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Assessment of the health impacts from air pollution in Ravenna (Italy) using the EVA model

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FOREWORD

Daily we hear about the economic and financial crisis, with such emphasis and concern to make it appear less important than the environmental crisis. In my opinion, if we are unable to contain the environmental crisis we cannot solve the economic crisis, because these two concepts, environment and economics, are related to each other. It is just this connection that pushed me to develop the topic of my final dissertation, paying specific attention to the health risk and related costs due to air pollutants.

ABSTRACT

The aim of this work is to assess the health impact from air pollution in Ravenna, a small Italian city located in the Pianura Padana. In this area the environmental pressure, because of air pollution, is worsened by unfavourable meteorological conditions. In fact Ravenna, in addition to being a large industrial area and one of the most important commercial harbours of Italy, has a temperate-continental climate characterised by a high relative humidity, because of the presence of fog, frequent thermal inversions during the winter and frequent conditions of wind lull. Because of these peculiar meteorological conditions and high pollutant emissions, e.g. from intense industrial activities, often alarming levels of air pollution occur, giving public health concern. These conditions stimulated the present study of the effects of air pollution on health in the area of Ravenna using the EVA model. This system was developed in the Atmospheric Modelling (ATMO) section of the Environmental Science Department of the Aarhus University (DK) to assess health-related economic externalities of air pollution, considering the main emission sectors and quantifying their relative importance in term of impacts on human health.

SUMMARY

| | |
|---|----|
| INTRODUCTION | 1 |
| AIM OF THIS RESEARCH | 5 |
| 1. QUALITY OF THE AIR AND ITS MONITORING..... | 7 |
| 2. LEGISLATION | 9 |
| 2.1 Definitions..... | 11 |
| 3. AREA OF STUDY | 12 |
| 3.1 Meteorological conditions..... | 12 |
| 3.2 Emission Sources | 15 |
| 3.3 Air Quality in Ravenna | 16 |
| 4. MATERIALS & METHODS | 18 |
| 4.1 Data Collection | 19 |
| 4.1.1 Population Data | 19 |
| 4.1.2 Emission Data | 20 |
| 4.1.3 Authorization Integrated Environmental (AIE)..... | 20 |
| 4.1.4 Geographic Information System (GIS)..... | 21 |
| 4.1.5. Residential and commercial emissions..... | 22 |
| 4.1.6 Industrial emission..... | 22 |
| 4.1.6.1 Method for collecting data from AIE | 22 |
| 4.1.7 Agricultural emissions | 23 |
| 4.1.8 Vehicular emissions | 24 |
| 4.1.9 Final emission data | 25 |
| 4.1.10 Measurement data | 27 |
| 4.2 Air Pollution Modelling..... | 28 |
| 4.2.1 DEHM model..... | 29 |
| 4.2.2 The UBM model..... | 30 |
| 4.3 Validation of the models | 31 |
| 4.3.1 Statistical evaluation..... | 32 |
| 4.4 EVA model | 35 |
| 4.4.1 Exposure-response functions and monetary values | 36 |
| 4.4.2 Mortality | 37 |
| 4.4.3 Morbidity | 37 |
| 4.4.4 Valuation..... | 38 |
| 4.4.5 Health effects from particles | 41 |

| | |
|---|----|
| 5. RESULTS..... | 43 |
| 5.1 Scientific validation..... | 43 |
| 5.2 Second validation | 43 |
| 5.3 EVA results..... | 46 |
| 5.3.1 Health impacts..... | 46 |
| 5.3.2 The total health-related externalities..... | 49 |
| 6. DISCUSSION AND OVERALL CONCLUSION..... | 51 |
| Attached A | 55 |
| Attached B | 63 |
| Attached C | 71 |
| Meteorological data | 71 |
| REFERENCES..... | 72 |
| <i>ACKNOWLEDGES</i> | 78 |

INTRODUCTION

The considerable increase of the industrial, commercial and agricultural development, and all human activities connected with the production of goods and services, have brought as a result different conditions of environmental pollution. But what is pollution? It is the establishment of “anomalous” conditions in an ecosystem, due to insertion of toxic substances, where people work and plants and animals have their life cycle. Therefore, pollution can modify the equilibrium between plants, animals (including humans) and climate of an ecosystem, especially by alteration of the air, water and soil.

Industrial emissions and incorrect disposal in the environment of non-biodegradable waste, waste water, plant protection products, fertilizers, hydrocarbons, dioxins, heavy metals and organic solvents can be considered as the main sources of pollution.

The chemical industry produces, each year, thousands of compounds, but we have scarce scientific information about their toxicity and real impact on health and environment.

Therefore, on the one hand the economic growth delivers better living conditions to millions of people around the world through industrial development, improved transport, modern energy systems and other technological facilities, while, on the other hand, it often causes serious problems associated with pollution. In particular, the attention of the present study is specifically turned to air pollution.

Since the late 1970s, air pollution has been one of the main environmental policy concerns of the European Union. According to the European Environment Agency (EEA), air pollution is “the presence of contaminant or pollutant substances in the air at concentrations that interfere with human health or welfare, or produce other harmful environmental effects”.

Air pollution constitutes a severe problem for the environment and, consequently, for the human health. In Europe there are excessively high concentrations of air pollutants leading to health and economic issues associated to these pollutants. A large portion of the European population lives in areas where the emission limits [1], as defined by Directive 2008/50/CE, are exceeded.

The Directive 2008/50/CE [2] of the European Parliament and Council (21th May 2008) deals with the quality of the air, and is aimed to obtain a cleaner air in Europe. This directive establishes targets to be reached within 2020 to improve the quality of the air, the human health and the quality of the environment. Moreover, the same Directive indicates how to evaluate and reach these objectives, and implements actions in the case the fixed rules are not followed. In addition, it provides public information.

The main effect of emissions of gaseous pollutants (e.g., carbon monoxide, sulphur dioxide, nitrogen oxides, benzene, and particulate matter) in the atmosphere is a chemical and physical alteration of the air.

According to the European Commission [3], every year more than 400.000 people in the UE die prematurely as a consequence of air pollution. Another 6.5 million people fall sick because air pollution causes diseases such as strokes, asthma and bronchitis. Air pollution also harms our natural environment, impacting both vegetation and wildlife: almost two thirds of the European ecosystems are threatened by the effects of the air pollution.

Air pollution, as a side-effect to economic growth and development, is currently threatening citizens' health, thus leading to high expenses and severe environmental damages all around the world.

In fact, the presence of pollutants in the atmosphere results in a large damage to public health and economics of a country. These two factors, economy and health as evaluated by analysis of Environmental Impact Assessment (EIA), constitute the topic of my final dissertation.

According to current estimates, the joint effects of ambient and household air pollution cause 7 million premature deaths globally each year, representing one eighth of the total deaths worldwide [4]. From the economics point of view, there is evidence that air pollution imposes remarkable costs to society, of the order of magnitude of several trillion dollars per year, globally. Economic analyses show that, considering the impact of air pollution on both health and economics, the benefits of a cleaner air would be extremely large.

In Italy the economic costs caused by the effects of air pollution on health are evaluated to be 4.7% of GDP (Gross Domestic Product), while in ten countries of Europe the cost is slightly higher than 20% of the GDP [5].

According to the World Health Organization (WHO)¹ more than 90% of European citizens are exposed to annual amounts of air pollutants which exceed the limit established by the WHO guidelines (Economic cost of the health impact of air pollution in Europe - WHO 2015).

In 2012, 482000 premature deaths have been ascribed to the outdoor air quality, and 117200 premature deaths to the indoor air quality [6].

Therefore illness and premature death caused by air pollution not only are a damage for public health, but also for economics, costing to Europe about 1463 billion euro a year. According to the WHO, this cost is associated with about 600 thousand premature deaths caused by air pollutant.

The purpose of this work is to evaluate the effects of air pollution on the economy and human health. The area of study is the city of Ravenna, situated in the Emilia Romagna Region (NE Italy) on the Adriatic Sea.

The city of Ravenna includes a large industrial area and one of the most important commercial harbours of Italy. Despite the air quality in the Province of

¹WHO is directing and coordinating authority on international health within the United Nations' system. WHO works together with policy-makers, global health partners, civil society, academia and the private sector to support countries to develop, implement and monitor solid national health plans.

Ravenna has significantly improved over the last decades, and concentrations of some pollutants, such as particulate matter, nitrogen oxides, and ground-level ozone, are now levelling off, air pollution monitoring and related health problems, particularly in the urban areas, remain an important issue. Road transport, harbour and industrial activities and burning of fossil fuels are the main sources of these pollutants.

A reliable assessment of the health-related costs connected with air pollution is a powerful tool for decision making, since these costs must be taken into account as well as other social costs.

In order to make an assessment of the influence of external cost of the health impact because of air pollution on the society, an integrated model system has been employed.

The development and the implementation of models allow to simulate the effects of air pollution, paying specific attention to the negative consequences on public health and economy.

For this kind of study, we used an atmospheric health impact assessment model (EVA: Economic Valuation of Air Pollution) that has been developed in the ATMO (Atmospheric Modelling) section of the Environmental Science Department of the Aarhus University.

The EVA system has been applied to the Ravenna city to assess health-related economic externalities of air pollution considering the major emission sectors and quantifying their relative importance in term of impacts on human health and related external costs in the area.

AIM OF THIS RESEARCH

This thesis addresses the economic cost of public health impacts of air pollution in Ravenna, Italy. The idea of this project arise from the need to inform the community about the health risks caused by air pollution and their costs on the society, in order to push people to face this problem.

In the Province of Ravenna the most frequent meteorological condition, in all seasons, is a “meteorological stability” associated with the lack of thermodynamic turbulences and small variations of the wind speed with altitude.

The pollutants emitted from human activities influence directly the quality of the air that we breathe, being thus responsible for the impacts on the health and environment. Many of these pollutants are considered potentially dangerous for the health and corrosive for the cultural heritage. The health impacts of air pollution carry many significant financial and economic implications, not only in terms of social costs and mortality, but also household, hospital and public budgets and, therefore, imply decision making within and outside the health sector.

5

The quality of the air is a typical indicator of the impact of human activities on the quality of life, and accordingly on economy. Different kinds of instruments, through regulations and monitoring, have been developed to face and assess this problem.

The present work describes a methodology to evaluate the economic cost of health impacts using the EVA model. The EVA system, based on the impact-pathway chain, allows to assess the health-related economic externalities of air pollution resulting from specific emission sources and to support policy-making with respect to emission control [7]. In fact the main goal of this work is to identify the anthropogenic emission sources in Ravenna that contribute the most important impacts on human health.

In this study, we apply the EVA model to Ravenna to examine the contributions from four sectors, or SNAP (Selected Nomenclature for Sources of Air Pollution) emission sectors, and to quantify their relative importance in terms of impacts on human health and related external costs.

The EVA model is based on an Eulerian atmospheric model for regional transport and chemical transformation of air pollutants (Danish Eulerian Hemispheric Model - DEHM) and an urban background model (UBM).

The purpose of this work is to evaluate the health impact and the external costs of air pollution using the EVA model integrated with estimates of exposure from the DEHM (Danish Eulerian Hemispheric Model) and UBM (Urban Background Model) models. The exposure-response functions (ERF) used in EVA are based on the assessment of European experts in public health and consultation with the WHO [8].

This work was carried out in the ATMO section of the Department of Environmental Science of the Aarhus University with the collaboration of the Department of Analysis and Management of Environment of the University of Bologna.

1. QUALITY OF THE AIR AND ITS MONITORING

The air pollution is defined by the Legislative Decree 152/2006 as “each change of the atmosphere because of the introduction of one or more substances whose properties can create a risk for the human health or for the quality of the environment or damage material goods or compromise the legitimate uses of the environment”. Most of the substances that are emitted in atmosphere can change and became dangerous for the health and for the environment. These kind of species are evaluated and analyzed on the basis of their effects, temporary or irreversible, immediate or long-term effects. So these species are classified on the basis of the limit of concentration at which they become dangerous [9].

Air pollution is the result of emissions from various sources with extremely different features regarding height and temporal variability. The most important pollutants are the so-called primary pollutants, which originate from fossil fuels in various ways, such as CO₂ (from combustion), impurities or additives (typically sulphur in oil and lead in petrol), CO, NO_x and hydrocarbons. Some pollution comes from industrial activities. Typical agricultural emissions are NH₃, CH₄ and NO_x. These pollutants are also naturally emitted, but human activities have increased the emission manifold. Compounds formed in the atmosphere through reactions of primary pollutants are referred to as secondary pollutants [10].

The regulations about air pollution and its effects on the human health and environment consider two important aspects:

- Evaluation of the level of pollutions in the air (by means of measurements, calculus and esteem)
- Management of the quality of air through actions suitable for programming and planning its protection, rehabilitation and improvement of the quality [11].

On the basis of the Legislative Decree 155/2010, the valuation of the quality of air depends on a network of measurements of the pollutants and on the system of valuation [9]. To evaluate the concentrations of air pollutants a monitoring network is used, which supplies hourly measurement. This network consists in a series of fixed stations located on the entire national territory [12]. The data collected are elaborated and analyzed by the Regional Agency responsible for each area. For instance, in Italy these Agencies are designated as ARPA (Regional Agency for the Protection of the Environment). The data are then collected in a database that can be national (e.g., Brace²) or European (e.g., AirBase³). The locations of the stations, the choice of the analyzers installed in each station, the sampling techniques used and the analysis of the results are established by national and regional regulations, which take into consideration the following pollutants:

- Gas: compounds that contain sulphur, nitrogen, carbon and ozone.
- Particulate (PM₁₀ and PM_{2.5}) [9].

² <http://brace.sinanet.apat.it/>

³ <http://acm.eionet.europa.eu/databases/airbase>

2. LEGISLATION

In Italy the first procedural guidelines about the air were given by the framework law 651/66, followed by other regulatory national and local rules. The aim of the regulation was to “reach a level of the quality of the air that doesn’t bring negative consequences or risks for the human health and for the environment”. This legislation was adopted to reduce the exposure to air pollutants, by decreasing emissions and fixing limits to the concentrations of pollutants. Today, the Community measures are managed by the Directive 2008/50/EC (European Legislation), while the Italian measures are managed by the Legislative Decree of the 13 August 2010, n. 155 [9]. This Decree, subsequently amended and supplemented in 2012 (Legislative Decree 250/2012), gives information about zoning, and also on limit and target values and critical levels [11].

| Pollutant | Averaging period | Limit value |
|-------------------|---|-----------------------|
| NO ₂ | Hourly (not to be exceeded more than 24 times per year) | 350 µg/m ³ |
| | Daily (not to be exceeded more than 3 times per year) | 125 µg/m ³ |
| SO ₂ | Hourly (not to be exceeded more than 18 times per year) | 200 µg/m ³ |
| | Yearly | 40 µg/m ³ |
| CO | Max daily average in 8 hours | 10 µg/m ³ |
| PM ₁₀ | Daily (not to be exceeded more than 35 times per year) | 50 µg/m ³ |
| | Yearly | 40 µg/m ³ |
| PM _{2.5} | Yearly | 25 µg/m ³ |

Table 1. Limit values (Annex XI D.Lgs 155/2010)

| Pollutant | Averaging period | Critical level for the vegetation |
|-----------------|--|-----------------------------------|
| NO ₂ | Yearly | 30 µg/m ³ |
| SO ₂ | Yearly | 20 µg/m ³ |
| | Winter (1 st October - 31 st March) | 20 µg/m ³ |

Table 2. Critical levels for the vegetation (Annex XI D. Lgs 155/2012)

| Purpose | Averaging period | Target value | Deadline |
|--------------------------------|--|---|------------|
| Protection of the human health | Max daily average in 8 hours per year | 120 µg/m ³ to not exceed over 25 days per year as a average on 3 years | 2013 |
| Protection of the vegetation | AOT40 calculated on the base of hourly values from May to July | 1800 µg/m ³ h as a average on 5 years | 2015 |
| Long-term targets | | | |
| Protection of the human health | Max daily average in 8 hours per year | 120 µg/m ³ | No defined |
| Protection of the vegetation | AOT40 calculated on the base of hourly values from May to July | 6000 µg/m ³ | No defined |

Table 3. Target values and Long-term target for the Ozone (Annex VII D.Lgs. 155/2010) [13]

At the European level, the Council and the European Parliament reached an agreement on June 30th 2016, to reduce the emissions of pollutants in the atmosphere. This new Decree establishes limits more stringent than the previous ones, to be adopted from 2020 to 2029, and even more restrictive from 2030 on. The Decree aims to address the risks for the human health and for environment, but also to extend the European legislation at the national levels (following the revision of the Göteborg Protocol⁴ in 2012). The new Decree establishes the national limits for five pollutants: NO₂, SO_x, NMVOC (Non Methane Volatile Organic Compounds), NH₃ and PM. The limits that each nation should respect in the years 2020-2029 are those established by the Göteborg Protocol, but from 2030 on the limits will become more severe. According to various estimates, these new limits will reduce the effects of air pollution on human health by 50%, compared to 2005 [15].

