rangle$ and ΔT in the same units. Once the amount of kilometers K "avoided" through the bicycle tracks system is known, using the weighted average emission factor for the specific area, the amount of emissions Qx avoided in the unit of time ΔT *will* be given by

$$Q_x = K \cdot EF$$

Before to conclude it is worth to underline the fact that probably this value is underestimated because, usually, with a car a person has to ran more kilometers than those needed because even the extra distance devoted to find the car park should be taken into account.

A2. Bike sharing

The evaluation of the impacts of a bike sharing system can be an extremely easy task if the bicycles have even a device to register the kilometers ran. If this is the case, it can be assumed that every km ran through a bicycle is a kilometer avoided for a car and, using the weighted emission factor EF, the amount of emissions avoided is given as above b

$$Q_x = K \cdot EF$$

Where K is the total number of kilometers avoided by the bike sharing system in a fixed amount of time ΔT. If the bike sharing does not have this kind of devices, then extra evaluations have to be carried out. The simplest solution then is that to use the origin destination matrix U_{ij} that gives the number of times a bicycle was taken from the position i and released in the position j. Knowing the distances matrix D_{ij} between every position i and every position j the total number of kilometers avoided K is given by

$$K=\sum U_{ij} \cdot D_{ij}$$

This evaluation of the kilometers avoided is, however, an underestimate because the amount of kilometers ran taking a bike and releasing it at the same position i are completely neglected since the matrix D_{ij} has a null diagonal. This amount of kilometers can be estimated evaluating the average distance P=<Dij>, in fact it seems reasonable that if a person has to ran for a distance larger than P, then it would find another place where to release the bike. With this assumption the correction C to include in the evaluation of the correct number of kilometers avoided Kcorr will be

$$C = \langle P \rangle \cdot \sum U_{ij}$$

Then the correct number of kilometers avoided would be

$$K_{corr} = K + C$$

and the amount of emissions avoided in the period taken into account

$$Q_x = K_{corr} \cdot EF$$

Even with this correction, however, it seems reasonable to consider the above evaluation an underestimate because the number of kilometers ran to find a car park are not taken into account.

Glossary

Acidifying substance: any kind of substance that, once added to water, increases its acidity. Among the most relevant acidifying substances have to be mentioned all the sulfur compounds.

Bike (car) sharing: any system that gives people the opportunity to take a bike (or car) in a place and release it into another one after having used it for their displacements.

CLRTAP: is the Convention on Long-Range Transboundary Air Pollution, signed in 1979 and entered into force on 16^{th} march 1983 to assess and mitigate the transnational impacts of human activities on environment by way of scientific exchange of information and policy negotiation (http://www.unece.org/env/lrtap/)

Coke: a solid composed mainly by carbon atoms which is the result of a total pyrolysis and consequent release of volatile organic compounds from organic matter. Coke particles constitute the elemental carbon in particulate matter.

Condensable organic compound: every compound based on carbon with a low surface tension. These compounds are released during the pyrolysis phase of combustion and, if not fully oxidized, can condensate at low temperatures giving rise to particulate matter. This is not a chemical reaction but a merely physical one, for this reason these compounds are not

reproduced by photochemical numerical models and only suited emission factors can give information on their amount. They constitute the organic carbon in particulate matter.

Dose: it is the amount of pollutant actually entered into or onto the target. If C(t) is the pollutant concentration, varying in time, and K(t) is the effective rate of contact (e.g., the amount of pollutant that remains into the lungs after each breath), then the dose becomes $D=\int C\ t\ \ K\ t\ dt$.

Emission factor: (or emission intensity) is the amount of pollutant released per unit of fuel consumed or unit of energy released or kilometer run or similar. Emission factors are basics to estimate the amount of pollutants released in a fixed period of time starting from the proxy indicators (amount of fuel, amount of energy, kilometers, ...) which are much more easy to determine operationally.

Exposition: it is an estimate of the amount of pollutant that might potentially come in contact with the sensitive area of a target (animate or inanimate). If C(t) is the pollutant concentration, varying in time, then exposition E between times (t_1 and t_2) is defined as $E=\int C\ t\ dt$.

Euro class: (or Euro Concept or European emission standard) is a classification of vehicles according to their amount of emissions in atmosphere. The Euro classes are mandatory for vehicles to be sold in the EU union. Emissions are evaluated according to fixed driving cycle. Similar emission classes exist in other areas of the World.

Heating-degrees-day: they are the sum of the positive differences between the threshold level of 20 °C and the average daily temperature (expressed in Celsius) for the area of interest. In formulas $HDD=\sum[20-T_i]^{pos}$. HDD represent a measure of the amount of thermal energy required to keep indoor temperature at a level of comfort.

Mobility: is the capability to realize transports or transfers in a specific area. Mobility is considered as a pounding value of several economical or social systems even if, currently, it has a large impact on pollutants emissions.

Pyrolysis: is the first phase in the combustion of solids. In this phase, the organic compounds that are part of the solid (wood or coal) evaporate thanks to the supply of thermal energy (fire ignition). This is the most delicate phase of combustion in solids because it releases compounds potentially harmful for human health. The other phases of combustion in solids are that of volatile organic compounds oxidation and that of coke combustion.

Pollutant: every substance directly or indirectly released in atmosphere by human activities, that changes in a measurable way the natural composition of the atmosphere. If the pollutants are directly released by human activities, they are called "primary". If they are not directly released, but form in atmosphere through chemical reactions involving primary pollutants, they are called "secondary".

Scrubber: a device used to clean a gaseous flow from particulate matter or from acidifying substances. In a scrubber the gaseous flow is mixed with a liquid or recently even with a dry reagent to be cleaned. After the cleaning, the reagent is removed by the gaseous flow which can be released in atmosphere or used in other industrial processes.

Source apportionment: it is any procedure to evaluate the relative weight of the different sources for the formation of the observed particulate matter. It can be carried out via numerical modelling or through laboratory analysis.

Transfer: an immaterial displacement of person or a good (e.g., video conferences or digital documents).

Transport: a material displacement of a person or a good.

Volatile organic compound: every compound formed by atoms of carbon and hydrogen with a low surface tension. These compounds at ambient temperature can pass easily from the solid or liquid phase to the vapour phase, giving rise to complex chemical reactions. Some of them, as benzene, are even recognized as carcinogenic, then represent a direct threaten for human beings.

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