The region Emilia-Romagna has developed its own legal regime, in line with the national legal regime. In particular, the region has entrusted the monitoring of

⁴ The Göteborg Protocol (1999) is relative to the abate acidification, eutrophication and atmospheric ozone [14].

air pollution to ARPA and implemented the Legislative Decree 155/2010 at a regional level through the D.G.R.⁵ n°2001, dated 27/12/2011 [11].

2.1 Definitions

- **Limit Value:** is the value established on the basis of scientific knowledge in order to avoid, prevent and reduce negative effects on the human health and the environment, that have to be achieved within the scheduled deadline; after the deadline this values have not to be exceeded.
- **Critical Value:** is the value established on the basis of scientific knowledge over which negative effects on “receptors” like trees, plants or natural ecosystem, except for humans, may appear.
- **Target Value:** is the value established in order to avoid, prevent and reduce negative effects on the human health and the environment, to be achieved, when possible, within a deadline [13].

⁵ D.G.R. (Deliberazione della Giunta Regionale, Decision of the Regional Council)

3. AREA OF STUDY

The area considered in this study is Ravenna, in Emilia-Romagna, north-east of Italy, a small Italian city on the Adriatic sea with approximately 153900 residents in 2012 (652.9 km² and 4 m above sea level).

3.1 Meteorological conditions

Ravenna is located in the Pianura Padana, where the environmental pressure associated with air pollution is worsened by unfavourable meteorological conditions. In fact, Ravenna is characterized by a continental-temperate climate with high relative humidity, because of the fog, frequent thermal inversion conditions during the winter and frequent wind lulls. Information about temperature, precipitations, wind speed and direction is recorded by several meteorological stations located in the Province of Ravenna, one of them being located in the urban area (Figure 1).

- **Temperature:** Figure 2 reports the average, minimum and maximum monthly temperatures for the year 2014, as measured by the meteorological station of ARPA in Ravenna.

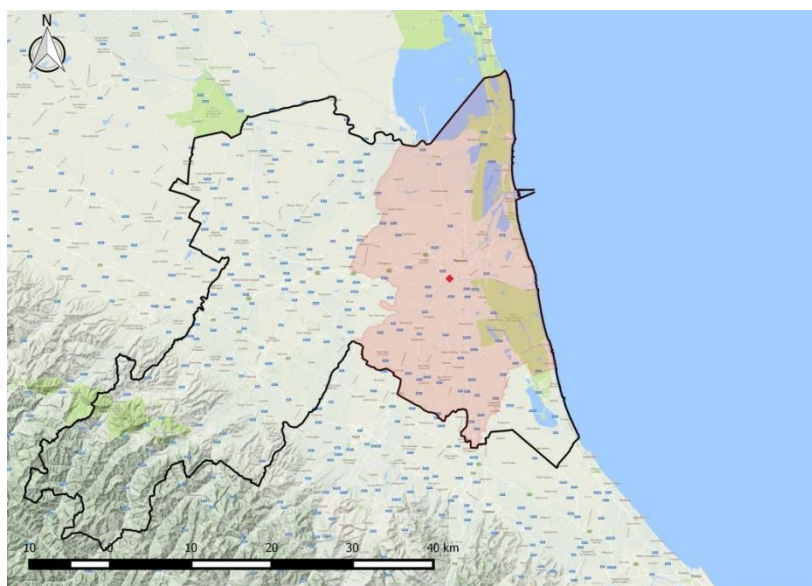


Figure 1. Meteorological station in Ravenna

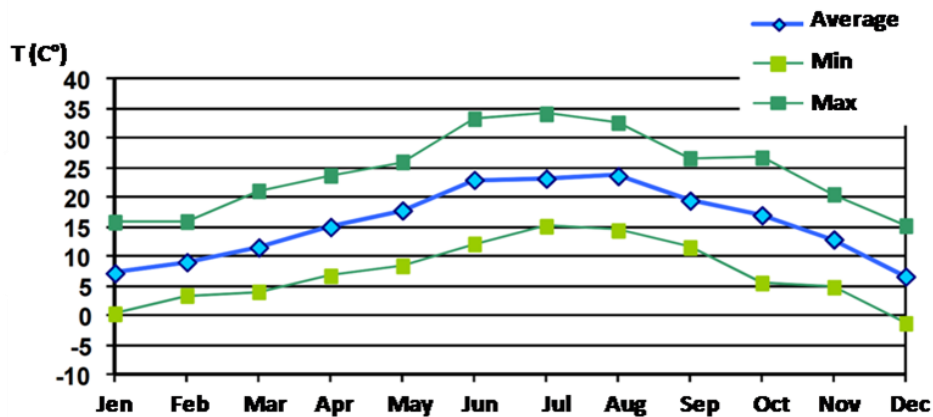


Figure 2. Average, minimal and max monthly temperatures for the year 2014 [16]

- Precipitation:** the total monthly precipitations and the number of days where the precipitations exceeded 0.3 mm are shown in Figure 3. In this case two meteorological stations are involved in the measurements: one in the heart of downtown, the other in the harbour area (Porto San Vitale). The value of 0.3 mm was chosen as a threshold of the total daily precipitations because below this value the critical conditions for accumulation of the PM₁₀ are favoured, in agreement with the SIMC (Service Hydro Weather Climate). In fact the SIMC states that precipitations lower than 0.3 mm and index of ventilation lower than 800 m²/s facilitate a concentration increase of PM₁₀ in atmosphere. The precipitations measured in the harbour area were lower than those of the urban area.

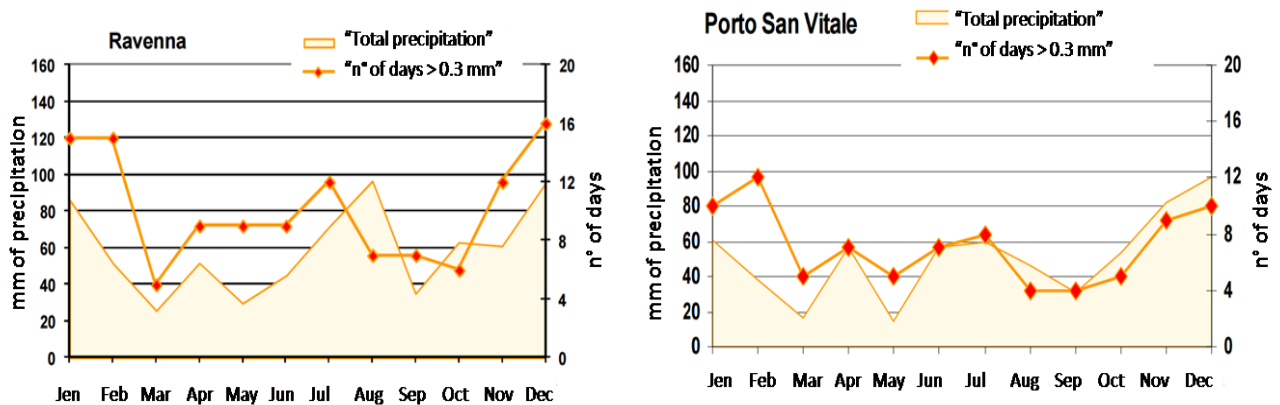


Figure 3. Total monthly precipitations and number of days with daily precipitations over 0.3 mm for the year 2014 [16]

- **Wind Speed & Wind Direction:** Figure 4 shows the wind rose, as recorded by the urban meteorological station, which describes the wind trends. The distribution of the speeds shows that values lower than 3 m/s is prevailing over a whole year. The most frequent wind directions are W-NW and NW, to a lesser extent E-SE.

Figure 5 displays the prevailing season wind directions and speeds. In winter and autumn wind directions do not look like dispersive. In summer small variations are observed because of the influence of sea breezes with direction E-SE. Spring is the season in which the highest variability is observed.

So because of these meteorological condition and the intensive industrial activities, in Ravenna there is an alarming air pollution and the relative public health concern [16].

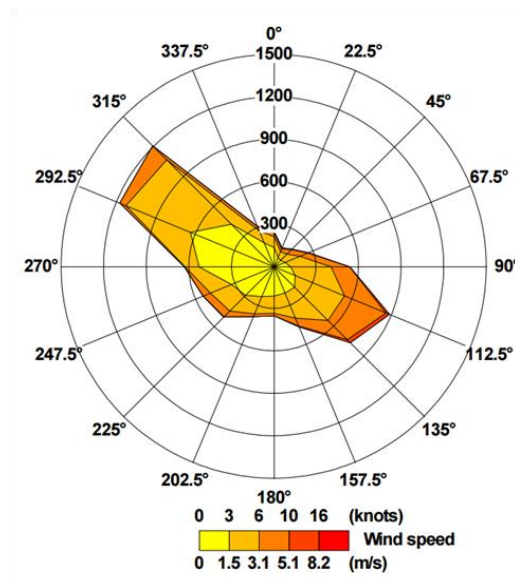


Figure 4. Wind rose corresponding in Ravenna [16]

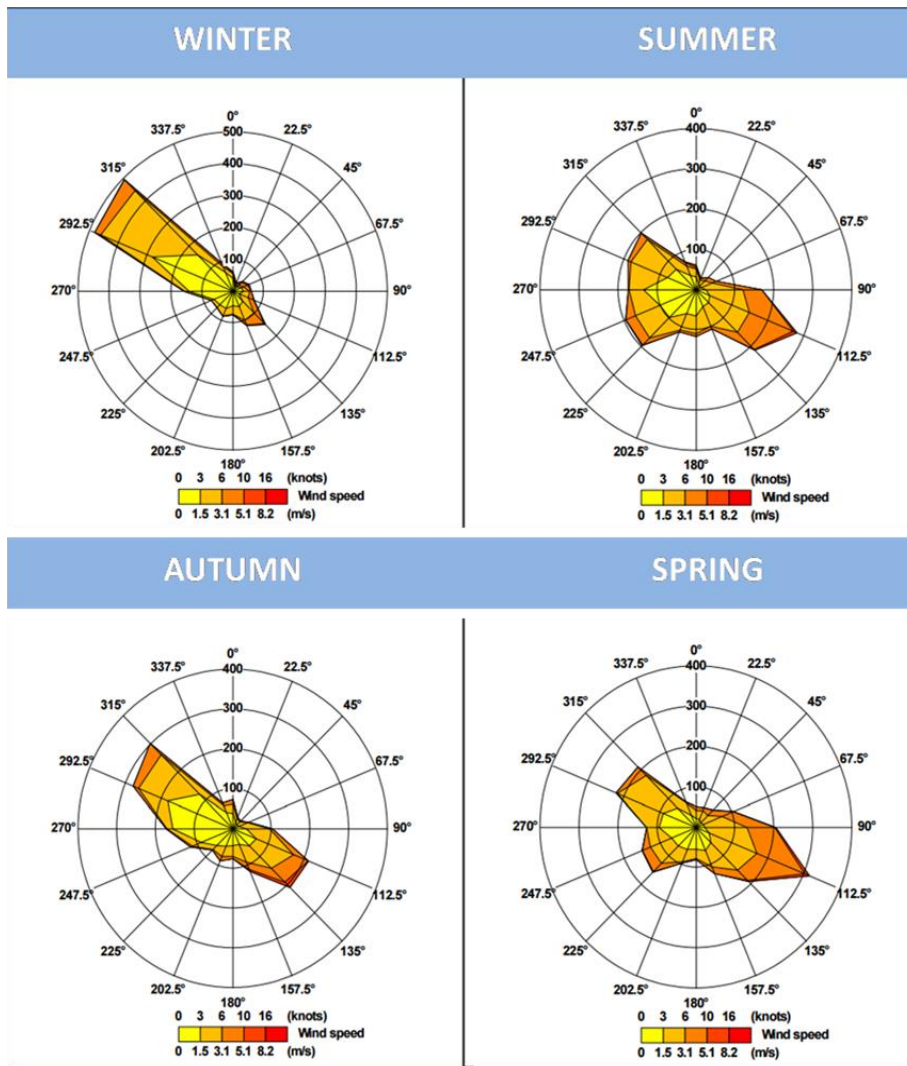


Figure 5. Seasonal wind rose for the meteorological station of Ravenna [16]

3.2 Emission Sources

Ravenna is characterized by the presence of emission sources which cause a significant environmental pressure. The emissions of pollutants in atmosphere are the result of intense industrial activities. In fact, in addition to a strong agricultural activity in its surroundings, Ravenna has a large industrial area and an harbour among the most important in Italy. The industrial and dock areas are characterized by the presence of chemical and petrochemical plants, two thermal power stations, metallurgical companies, construction factories and port activities. The harbour, one

of the most important in the Adriatic Sea, is of great support to the economy of Ravenna. However, this economic development is causing serious problems for the environment. In fact in 2000 a protocol of understanding was signed by 16 companies to achieve the ISO14001⁶ and EMAS⁷ certifications [17].

3.3 Air Quality in Ravenna

The ARPA of Ravenna reports in the web the results of the monitoring of the quality of the air for each pollutant [27].

- **Sulphur dioxide (SO₂)**

The concentrations in 2015, as well as in the last years, are low and well below the limit value. Therefore, it is not a problem to exceed the limit value for SO₂. Moreover, the concentration profile shows that there is a trend towards a further improvement.

- **Nitrogen dioxide (NO₂)**

The limit value of the annual average of NO₂ is not exceeded since 2010, its concentration being decreasing since 2007. A slight increase observed in 2015 (relative to 2014) was ascribed to the occurrence of unusual meteorological conditions. The highest concentrations are measured in the urban area (*Zalamella* station), due to vehicular traffic.

- **Carbon monoxide (CO)**

The values of CO concentration are decreasing, especially since 2007. The limit value, to protect the human health, established by the D.Lgs. 155/20101, was never exceeded. Actually, the measured values are much lower than the limit value, and display a decreasing trend over the last years.

⁶ The acronym ISO1401 identifies an environmental management standard (EMS) that establish the requirements for a management of environment for each organization.

⁷ EMAS (Eco-Management and Audit Scheme) is a voluntary instrument created by the European Community to which the organizations can adhere to evaluate and improve their environmental performances.

- **Ozone (O₃)**

The values of O₃ concentration in 2015 are very critical, exceeding both the limit and target values (240 µg/m³ and 120 µg/m³⁸). There is a strong correlation between O₃ concentrations and meteorological conditions. In fact the warm summer of 2015 favored the increase of O₃ levels compared to 2014. The observed trend shows that there is a nearly constant concentration of O₃ in whole the region [16].

⁸ The number of days where the target of 120 µg/m³ must not exceed 25

4. MATERIALS & METHODS

In this work a detailed analysis of health-related external costs associated with the major emission sectors and their relative contributions is performed using the EVA model. The application of this model requires the use of other two models: DEHM and UBM. In turn, to adopt these models it is necessary to collect all the data relative to the emissions of the area of Ravenna. Four kinds of emissions sectors are considered for this case of study: residential/commercial, industrial, agricultural and vehicular. In addition to the emission data, it is necessary to collect data regarding the population distributed in a grid, the concentration measurements and meteorological data (Attached C) . The scheme of Figure 6 represents the way these data are used.

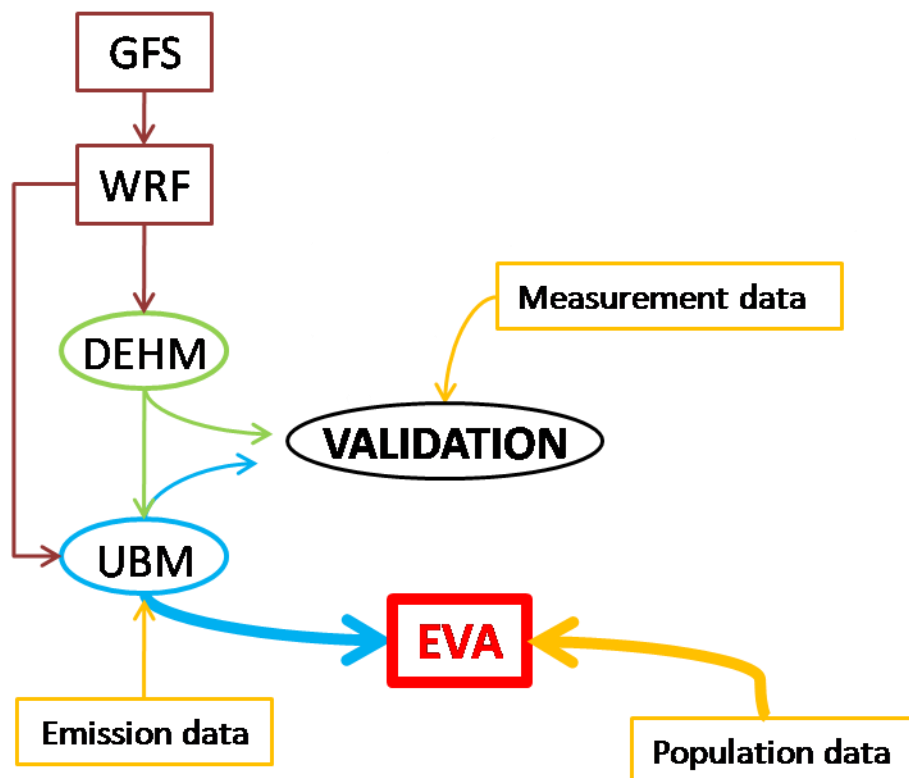


Figure 6. The scheme displays how the meteorological data, from the GFS (Global Forecast System), WRF (World Research Forecast) and meteorological stations, emission measurements and population data are used with the DEHM, UBM and the EVA system.

4.1 Data Collection

4.1.1 Population Data

A gridded data set was obtained from the GEOSTAT 2011 grid dataset [18] covering all Italy. The grid is formed by cells 1km x 1km wide. For each cell the number of people that are present is indicated, thus allowing evaluating the distribution of the population. We have also calculated the percent contributions from various ages applying a proportion. It is important to analyse the health outcomes as a function of age as different age groups respond differently to pollution. We have subdivided the population into five groups of age, and the equation used is provided in Eq. 1.

$$\sum Pop (Age)_{(1)} : Tot Pop_{(1)} = \sum Pop (Age)_{(2)} : Tot Pop_{(2)}$$

Eq. 1

| Age | Percentage |
|-----|------------|
| ≤14 | 13% |
| ≥15 | 87% |
| ≥30 | 75% |
| ≥65 | 24% |
| ≤5 | 4% |

Table 4. percentage of the age of the population of Ravenna

where $Pop (Age)_{(1)}$ and $Tot Pop_{(1)}$ are taken from the website ISTAT [19]. These data refer to the year 2011. The total population of Ravenna is 153740 inhabitants, while $Tot pop_{(2)}$ is the population of the grid dataset (163763). Eq.1 is used to calculate the number of people, with a specific age, at each grid cell.

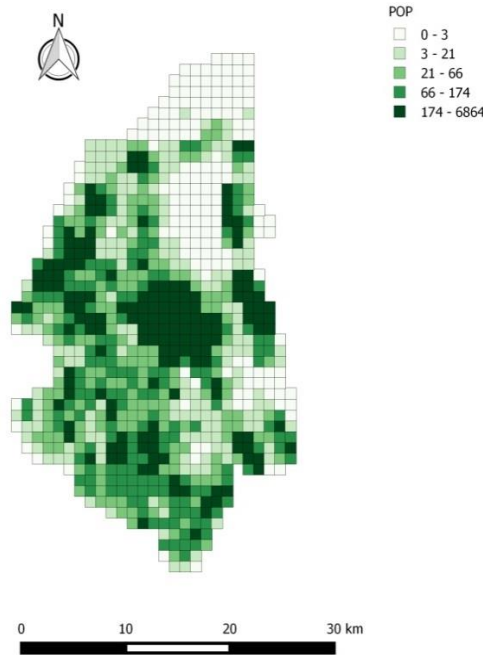


Figure 7. Population distribution of Ravenna for each cell (1km x 1km)

4.1.2 Emission Data

To use the EVA model is necessary to collect emission data for each cell (1 km² resolutions), for residential/commercial, agricultural and vehicular emissions, and from each factory stack for industrial emissions. All data gathered lead to an emission expressed in kg/year. For each chimney and each cell we have determined the coordinates. The pollutants considered are: NO_x, SO_x, NMVOC, CO, TSP, PM₁₀, PM_{2.5}. During the data collection step, I used two instruments: the AIE (Authorization Integrated Environmental) and the Q-Gis (Quantum Geographic Informatics System).

4.1.3 Authorization Integrated Environmental (AIE)

To evaluate the emissions from all industries in the area of Ravenna I decided to consult the AIE of each industry. This document authorizes the activities of an industry. These activities have to guarantee compliance with the requirements specified in the second part of the Legislative Decree 152/2006. This Decree is

relative to industrial emissions (prevention and integrated reduction of pollution). This Authorization is released to the industries listed in the VIII attachment of the second part of the same Decree [21].

Each authorization reports complete information about the factory: hours and days of activity, position, productive processes and emissions in water, soil and air. In the chapter dedicated to the air, the stack characteristics are described: height, coordinates, hours of activity, payload and kinds of emitted pollutants.

In AIE the emissions are classified as funnelled and fugitive emissions. In the fifth part of the Legislative Decree 152/2006 [22] the two kinds of emissions are defined. Funnelled emissions involve the discharge of pollutants from a release point, for example from a stack. Before their release in atmosphere, funnelled emission can be treated to reduce, or delete, the pollutants. Essentially, the treatment systems can be of two kinds: one to remove the pollution, the other to capture it. The latter allows the recovery and reuse the pollutants, otherwise the pollutants can be processed and conferred like waste. In contrast, fugitive emissions can not be located in specific points, they are considered as area sources.

4.1.4 Geographic Information System (GIS)

The GIS system is able to assemble, memorize, modify and visualize geographic information, that is, data identified on the basis of their geographical locations. This instrument was used:

- to collect all geographic information used in the area of study
- for processing and analyzing the collected data
- for managing the input file according to the mathematical model of dispersion of pollutants
- for the representation of the data

- for the management of the collected and elaborated data during the research in a geo-database

4.1.5. Residential and commercial emissions

The term “residential/commercial” is used to indicate emissions from combustion in commercial, residential and institutional activities, where combustion is used for domestic heating, water heating and food preparation. The data of Table 5 were derived from the total provincial emissions reported by ARPA in the inventory of emissions in atmosphere for the year 2010 [20].

| Macro sector | Sector | CO | SO ₂ | COV | CH ₄ | NOx | PTS | CO ₂ | N ₂ O | NH ₃ | PM ₁₀ |
|--------------------------|-------------------|------|-----------------|------|-----------------|-----|-----|-----------------|------------------|-----------------|------------------|
| No industrial combustion | Residential plant | 6595 | 280 | 2473 | 436 | 787 | 489 | 929 | 96 | 12 | 467 |

Table 5. Pollutants (Mg, Gg for CO) emitted per year from no-industrial activities in the whole Province of Ravenna.

Knowing the total emissions, the total population, the population for each cell of the province of Ravenna, it is possible to calculate, via a mathematical proportion, the emission associated with each cell. For example, in the case of CO:

$$CO(\text{ton}): Tot\ Pop = CO(\text{ton})\ \text{in}\ \text{each}\ \text{cell} : Pop\ \text{in}\ \text{each}\ \text{cell} \quad \text{Eq.2}$$

The total provincial population (393623) and the population of each single cell are given by the grid dataset (2011) [18].

4.1.6 Industrial emission

4.1.6.1 Method for collecting data from AIE

The required authorizations are of two kinds: one is released from the Province, the other from the State. In the State authorization, the manager declares

the quantity of pollutants emitted from each chimney. From these declarations I could obtain data relative to the pollution emitted from the four different sources. In the authorization released by the Province, the quantity of pollutants emitted is not declared. However, from the information about the characteristics of the stacks, it was possible to estimate the emissions applying the following formula:

$$Emission \left(\frac{kg}{year} \right) = Payload \left(\frac{Nm^3}{h} \right) * Duration \left(\frac{h}{year} \right) * Max Permissible Concentration \left(\frac{kg}{Nm^3} \right)$$

Eq. 3

where Nm^3 is the volume normalised to $P=1$ atm and $T= 0$ °C.

The application of this formula allows to calculate the flow of the pollutants emitted from the stacks.

As far as the fugitive emissions are concerned, we decided to distribute them in each grid cell of the domain. The industrial fugitive emissions, as taken from IEA, were located in the same area where the industry that emitted them is placed.

4.1.7 Agricultural emissions

Over the industrial, residential and commercial emissions, the agricultural sector is one of the biggest source of GHG emissions. The fundamental GHG emission is the enteric fermentation (methane that is released from the livestock during the digestion). Another kind of agricultural emissions are caused by the use of synthetic fertilizer [60]. To evaluate the agricultural emissions, the same method adopted for industrial emissions was used. Before collecting the data, I had to classify the IEA as authorization for agricultural activities, for example, pig farming or poultry farming.

4.1.8 Vehicular emissions

To collect the data regarding the vehicular emissions, it was decided to consider the total provincial emission, percentage of emission for each kind of street and, finally, the length of the streets (the total streets and the streets in each cell). The data relative to the Province, expressed in ton/year (kton/year for CO), are inserted in the inventory of emissions in atmosphere for the year 2010 [23], the percentage of emission for each kind of street is inserted in the PhD thesis of S. Marinello [9]. The length of each street was obtained with Q-Gis (Quantum Geographic Information System).

The percentages of emission are the results obtained from an unbundling model of emissions from vehicular traffic. The data used were provided by ARPA, as obtained from traffic data measured in conformity of the representative road section; thus it is possible to have an estimate of vehicular traffic in the urban area of Ravenna. These percentages allow one to assign to each kind of street the total provincial emission given by the inventory [9].

| Province | CO | SO ₂ | NMCOV | CH ₄ | NO _x | PTS | CO ₂ | N ₂ O | NH ₃ | PM ₁₀ |
|----------|------|-----------------|-------|-----------------|-----------------|-----|-----------------|------------------|-----------------|------------------|
| Ravenna | 5928 | 32 | 1116 | 101 | 5387 | 510 | 1103 | 31 | 69 | 413 |

Table 6. Pollutants (Mg, Gg for CO) emitted per year from vehicular in the whole Province of Ravenna

| Kind of street | PM ₁₀ % | NO _x % | CO% | SO ₂ % |
|----------------|--------------------|-------------------|------|-------------------|
| Urban street D | 0.25 | 0.24 | 0.28 | 0.26 |
| Urban street E | 0.17 | 0.16 | 0.19 | 0.17 |
| Local road F | 0.42 | 0.43 | 0.35 | 0.40 |
| Other | 0.16 | 0.17 | 0.18 | 0.17 |

Table 7. Percentages of emissions for each kind of street in Ravenna

The road network downloaded from Open Street Map (OSM) has been superimposed on the grid in Q-GIS. Q-GIS allows to measure the length of the

streets in each cell, as well as the total length. Therefore, knowing the total Provincial emission for each pollutant, the total length of the streets and their length in each cell it is possible to determine the vehicular emission for each cell, applying the following proportion:

Tot Len of the street:Tot Provincial Emission = Len for each cell:Emission for each cell

$$Emission\ for\ each\ cell = \frac{Tot\ Provincial\ Emission * Len\ for\ each\ cell * percentage}{Tot\ Len\ of\ the\ street}$$

Eq. 4

where *Tot* stands for total and *Len* for length.

For the present case of study four kind of streets were considered:

- **Urban street D:** independent roadway or road separated by traffic divider; in OSM is highway = tertiary
- **Urban street E:** a single-carriage way with at least two lanes; in OSM are highway = residential and living street
- **Local road F:** urban or suburban road not considered in other types of roads
- **Other:** street whose classification is not defined; it is used as temporary tag for a street whose classification is unknown; in OSM are highway = motorway, primary, secondary and track [24].

4.1.9 Final emission data

In the present case NO_x, SO_x, NMVOC, CO,TSP, PM₁₀ and PM_{2,5} have to be considered to run the UBM model. These data are collected in two files: one for pollutants emitted from stacks, the other for pollutants associated with each cell. Unfortunately, the Italian Authorizations do not consider the particulate (PM₁₀ and

PM_{2.5}) but just the total suspended dust (TSD). An evaluation of PM₁₀ and PM_{2.5} from TSD was obtained by consulting the emission factors provided by the EMEP/EEA Guidebook [25]. As far as the emissions for each cell are concerned, we have data only for PM₁₀, not for PM_{2.5}. It was possible to esteem PM_{2.5} from PM₁₀ on the basis of the emission database from EMEP/CEIP [26]. The different kinds of emission are classified according to the SNAPS:

- SNAP 01: no industrial emission
- SNAP 02: Vehicular emission
- SNAP 0201: Urban Street D
- SNAP 0202: Urban Street E
- SNAP 0203: Local Road F
- SNAP 0204: Other
- SNAP 03: Agricultural emission
- SNAP 04: Industrial emission

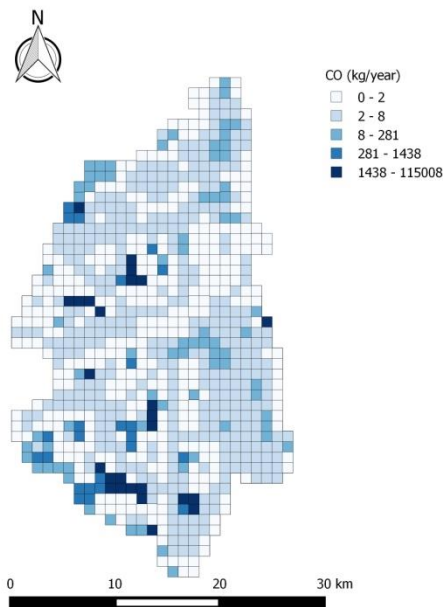


Fig. 8a

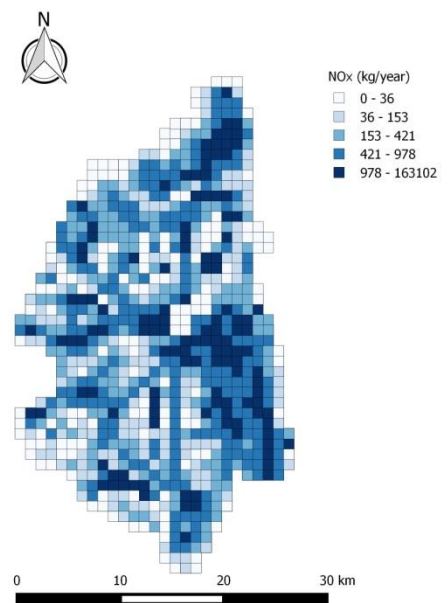


Fig.8b

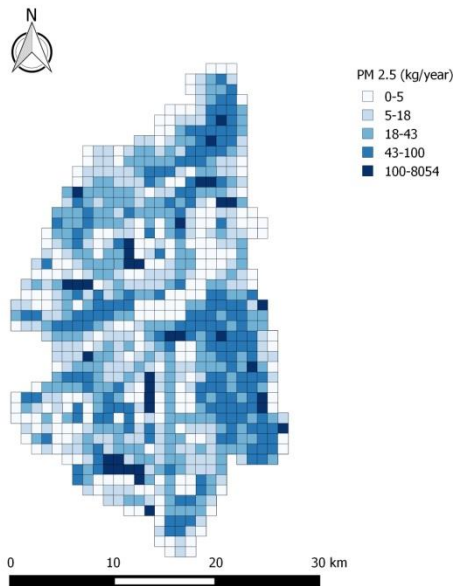


Fig. 8c

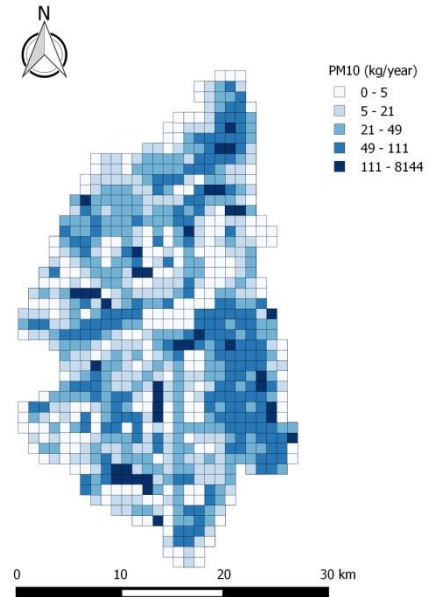


Fig.8d

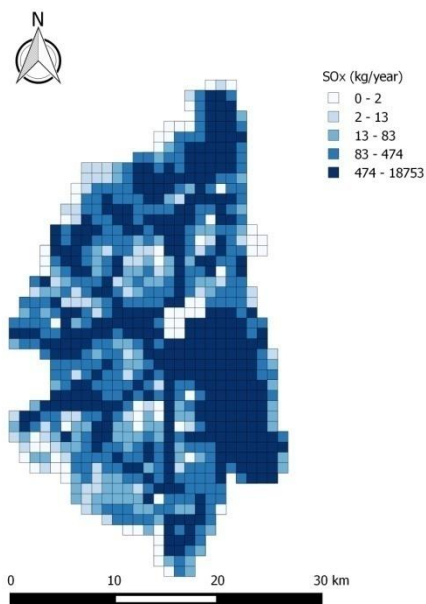


Fig. 8e

Figure 8 (a,b,c,d,e). Distribution of the emissions for various pollutants.

4.1.10 Measurement data

The observed air pollutant concentrations from different monitoring stations were obtained from the ARPA network. These stations continuously measure hourly concentrations. In all environments (urban, rural or industrial) various pollutants, like CO, SO₂, O₃, PM_{2.5}, NO₂, C₆H₆ and PM₁₀, are monitored.

In this work, three stations have been considered for the area of Ravenna, one located in the urban area and two in rural areas.

The measured concentrations and information about each station of the Ravenna area (Table 8) were taken from the ARPA website of Emilia Romagna [27].

| Stations | Elevation (m) | Kind of Area | Longitude | Latitude |
|--------------|---------------|---|-----------|----------|
| Caorle | 4 | Urban zone, characteristic residential zone | 12,22539 | 44,4193 |
| Delta Cervia | 0 | Suburban zone, characteristic agricultural zone | 12,33225 | 44,2839 |
| Ballirana | 6 | Rural zone, characteristic natural zone | 11,98236 | 44,5274 |

Table 8. Characteristics of the four stations

4.2 Air Pollution Modelling

The use of air pollution models is useful to supplement and extend the information obtained from various measurements, as a tool for the interpretation of the measurements. In general, air quality models may be used for a variety of different purposes in environmental monitoring, management and assessment, such as in the characterisation of air pollution. Another important use of these models is the prediction of pollution loads and levels in the future. Models are the only option for providing short term predictions of air pollution at a regional and local scale. Air pollution is a trans-boundary problem, but the development of integrated modelling frameworks allows to describe atmospheric long-range transport of pollutants and all the processes that take place during their transport. Some of these models simulate the fate of individual air parcels along trajectories (referred to as Lagrangian models), while other models describe the concentration and processes in a fixed grid (Eulerian models). Eulerian models are able to describe the dispersion of the pollutants on a large scale, covering a large domain, giving results on a grid [10].

Eulerian models can calculate the variation of concentration (ρ) as a function of time (t) in a fixed point (*partial derivate*, $\partial\rho/\partial t$) [30]. Lagrangian models are suitable to describe the dispersion in proximity of the source, handling sharp gradients and giving good results when used on a short scale [10]). Lagrangian models calculate the variation of concentration (ρ) as a function of time (t) in a parcel that moves in the space with a given speed (*substantial derivate*, $d\rho/dt$) [30].

4.2.1 DEHM model

The Danish Eulerian Hemispheric Model (DEHM) is a three-dimensional, offline, large-scale, Eulerian, atmospheric chemistry-transport model which aims to study long-range transport of air pollution in the Northern Hemisphere and Europe. The model was originally developed in the early 1990's to study the atmospheric transport of sulphur and sulphates into the Arctic region, but it has been continuously modified, and now it can be applied to the dispersion of 58 chemical compounds, 8 class of particulate matter and 122 chemical reactions [31].

An important development of the model consists in the ability to obtain a high resolution over limited areas, joining the DEHM to several emission databases and accounting for different conditions, such as wet and dry deposition [32, 33, 34, 35].

The model setup used in this study includes three two-way nested domains. The first domain covers most of the Northern Hemisphere, the second domain covers Europe and the third domain covers North Europe. Each domain has a different resolution, the first domain with a resolution of 150 kmx150km, the European domain with a resolution of 50kmx50km and the third domain with a resolution of 16.67kmx16.67km [31]. The model configurations used in the present work are the first and the second domain. The necessary information to run the DEHM model concerns input data of meteorology and emission, applying the following equation:

$$\frac{\partial c}{\partial t} = \left(u \frac{\partial c}{\partial x} + v \frac{\partial c}{\partial y} + \dot{\sigma} \frac{\partial c}{\partial z} \right) + K_x \frac{\partial^2 c}{\partial x^2} + K_y \frac{\partial^2 c}{\partial y^2} + \frac{\partial}{\partial \sigma} \left(K_\sigma \frac{\partial c}{\partial \sigma} \right) + P(c, t) - L(c, t)$$

Eq.5

where c is the mixing ration, t is time, u , v , and $\dot{\sigma}$ are the wind-speed components in the x, y (horizontal) and σ (vertical) direction, respectively. K_x , K_y and K_σ are dispersion coefficients, while P and L are production and loss terms, respectively [31]. The meteorological data used in the DEHM model come from the WRF model (Weather Research Forecasting) that, in turn, uses data coming from the GFS (Global Weather Forecast System). The WRF is an open source software which collects meteorological data and represents them on graphic maps that give information about the evolution of atmospheric conditions in the time [36]. This model is based on the data supplied from the global system GFS that provide atmospheric and land-soil variables, such as temperature, wind speed, precipitation, soil moisture and atmospheric ozone concentration [37]. The output of the DEHM model is used for the validation, but also to run the UBM model.

30

4.2.2 The UBM model

The Urban Background Model (UBM) calculates the urban air pollution on the basis of emission inventories, with a spatial resolution of 1kmx1km. The UBM is a Gaussian plume model that allows to calculate the dispersion and transport of air pollutants to every receptor point, accounting for the photochemical reactions of NO_x and O_3 . This model is constantly developed, and provides a realistic spatial distribution of the pollutant concentrations over the grid, also around large point sources. The vertical dispersion is assumed to be linear (from the initial vertical dispersion and up to the mixing height) with the distance to the receptor point. Horizontal dispersion is accounted for by averaging the calculated concentrations over a certain, wind-speed dependent, wind direction sector, centered on the

average wind direction using a Gaussian distribution [38]. The meteorological data, used to have information about the distribution of pollutants in the space, derive from the WRF. In the UBM model, in addition to consider the meteorological data, it is necessary to use the regional air pollution forecast from the DEHM, which gives information about the distribution of pollutants in areas around the area of study, and emission data. The model calculates the concentrations of NO_x, NO₂, O₃, CO, PM₁₀ and PM_{2.5} in each point, which in the case of my work are the measurement stations, and over all the grid. The first results, relative to the measurement stations, were used to validate the model. The species considered are NO₂, O₃, CO, PM₁₀ and PM_{2.5}, because the data that I collected from the database of the measurements include only these species in the three-year period (2010, 2011, 2012) considered in this study. The next results were used as input data for the EVA model.

4.3 Validation of the models

At the end of this first stage of the work, we get the results from the DEHM and UBM models, measurements and meteorological data (observations), i.e., all the information necessary to start the validation. The validation includes comparing simulated air pollutant levels from the UBM and DEHM model with the observed levels using statistical parameters. The purpose of the validation is to evaluate how the model is performing against a set of observation. The model validation is performed comparing model results with observation using some statistical measures. In this way we can see if the results that we get from UBM and DEHM model are congruent with the data relative to observations. The discovery of an error during the validation is for sure a benefit for the quality of the models results and it requires an improvement in the different modelling compartments such as emission, meteorology or chemistry.

4.3.1 Statistical evaluation

Statistical evaluation was performed using the “openair” package of the R software, which aims to provide a collection of open-source tools for analysis of air pollution data. This statistical/data analysis software allows to compare the results supplied by a model either with measurements or with other models. The factors considered for the statistical evaluation are indicated in the equation reported below, where O_i represents the i th observed value and M_i represents the i th modelled value for a total of n observations.

- **FAC2 (Fraction of prediction within a factor or two)**

The fraction of modelled values within a factor of two relative to the observed values is the fraction of the model predictions that satisfy :

$$0.5 \leq \frac{M_i}{O_i} \leq 2.0$$

32

Eq.6

- **MB (Mean Bias)**

The mean bias provides a good indication of the mean over- or underestimation of the predictions. The mean bias has the same units as the quantities being considered.

$$MB = \frac{1}{n} \sum_{i=1}^N M_i - O_i$$

Eq. 7

- **MGE(Mean Gross Error)**

The mean gross error gives a good indication of the mean error regardless of whether it is an over or under estimate. The units of the mean gross error are the same used for the quantities being considered.

$$MGE = \frac{1}{n} \sum_{i=1}^N |Mi - Oi|$$

Eq. 8

- **NMB (Normalized mean bias)**

The normalized mean bias is useful for comparing pollutants that cover different concentration scales, the mean bias being normalized by dividing MGE? o MB? by the summation of the observed concentrations.

33

$$NMB = \frac{\sum_{i=1}^n Mi - Oi}{\sum_{i=1}^n Oi}$$

Eq. 9

- **NMGE (Normalized mean gross error)**

The normalized mean gross error further ignores whether a prediction is an over or under estimate.

$$NMGE = \frac{\sum_{i=1}^n |Mi - Oi|}{\sum_{i=1}^n Oi}$$

Eq. 10

- **RMSE (Root mean squared error)**

The RMSE, commonly used in statistics, provides a good overall measure of the proximity of the modelled values to the measured ones.

$$RMSE = \left(\frac{\sum_{i=1}^n (Mi - Oi)^2}{n} \right)^{1/2}$$

Eq. 11

- **r (Correlation coefficient)**

The correlation coefficient is a measure of the strength of the linear relationship between two variables. The correlation coefficient r is +1 (or -1) in the case of a perfect linear relationship, with positive or negative slope, between two variables, while a correlation coefficient $r = 0$ indicates the absence of a linear relationship between the variables.

$$r = \frac{1}{(n-1)} \sum_{i=1}^n \left(\frac{Mi - \bar{M}}{\sigma_M} \right) \left(\frac{Oi - \bar{O}}{\sigma_O} \right)$$

Eq. 12

where σ_M and σ_O are the standard deviations of the M and O sets of data, respectively.

- **COE (Coefficient of Efficiency)**

The COE is used to interpret the measuring model performance. A perfect model has a COE=1. For the negative values of COE, the model is less effective than the observed mean in predicting the variation in the observations. A

COE=0 implies that the model is not able to predict the observed values better than the observed mean.

$$COE = 1.0 - \frac{\sum_{i=1}^n |Mi - Oi|}{\sum_{i=1}^n |Oi - \bar{O}|}$$

Eq. 12

- **IOA (Index of Agreement)**

The IOA is commonly used in model evaluation. It ranges between -1 and +1, values approaching +1 representing better model performances.

$$IOA = 1.0 - \frac{\sum_{i=1}^n |Mi - Oi|}{c \sum_{i=1}^n |Oi - \bar{O}|} \text{ when } \sum_{i=1}^n |Mi - Oi| \leq c \sum_{i=1}^n |Oi - \bar{O}|$$

$$IOA = \frac{c \sum_{i=1}^n |Oi - \bar{O}|}{\sum_{i=1}^n |Mi - Oi|} - 1.0 \text{ when } \sum_{i=1}^n |Mi - Oi| > c \sum_{i=1}^n |Oi - \bar{O}|$$

35

Eq. 13

[13]

4.4 EVA model

The concept of the EVA system [39, 40, 41, 42, 43, 44, 45] is based on the impact-pathway chain [46, 47]. The EVA system consists in a regional-scale chemistry transport model, which include gridded population data, exposure-response functions for health impact and economic valuations of the impact from air pollution. The system was originally developed to evaluate site-specific health costs related to air pollution, such as those deriving from specific power plants [41].

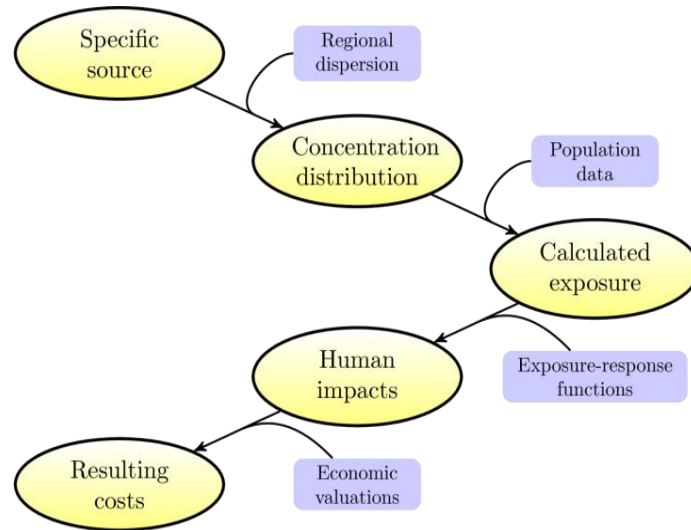


Figure 9. A schematic diagram of the impact-pathway methodology

Figure 9 reports a schematic diagram which describes the methodology of the EVA model. Starting from site-specific emission results, through a regional dispersion described in this study with the DEHM and UBM models, a concentration distribution is obtained. This concentrations, together with detailed population data, can be used to estimate the population-level exposure. Using exposure-response functions and economic valuations, the exposure can be transformed into impacts on human health and related external costs [8].

4.4.1 Exposure-response functions and monetary values

To calculate the impacts of emissions from a specific source, i.e., the response to the exposure to pollution, an exposure-response function (ERF) is used. The follow formula (Eq. 14) combines concentration (δc) and population data to estimate human exposure, and then the response (R):

$$R = \alpha \cdot \delta c \cdot P$$

where α is an empirically determined constant for the particular health outcome typically obtained from the published cohort studies, P the affected share of the population [8]. This function is an approximation based on cohort studies of 500000 individuals [48] also supported by the joint World Health Organization/UNICEF Task Force on Health [49, 50]. All the exposure-response functions (shown in Tab. 9) are applicable to the European conditions. The chemical compounds related to human health impacts included in the EVA model are O_3 , CO , SO_2 , SO_4^{2-} , NO_3^- and $PM_{2.5}$. Furthermore, NH_4^+ is included when it contributes to the particle mass through reactions with sulphates or nitrates [8]. In the case of the present study human health impacts are ascribed only to CO , O_3 and $PM_{2.5}$.

4.4.2 Mortality

On the basis of the ERF, the chronic mortality in response to long-term $PM_{2.5}$ exposure can be evaluated [8]. The results depend on a re-analysis of the original data applying alternative and extensive statistical analyses [51]. Chronic mortality is referred to the mortality risk associated with long-term exposure while the ERF for chronic mortality is derived from cohort studies. Numerous time-series studies have shown that air pollution exposure may also cause acute effects [8]. The acute mortality is valued differently from the chronic mortality, so that it is necessary to quantify them separately [52]. It has also been established that O_3 concentrations above 335 ppb cause an acute mortality increase, mainly for weak and elderly individuals.

4.4.3 Morbidity

Chronic exposure to $PM_{2.5}$ is associated with morbidity. For each kind of illness we apply a specific ERF on the basis of specific studies. It was shown [8] that in most cases the chronic disease bronchitis increases with chronic exposure to $PM_{2.5}$. For this case we apply an $RR = 1,007$ per $10 \mu g PM_{2.5} m^{-3}$ according to the AHSMOG study

[53, 54], the same epidemiological study as in CAFE [55, 56]. In the case of lung cancer we apply $RR=1.08$ per $10 \mu\text{g PM}_{2.5}\text{m}^{-3}$ [57]. Restrictive activity days (RADs) comprise two types of response to exposure: minor restricted activity days and work-loss days. This distinction enables to account for the different costs associated with days of reduced well-being or actual sickness. We assume that rate and incidence can be derived from ExternE (External Cost of Energy) (1999). Hospital admissions and health effects for asthmatics are also evaluated on the basis of ExternE (1999) [58].

4.4.4 Valuation

Table 9 lists specific valuation estimates applied to the modeling of externality costs for mortality and morbidity effects. The OECD (Organisation for Economic Co-operation and Development) guidelines for environmental cost-benefit analysis [57] address the complex debate on valuation of mortality. The aim is to evaluate the costs, knowing the willingness to pay for preventing risks, but not the human life per se. Whereas in transport economics it has become customary to employ a value of statistical life (VSL), environmental economics has applied a different valuation by developing a metrics of value of life year lost (VOLY). OECD guidelines recommend to apply a VSL approach for the valuation of acute mortality and a VOLY approach for chronic mortality. Acute mortality in this setting is defined as an immediate increase in mortality as a results of short-term peaks in exposure, whereas chronic mortality is defined as an increase in annual mortality associated with increased levels of exposure over long periods of time [8]. A principal value of EUR 1.5m was applied for preventing an acute fatality, following an expert panel advice (EC2001). For the valuation of a life year, the results from a survey relating specifically to air pollution risk reductions were applied [59], implying a value of EUR 57500 per year of life lost (YOLL). Most of the excess mortality is due to chronic exposure to air pollution over many years and the life year metrics is based on life tables that can

account for the number of lost life years in a statistical cohort [82]. Following the guidelines of OECD, the predicted acute deaths, mainly from ozone, have to be valued through an adjusted parameter to prevent a fatality. The approach recommended by OECD is conservative and does not result in upper-bound estimates of willingness to pay for a risk version [8]. The willingness to pay for reduction in risk obviously differs across income levels. However, in the case of air pollution costs, adjustment according to per capita income differences among different states is not regarded as appropriate, because long-range transport implies that emissions from one state will affect numerous other states and their citizens. The valuations are thus adjusted with regional purchasing power parities of EU27. The unit values have been indexed to 2013 prices as indicated in Table 9.

| Health effect (compounds) | Exposure-response coefficiente (α) | Valuation, euros |
|---|--|------------------|
| Morbidity | | |
| Chronic bronchitis (PM) | $8,2 \times 10^{-5}$ cases/ μgm^{-3} (adults) | 51856 per case |
| Restictive Activities days (PM) | = $8,4 \times 10^{-4}$ days/ μgm^{-3} (adults) | 132 per day |
| | $-3,46 \times 10^{-5}$ days/ μgm^{-3} (adults) | |
| | $-2,47 \times 10^{-4}$ days/ μgm^{-3} (adults>65) | |
| | $-8,42 \times 10^{-5}$ cases/ μgm^{-3} (adults) | |
| Congestive heart failure (PM) | $3,09 \times 10^{-5}$ cases/ μgm^{-3} | 14783 per case |
| Congestive heart failure (CO) | $5,64 \times 10^{-7}$ cases/ μgm^{-3} | |
| Lung cancer (PM) | $1,26 \times 10^{-5}$ cases/ μgm^{-3} | 21789 per case |
| Hospital admission | | |
| Respiratory (PM) | $3,46 \times 10^{-6}$ cases/ μgm^{-3} | 7145 per case |
| Respiratory (SO ₂) | $2,04 \times 10^{-6}$ cases/ μgm^{-3} | |
| Cebrovascular (PM) | $8,42 \times 10^{-6}$ cases/ μgm^{-3} | 9052 per case |
| Asthma children (7,6%<16 years) | | |
| Bronchodilator use (PM) | $1,29 \times 10^{-1}$ cases/ μgm^{-3} | 22 per case |
| Cough (PM) | $4,46 \times 10^{-1}$ days/ μgm^{-3} | 42 per day |
| Lower respiratory symptoms (PM) | $1,72 \times 10^{-1}$ cases/ μgm^{-3} | 12 per day |
| Asthma adults (75,9%>15 years) | | |
| Bronchodilator use (PM) | $2,72 \times 10^{-1}$ cases/ μgm^{-3} | 22 per case |
| Cough (PM) | $1,01 \times 10^{-1}$ days/ μgm^{-3} | 42 per day |
| Lower respiratory symptoms (PM) | $1,72 \times 10^{-1}$ cases/ μgm^{-3} | 12 per day |
| Mortality | | |
| Acute mortality (SO ₂) | $7,85 \times 10^{-6}$ cases/ μgm^{-3} | 2083594 per case |
| Acute mortality (O ₃) | $3,27 \times 10^{-6}$ x SOMO35 cases/ μgm^{-3} | |
| Chronic mortality, YOLL (PM) | $1,138 \times 10^{-3}$ YOLL/ μgm^{-3} (>30 years) | 78211 per YOLL |
| Infant mortality (PM) | $6,68 \times 10^{-6}$ cases/ μgm^{-3} (>9months) | 3125391 per case |

Table 9. Health effects, exposure-response function and economic valuation (2013 prices) applicable for European condition, currently included in the EVA model system. (PM is particulate matter, including primary PM_{2,5}, NO₃⁻, SO₄²⁻. YOLL is years of life lost. SOMO35 (-Sum of Ozone Means Over 35ppb- is the sum of means over 35 ppb for the daily maximum 8-hour value of ozone).

4.4.5 Health effects from particles

The health effects are mainly due to particulate matter and the related costs are dominant compared to those deriving from other species. A recent study indicated that worldwide 3.1million deaths are attributable to ambient PM annually [61]. Many studies, including experimental research on animals and humans, demonstrated the adverse effects of PM on health [8]. Correlations between PM and mortality have been demonstrated in studies of both short-term [62] and long term population exposure (i.e cohort studies). Cohort studies form the basis of the ERF used for calculation of chronic mortality [8]. In addition to the American Cancer Society studies [51,57,63,64,65] and the Harvard Six Cities Study [80], the most frequently cited cohort studies, a series of other cohort studies corroborate the link between long term exposure to PM and adult mortality [8].

The PM in the atmosphere is considered the cause of mortality and morbidity, primarily via cardiovascular and respiratory diseases [66]. Several studies indicate that the effects of PM could also depend on its source and the regions from where it is emitted [67, 68]. Long-term cohort studies indicate the occurrence of links between health effects and the sulphate fraction of particles [57]. In contrast, the same studies did not associate health effects with the nitrate fraction, while correlations with other compounds have not been excluded [69]. According to recent studies health impacts would also derive from transition metals, sulphates [67,70], nitrates [71,72] and potassium (from wood combustion) [69].

Some studies argue that it is reasonable to attribute greater risks to primary particles, directly released in atmosphere, than to secondary particles, formed in atmosphere [73,74]. This conclusion is based on the higher risks found in studies based on intra-city exposure gradients compared to inter-city exposure [8].

According to many reports, no components of particles show unequivocal evidence of zero health impact [8] and both EU and WHO are providing directives/guidelines for limit values of PM and ozone concentrations to minimize

impacts on human health [75, 76]. The following picture (Figure 10) shows the serious impact on human health due to the common pollutant present on the air. Children and the elderly are especially vulnerable.

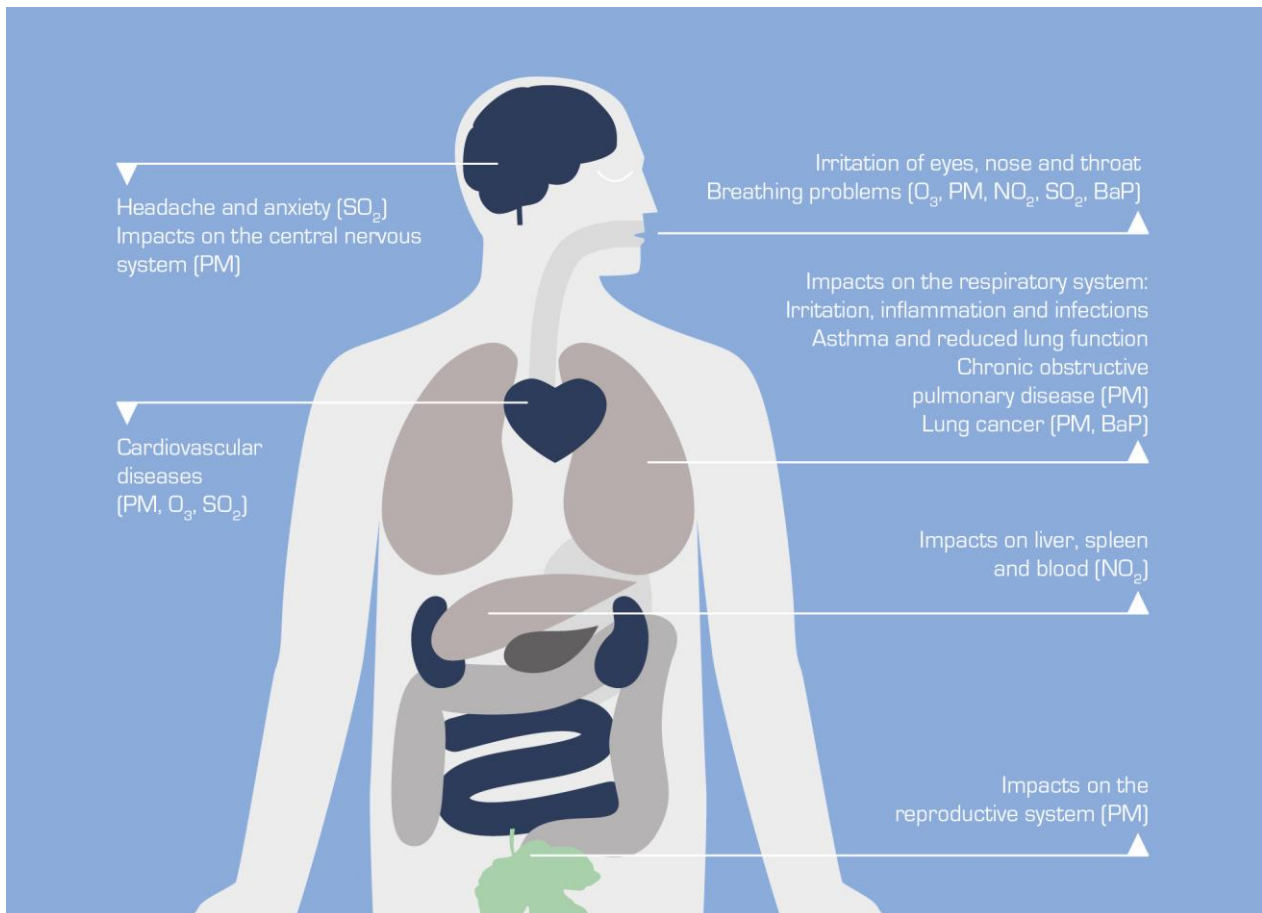


Figure 10. Portrayal of all negative effects because the air pollutant on the human health

5. RESULTS

5.1 Scientific validation

The observations were compared with the results of the DEHM and UBM models. The comparison was made on hourly, daily, monthly and annual basis for NO₂, O₃ and SO₂, while for PM_{2.5} and PM₁₀, comparisons we done on daily, monthly and annual basis. The daily statistics for the DEHM and UBM models are presented in Table 10. As can be seen in the Table, both models largely overestimate O₃. Averaged over the two rural stations, DEHM overestimates O₃ by 77% and UBM by 72%. In contrast both models largely underestimate NO₂. Averaged over all stations, DEHM underestimates NO₂ by 71% and UBM by 32%. The improvement in the UBM-simulated NO₂ levels suggests the more detailed representation of local sources due to higher horizontal resolution (1 km × 1 km) compared to the DEHM model (50 km × 50 km). Regarding the particulate matter, both DEHM and UBM underestimate the PM₁₀ concentration recorded in the urban station and one rural station (Caorle), and the PM_{2.5} concentration measured in the other rural station (Ballirana). DEHM underestimates PM₁₀ and PM_{2.5} by 53% and 54%, while UBM by 48% and 53%, respectively. These results, as also shown in the plots Attached A), suggest that the local emissions calculated in this study is underestimating the actual emissions or that the simulated background levels of O₃ is too high concentration of O₃ and too low for particulate matter.

5.2 Second validation

The above results indicated that the UBM model needs to be calibrated through a better analysis of the emission data, which was calculated based on the declarations (IAE - Impact Assessment of Environment) and the methods described above. Although this would be the scientific way to improve the model

performance, it would require extensive work on emission modelling and is not in the scope of this thesis project. To improve its performance, the UBM model was calibrated by multiplying the concentrations from the DEHM model by a factor of 1.4. In addition, the emissions of the UBM model was increased by a factor 2. In this way the concentration of NO₂ will increase, while that of O₃ will decrease because the NO₂ reacts with the O₃, that is defined as NO_x-titration. These factors were experimentally chosen, because the combination gives the best correlation and the minimal bias between observations and the UBM results. As reported in Table 11, comparison has always been made taking into consideration the daily statistics for the UBM model. UBM overestimates O₃ by 57%, somewhat less than the first simulation (Table 10: 72%). As far as NO₂ and PM₁₀ are concerned, the NMBs change significantly, being now overestimated by 21% and 2%, respectively. About PM_{2.5}, it is now underestimated by 7%, respectively, that is, not as much as in the first validation.

In conclusion, in the last validation the BIAS for each species and for each station is much lower than in the early validation, as is possible to see in the plots (Attached B). Therefore the agreement between the UBM model and the observations has been much improved.

| Species | Stations | DEHM | | | | | | UBM | | | | | |
|-------------------|--------------|--------|-------|-------|------|-------|------|--------|-------|-------|------|-------|------|
| | | MB | MGE | NMB | NMGE | RMSE | r | MB | MGE | NMB | NMGE | RMSE | r |
| NO ₂ | CAORLE | -17,38 | 17,41 | -0,74 | 0,75 | 21,81 | 0,50 | 1,94 | 9,70 | 0,08 | 0,42 | 13,12 | 0,55 |
| | DELTA CERVIA | -12,22 | 12,32 | -0,68 | 0,69 | 16,29 | 0,52 | -9,34 | 9,98 | -0,52 | 0,56 | 13,95 | 0,50 |
| | BALLIRANA | -9,81 | 10,14 | -0,60 | 0,62 | 15,04 | 0,59 | -7,55 | 9,15 | -0,46 | 0,56 | 14,16 | 0,40 |
| O ₃ | CAORLE | | | | | | | | | | | | |
| | DELTA CERVIA | 33,50 | 33,61 | 0,66 | 0,67 | 37,38 | 0,82 | 30,77 | 30,91 | 0,61 | 0,61 | 34,56 | 0,84 |
| | BALLIRANA | 38,06 | 38,12 | 0,87 | 0,87 | 40,97 | 0,80 | 35,92 | 35,98 | 0,82 | 0,82 | 38,85 | 0,81 |
| PM ₁₀ | CAORLE | -18,81 | 19,14 | -0,56 | 0,57 | 25,81 | 0,45 | -16,03 | 16,83 | -0,48 | 0,50 | 23,62 | 0,47 |
| | DELTA CERVIA | -13,72 | 14,72 | -0,49 | 0,52 | 20,51 | 0,37 | -13,36 | 14,48 | -0,47 | 0,51 | 20,26 | 0,38 |
| | BALLIRANA | | | | | | | | | | | | |
| PM _{2.5} | CAORLE | | | | | | | | | | | | |
| | DELTA CERVIA | | | | | | | | | | | | |
| | BALLIRANA | -14,44 | 14,92 | -0,54 | 0,55 | 20,85 | 0,40 | -14,19 | 14,74 | -0,53 | 0,55 | 20,73 | 0,39 |

Table 10. Daily statistical parameters calculated for the DEHM and UBM model (scientific validation)

| Species | Stations | UBM | | | | | |
|-------------------|--------------|-----------|------------|------------|-------------|-------------|----------|
| | | <i>MB</i> | <i>MGE</i> | <i>NMB</i> | <i>NMGE</i> | <i>RMSE</i> | <i>r</i> |
| NO ₂ | CAORLE | 14,45 | 17,57 | 0,62 | 0,75 | 20,42 | 0,54 |
| | DELTA CERVIA | 0,74 | 9,12 | 0,04 | 0,51 | 13,28 | 0,51 |
| | BALLIRANA | -0,41 | 8,52 | -0,03 | 0,52 | 11,99 | 0,42 |
| O ₃ | CAORLE | | | | | | |
| | DELTA CERVIA | 24,08 | 24,53 | 0,48 | 0,49 | 28,77 | 0,84 |
| | BALLIRANA | 29,04 | 29,26 | 0,66 | 0,67 | 32,68 | 0,81 |
| PM ₁₀ | CAORLE | 0,25 | 12,55 | 0,01 | 0,38 | 18,01 | 0,47 |
| | DELTA CERVIA | 0,91 | 11,85 | 0,03 | 0,42 | 16,43 | 0,38 |
| | BALLIRANA | | | | | | |
| PM _{2,5} | CAORLE | | | | | | |
| | DELTA CERVIA | | | | | | |
| | BALLIRANA | -1,97 | 10,61 | -0,07 | 0,39 | 16,19 | 0,40 |

Table 11. Daily statistical parameters calculated for the DEHM and UBM model (second validation)

5.3 EVA results

Once the validation is attained, the EVA model can be used to get the final results. The main purpose of the present work consists in the assessment of the contribution to health-related externalities of air pollution from the four SNAP emission sectors.

5.3.1 Health impacts

Table 12 reports the number of cases in Ravenna related to different effects of the emissions for the years 2010, 2011, 2012.

As can be seen in Table 12 the health impact results are relative to different kinds of illness but also to premature RAD (Restricted Activity Days), IM (infant Mortality), YOLL (Years Of Life Lost – Chronic) and AY (Years Of Life Lost – Acute).

| Health impact | Number of cases in Ravenna | | |
|---|----------------------------|------------|------------|
| | 2010 | 2011 | 2012 |
| Chronic bronchitis (CB) | 301 | 335 | 281 |
| Restricted activity days (RAD) | 307789 | 342114 | 286824 |
| Respiratory hospital admission (RHA) | 16 | 17 | 14 |
| Cerebrovascular hospital admission (CHA) | 38 | 42 | 35 |
| Congestive heart failure (CHF) | 15 | 17 | 14 |
| Lung cancer (LC) | 46 | 51 | 43 |
| Bronchodilator use, children (BDUC) | 7810 | 8680 | 7278 |
| Bronchodilator use, adults (BDUA) | 58904 | 65473 | 54892 |
| Cough, children (COUC) | 26982 | 29991 | 25145 |
| Cough, adults (COUA) | 60637 | 67399 | 56506 |
| Lower respiratory symptoms, children (LRSC) | 10413 | 11574 | 9704 |
| Lower respiratory symptoms, adults (LRSA) | 21873 | 24312 | 20383 |
| Acute mortality (AY) | 50 | 52 | 51 |
| Chronic mortality (YOLL) | 2989 | 3322 | 2785 |
| Infant mortality (IM) | 0 | 0 | 0 |
| Premature death (PD) | 282 | 313 | 263 |

Table12. Total number of cases in Ravenna of the different impacts related to the emissions

In the CAFE calculation [50] a factor of 10.6, as an appropriate average for Europe, is used to convert the cases of YOLL into the number of Premature Deaths (PD). This factor allows to evaluate the number of PD (Figure 11) in Ravenna (see Tab. 12) through application of the following formula (Eq. 15):

$$PD = YOLL/10.6$$

Eq. 15

Comparison of the number of PDs obtained with EVA system with the number esteemed from EEAD for Italy would indicate that the contribution of Ravenna to the total PD in Italy due to air pollution is 2%. Table 13 shows the number of PDs in the last years (2011, 2012, 2013) [78,79,80].

| Premature death | 2011 | 2012 | 2013 |
|------------------------|-------------|-------------|-------------|
| PM _{2,5} | 54500 | 59500 | 66600 |
| O ₃ | 3400 | 3300 | 3400 |

Table 13. Premature deaths attributable to PM_{2,5} and O exposure in 2011,2012, 2013 in whole Italy

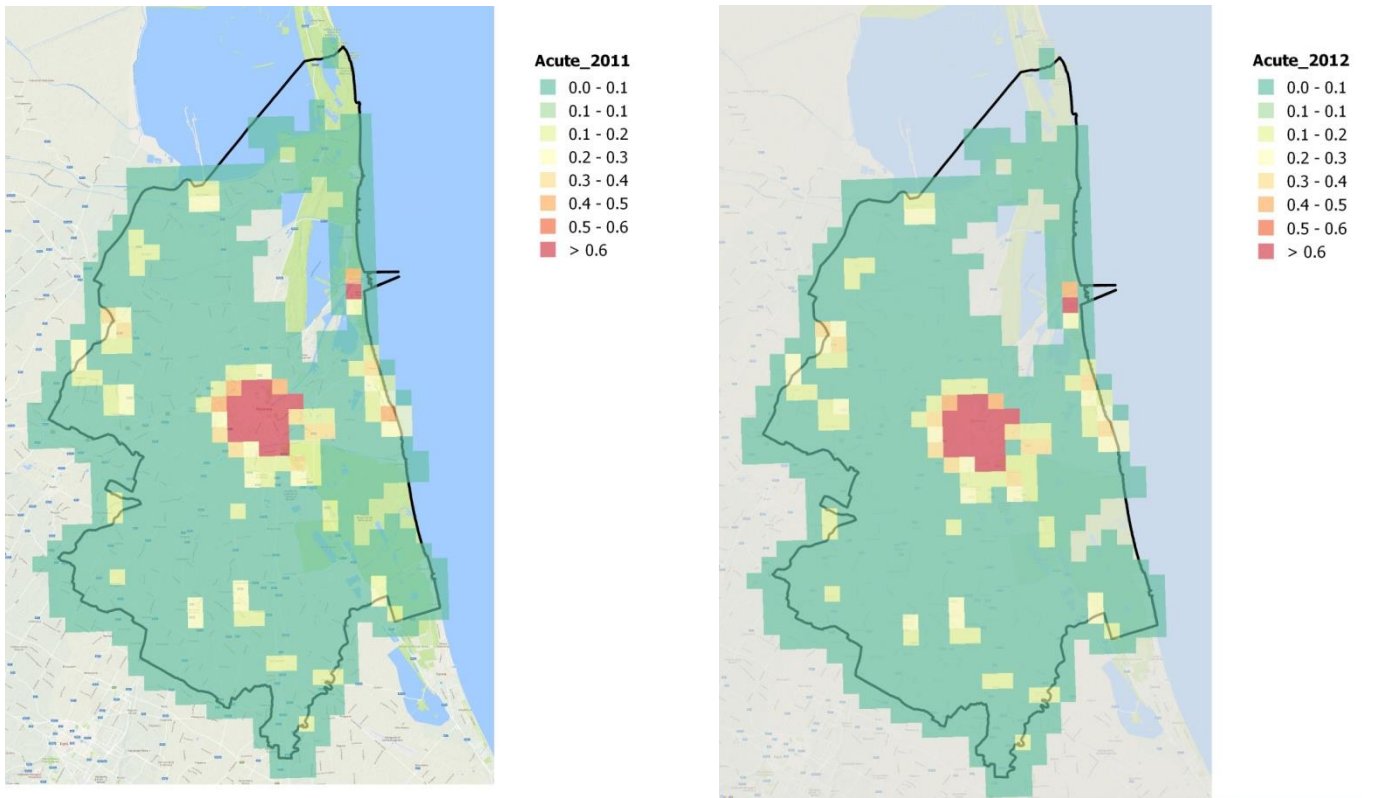


Figure 11. These two pictures show the number of premature deaths due to air pollution per grid cell in Ravenna, as calculated with the integrated EVA model system for the years 2011 and 2012. The area of the grid cell is 1km x 1km, so the colours refer to the number of premature deaths per 1 km². High numbers of premature deaths require both high levels of annual particles concentrations and high population density.

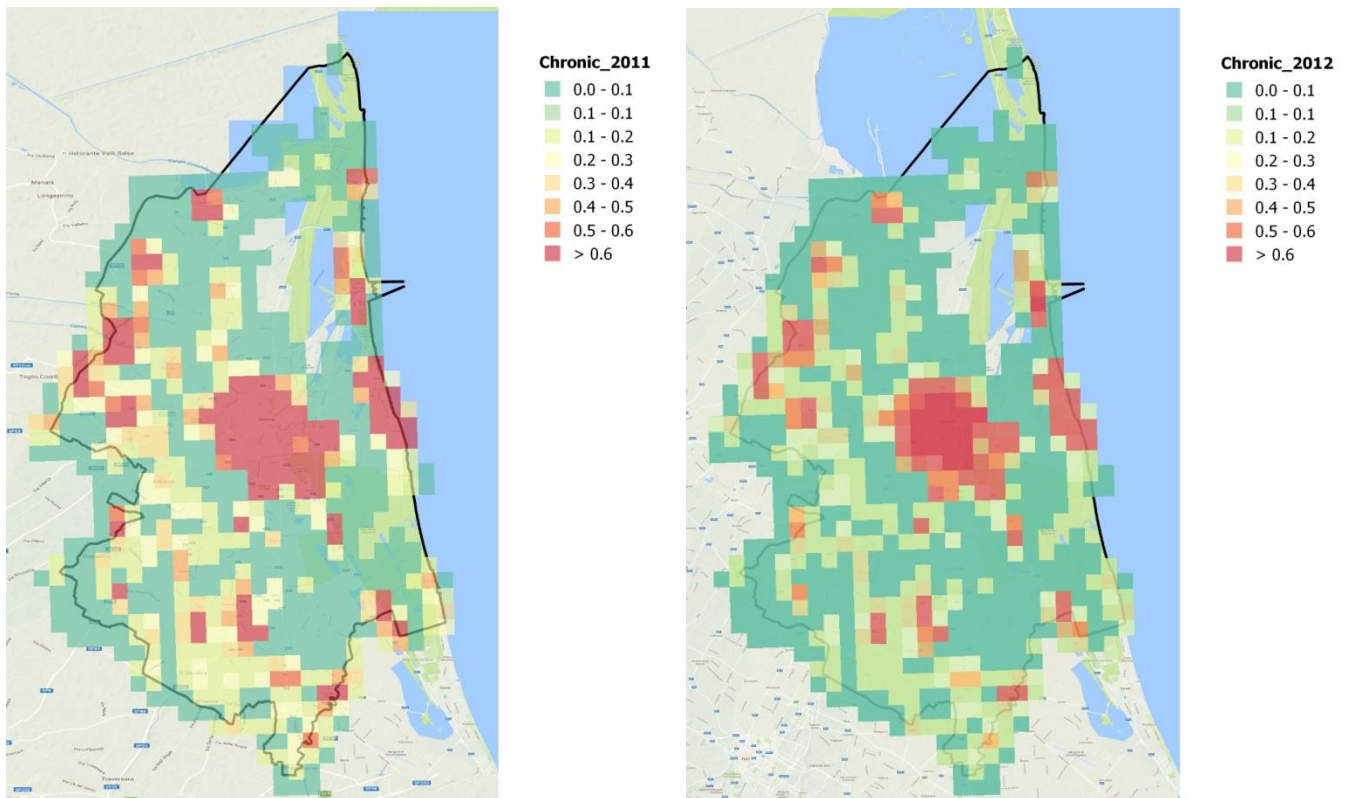


Figure 12. These two images show the spatial distribution of chronic mortality across Ravenna related to $PM_{2.5}$ for the years 2011 and 2012. The area of a grid cell is $1\text{km} \times 1\text{km}$, so the colour bar refers to number of cases per year per 1km^2 .

5.3.2 The total health-related externalities

The external costs of the health impacts associated with air pollution calculated by the EVA model in Ravenna are shown in Table 14. The exposure-response functions involve for CO , O_3 and $PM_{2.5}$. The primary emitted parts of $PM_{2.5}$ (consisting of mineral dust, black carbon and organic carbon) are treated as inert tracers in the DEHM model, and can therefore be considered as a direct effect due to emissions of the same chemical compound [8]. As seen in the Table 14, the total external costs due to anthropogenic emissions in Ravenna, taken as a sum over the three species (CO , O_3 and $PM_{2.5}$), for the three years (2010, 2011, 2012) is around 300 million Euros.

| Species | External costs | | |
|-------------------|----------------|-------------|-------------|
| | 2010 | 2011 | 2012 |
| CO | 35000 | 34000 | 33000 |
| O ₃ | 77m | 80m | 78m |
| PM _{2,5} | 219m | 244m | 205m |
| TOTAL | 296m | 324m | 283m |

Table 14. The total external cost because of the three species

| Health impacts | External costs | | |
|--------------------------|----------------|--------|--------|
| | 2010 | 2011 | 2012 |
| CB | 12m | 13m | 10m |
| RAD | 30m | 34m | 28m |
| RHA | 82000 | 91000 | 77000 |
| CHA | 254000 | 282000 | 236000 |
| CHF (CO) | 35000 | 34000 | 33000 |
| CHF (PM _{2,5}) | 133000 | 148000 | 124000 |
| LC | 739000 | 821000 | 668000 |
| BDU | 1m | 1m | 995000 |
| COU | 3m | 3m | 2m |
| LRS | 291000 | 323000 | 271000 |
| AY | 77m | 80m | 78m |
| YOLL | 172000 | 191m | 160m |
| IM | 606000 | 674000 | 565000 |

Table 15. The health-related external costs in Ravenna

The largest contributor to human health and related external costs is PM_{2,5}, because it includes different typologies of chemical species, originating from different kinds of human activities. Because of this dimension (diameter <2.5 μm), the PM_{2,5} is easily inhaled producing serious health impacts that will require high costs. PM_{2,5} contributes approximately 75% of the total external costs, while O₃ is responsible of about 25% of the external costs in Ravenna. The external costs of CO are much lower than those of PM_{2,5} and O₃. While PM_{2,5} causes a lot of health impacts, CO is the cause of just one illness, i.e., congestive heart failure. O₃, a secondary pollutant not directly emitted from human activities, is responsible of the AY. The final total external costs indicate a decrease in 2012 relative to 2011, most probably due to a significant decrease of the PM_{2,5}.

6. DISCUSSION AND OVERALL CONCLUSION

In this work we have presented results from an integrated model system, EVA, suitable to evaluate the health-related external costs deriving from specific atmospheric emission sources and sectors. The EVA system is based on the impact pathway approach. In the case of this thesis work the EVA system has been run for different scenarios, assessing the human health impact and associated external costs from different emission sectors for three different years (2010, 2011, 2012) in Ravenna.

The main objective of this work was to find the primary emissions in Ravenna that give the largest contributions to human health and related external costs.

The economic valuation in this study only includes some of the known harmful chemical compounds. In these evaluations, we did not include compounds such as polycyclic aromatic hydrocarbons, persistent organic pollutants, metals, heavy metals, dioxins and secondary organic aerosols. However, these compounds commonly share the same sources as the compounds considered in this study, and the health effects are likely to be included in our calculation due to their correlations with the included compounds, since the exposure-response functions used correlate the PM_{2.5} concentration with the total health impacts. The system does not include impacts (and corresponding external costs) on the nature, environment and climate.

Furthermore, taking into account that we included health impacts where the ERFs are well documented and accepted by the WHO and EU Commission, the overall results in this work can be considered conservative.

The absolute external costs in this work should be interpreted carefully, accounting for the associated uncertainties, which are difficult to quantify in such a complex model system. The main uncertainties in the integrated model system are associated with emissions and with the quantification of the ERF. With our present knowledge, we are not able to distinguish between the impacts from different

particle types, and this constitutes a major shortcoming of such a study. However, there are many studies linking the total mass of PM_{2.5} with health effects, showing strong and significant correlations. Besides internal uncertainties, the results will also be dependent on the meteorological years chosen in the study. The results can be sensitive also to spatial resolution in the model system. The DEHM system, usually employed to describe the health impacts down from 150 km² to 16.67 km², is optimal for describing the condition in the urban background in Ravenna, so an urban background system (UBM) is being implemented. The UBM can describe the conditions in the urban background with a resolution of 1km².

The model outcome in the form of health impacts and economic valuation depends, of course, on the concentration-response function and economic unit prices chosen.

Air pollution still constitutes a serious problem to human health and the related external costs are considerable.

The results of this work suggest that the PM_{2.5} contribute significantly to health impacts and related external costs. But the O₃ contribution is also significant. These two pollutants are respectively responsible of the ~74% and ~25% of the external costs.

The results in this study show that air pollution constitutes a serious problem to human health and that the related external costs are considerable. For each year, considered in this study an amount of about 300m Euros was lost as external costs, thus implying that every year a citizen spends (considering the population of Ravenna) an amount of about 2000 Euros for the health impacts caused by air pollution.

These results show that the integrated EVA model system is suitable to supply answers raised by relevant health-related socio-economic questions. The results strongly depend on geography, emission sector and nature and extent of emission reduction.

The EVA system has the capability to give useful inputs to the planning and prioritization of the regulation policies and instruments. In fact the related external costs found in this work can be used to compare directly the contributions from different emission sectors, potentially as a basis for decision-making on regulation and emission reduction.

Therefore, once Ravenna, one of the most important industrial area in Italy, is analyzed, considered the socio-economic development of the city and assessed the negative consequences of the air pollution, it is possible to infer that the situation in Ravenna is not one of the best. It is true that the development of the city, the increase of the industrial, commercial and agricultural activities are producing positive effects, such as goods and services for the citizens. However, unfortunately these results are accompanied by a notable increase environmental pollution, with serious repercussions on the health and, consequently, on the economy. Air pollution is causing severe problems, often irreparable.

In my opinion, first of all stricter environmental control and a better information would be required. All citizens should know the negative effects of the pollution generated by anthropic activities.

A comprehensive policy approach towards the prevention of risks and protection of the environment, health and quality of life is required, not a policy devoted only to economic development, considered as an end in itself.

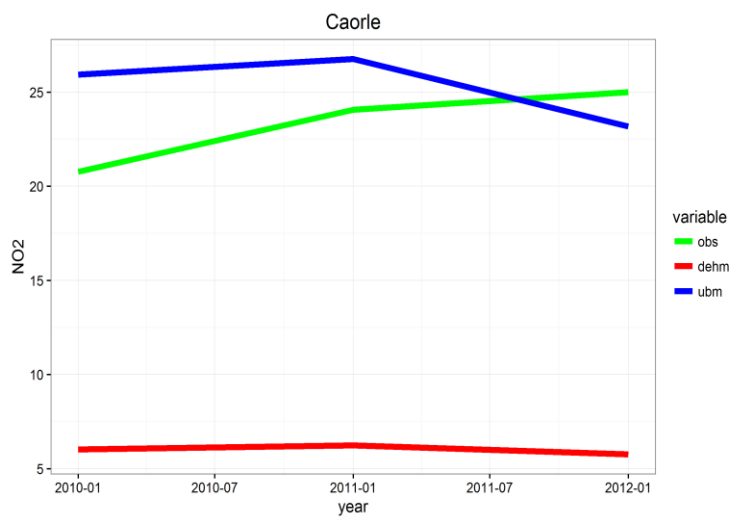
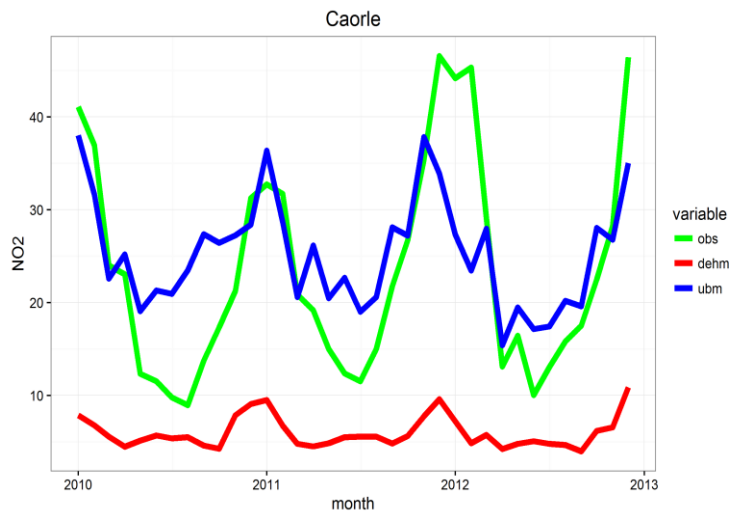
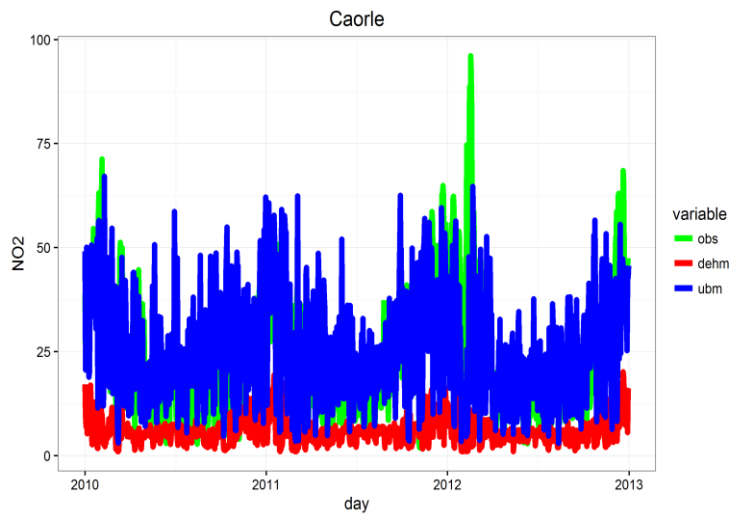
Such a policy would overcome these problems. The respect of law and regulations and use of advanced technologies, in addition to better health conditions, would also result in economical benefits.

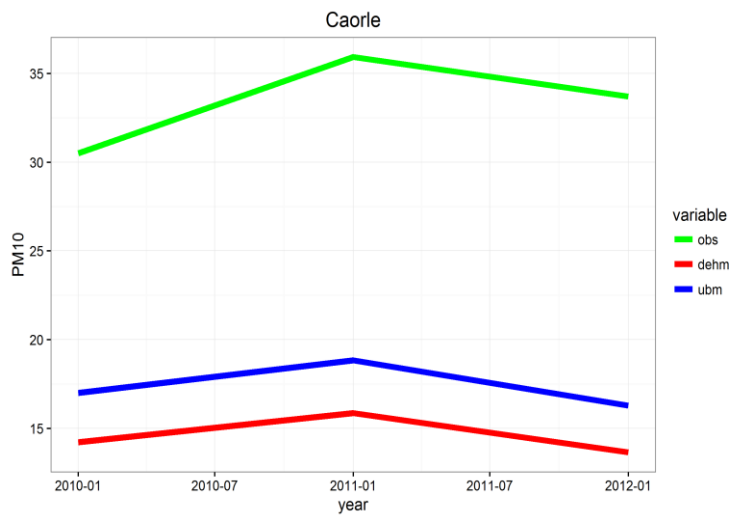
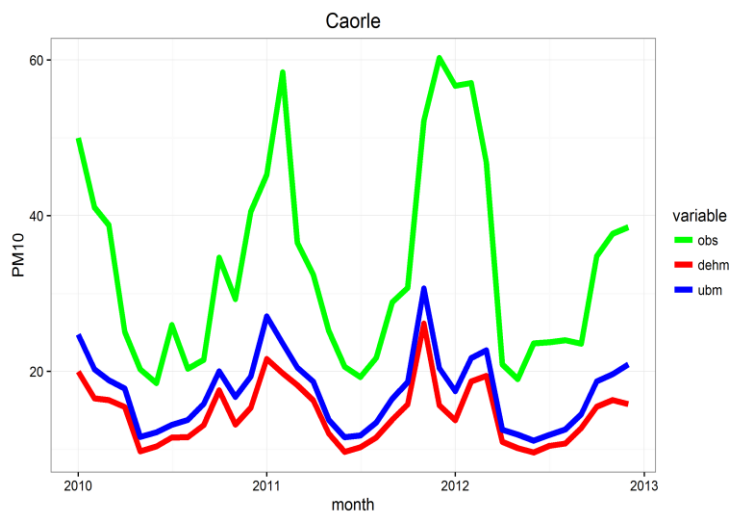
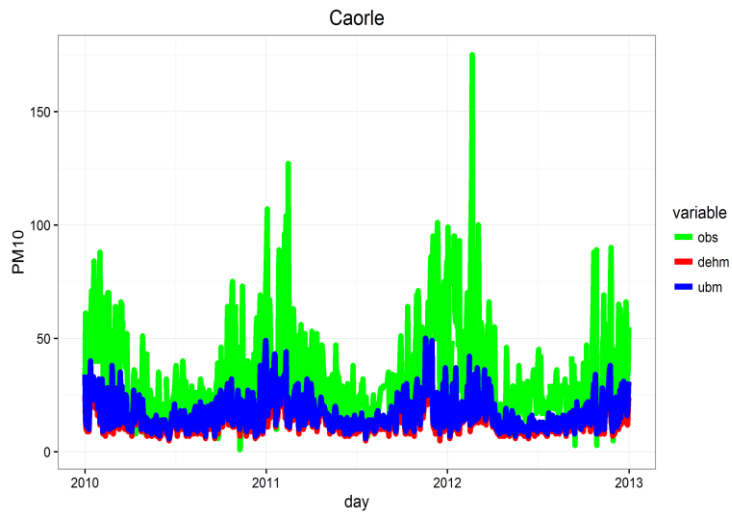
In conclusion, I recommend that these external-cost should be used for the protection of the health and environment, thus meaning that these costs should be considered in the balance sheet of the different sectors. Probably in this way the profits of the commercial, industrial and agricultural activities would be reduced, but the costs born by the community would also sizeably be reduced.

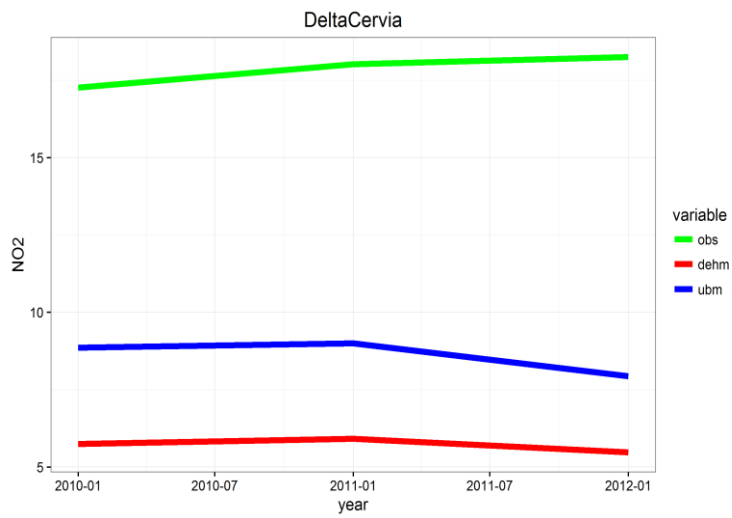
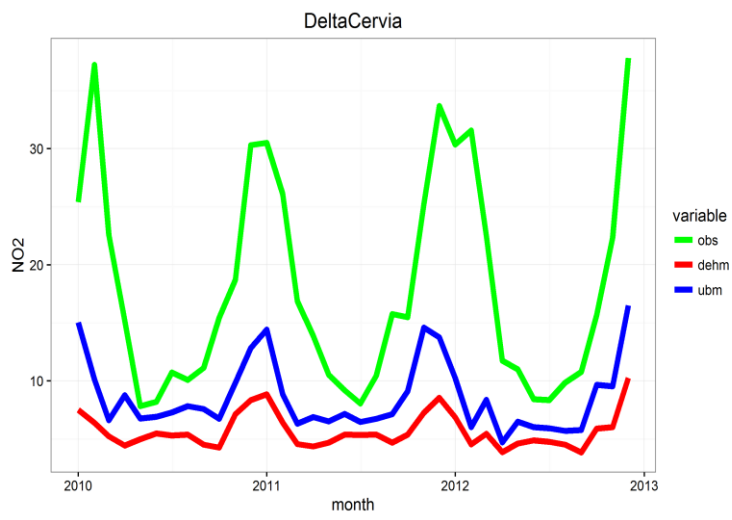
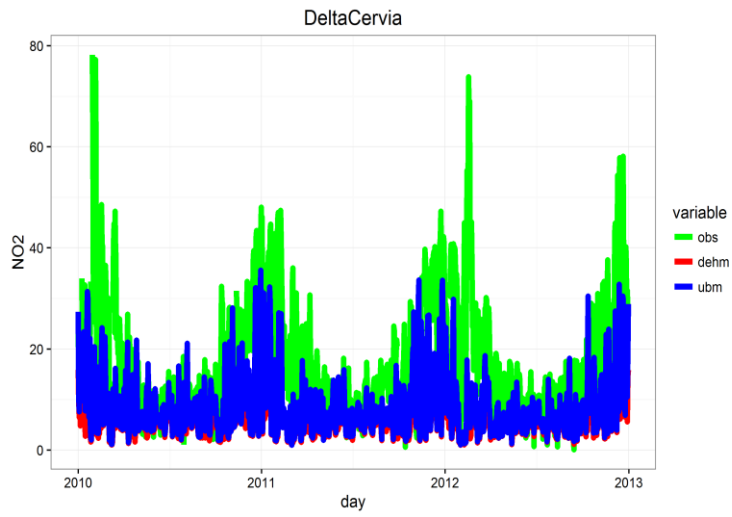
"Poisons will embrace earth like a sultry lover. And in the deadly embrace, the skies will have the breath of death and the sources won't give anything but bitter waters and many of these waters will be more toxic than the serpent's rotten blood. The humans will die of water and air, but it will be said that they died of heart and kidneys. "

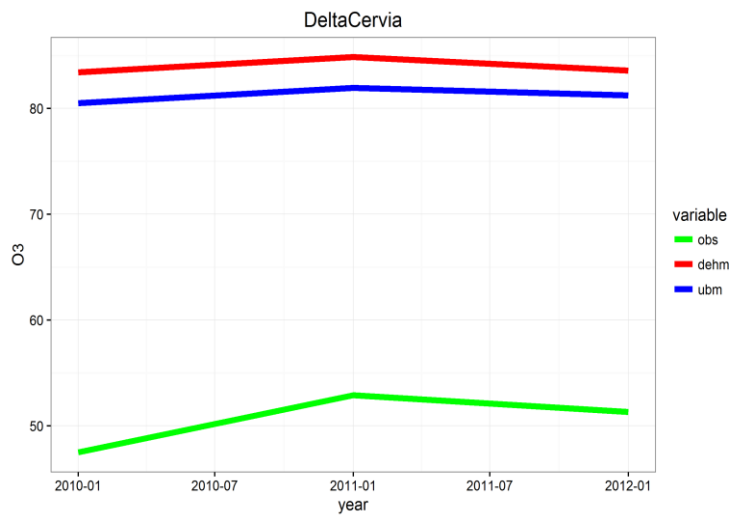
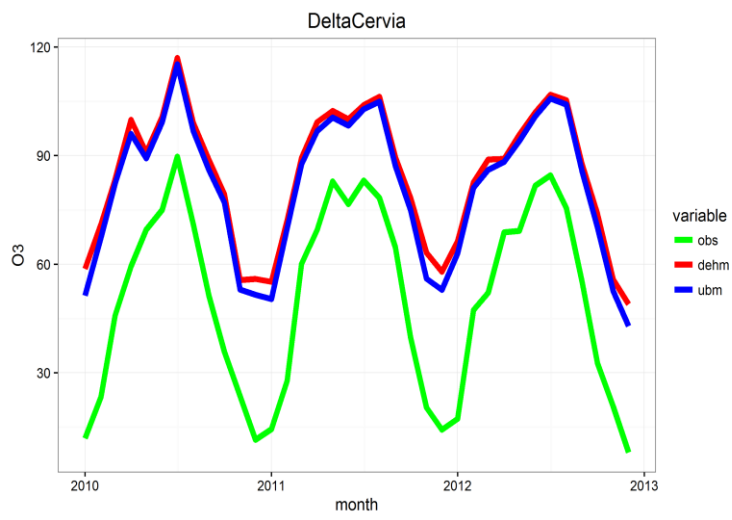
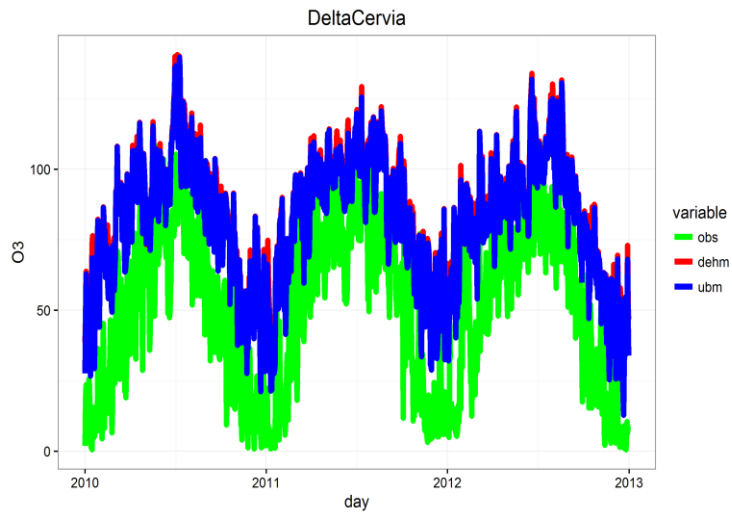
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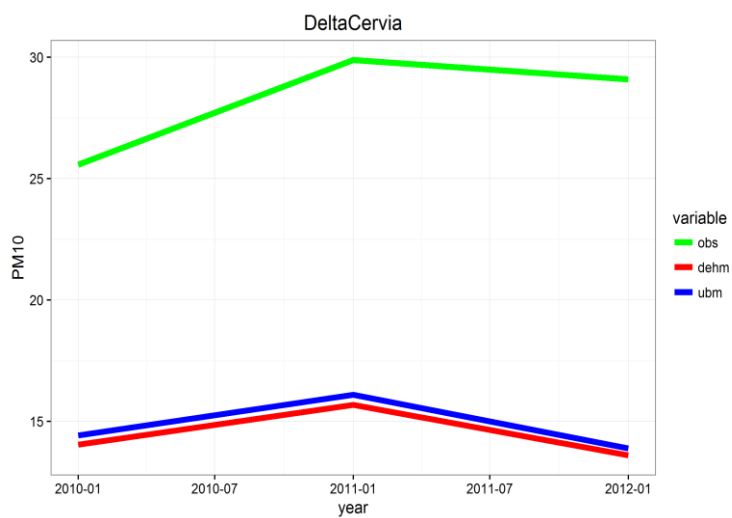
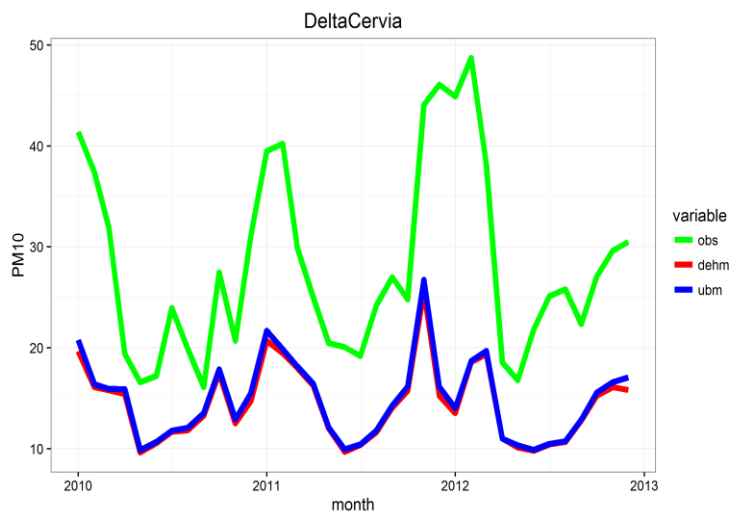
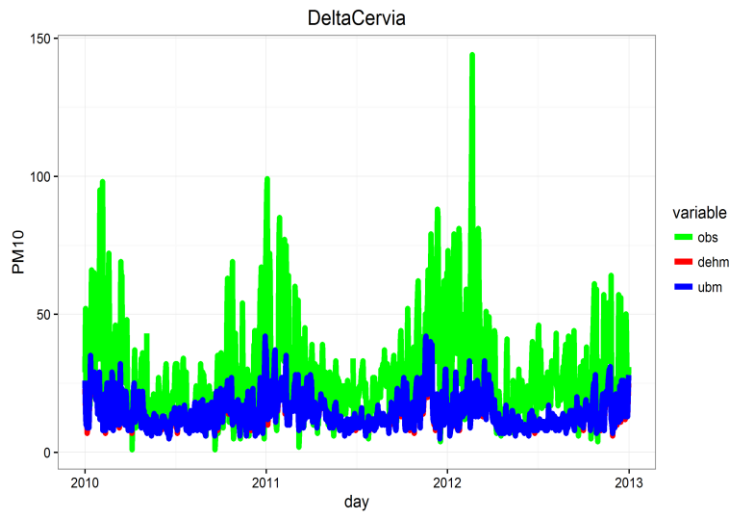
Attached A

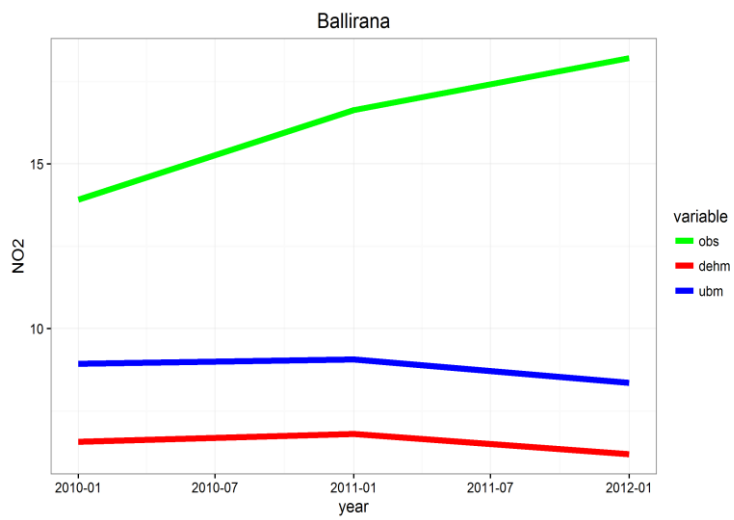
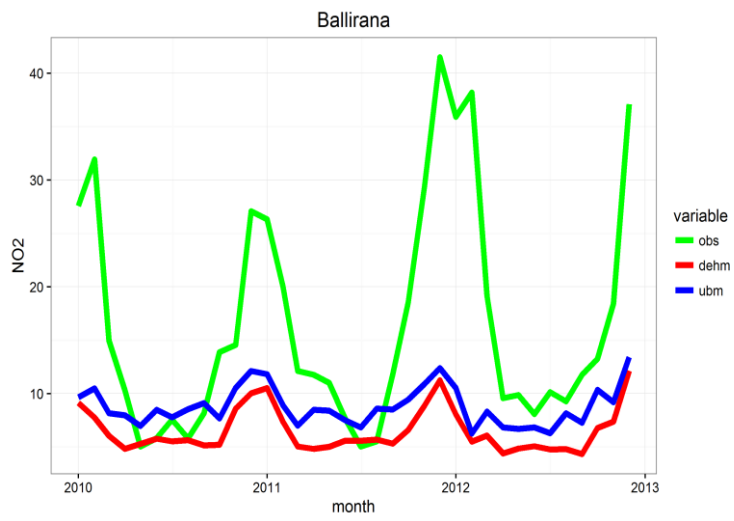
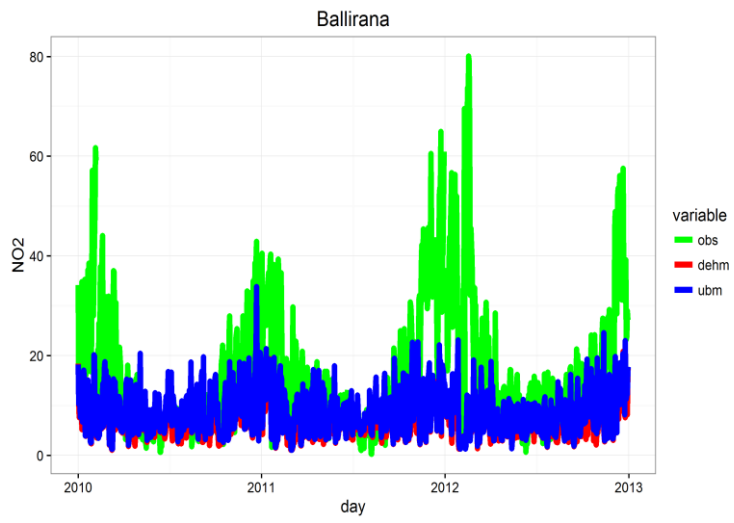


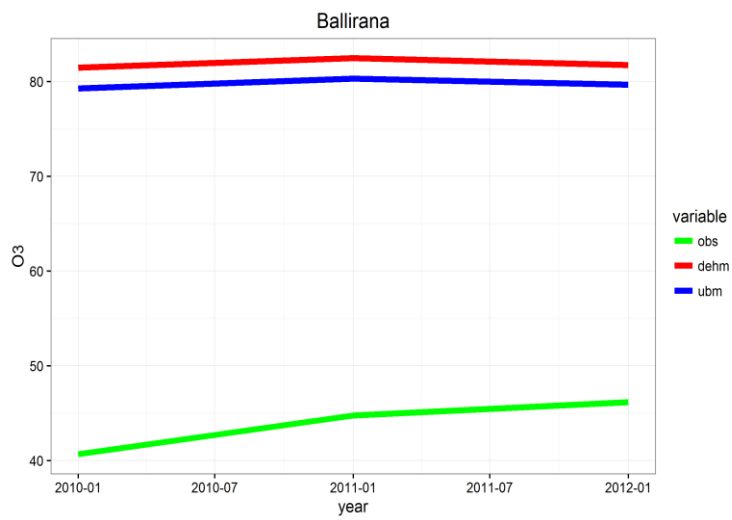
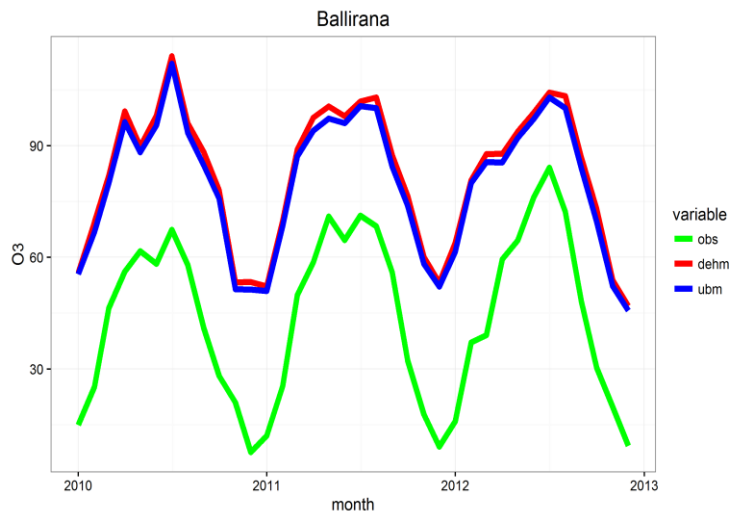
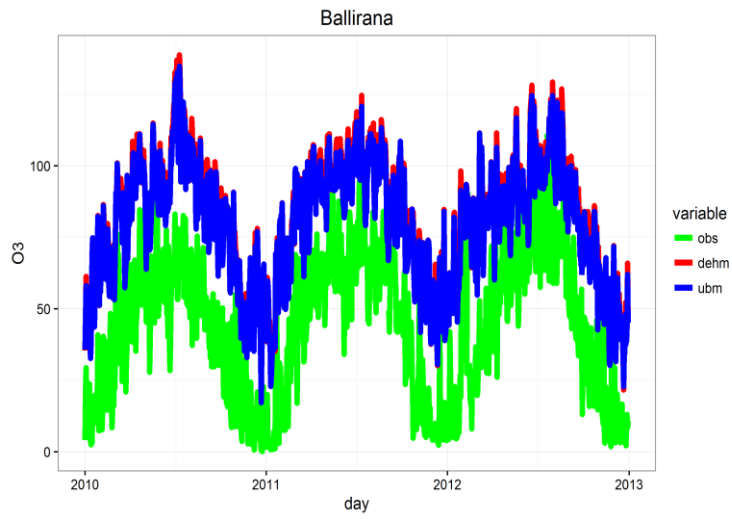


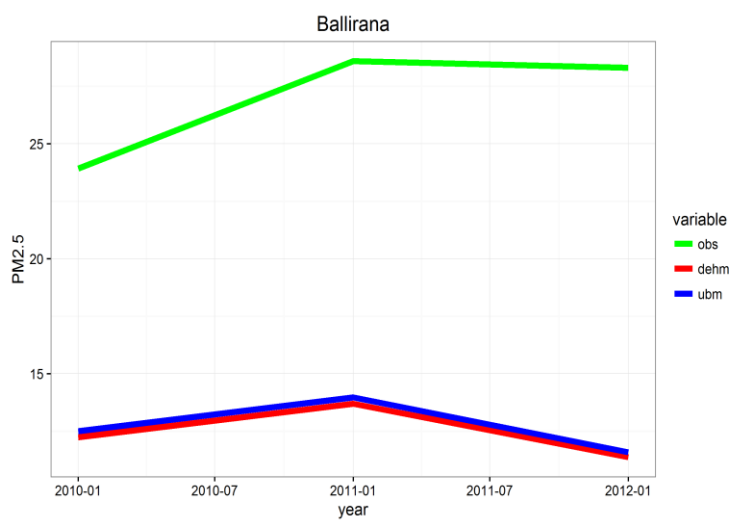
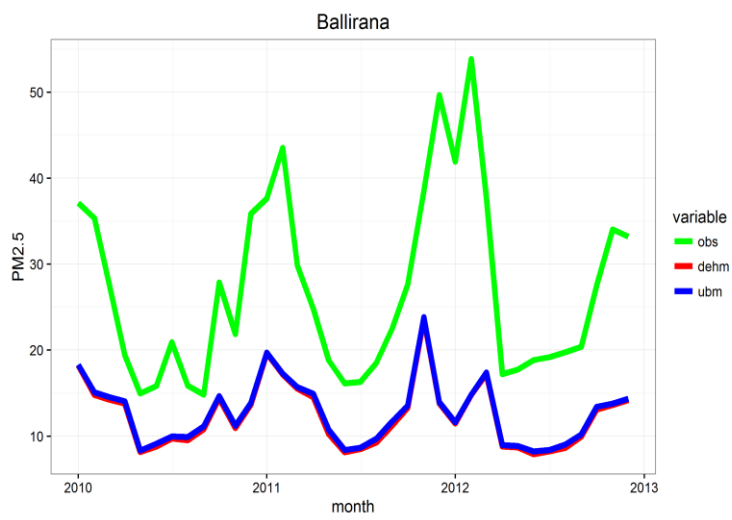
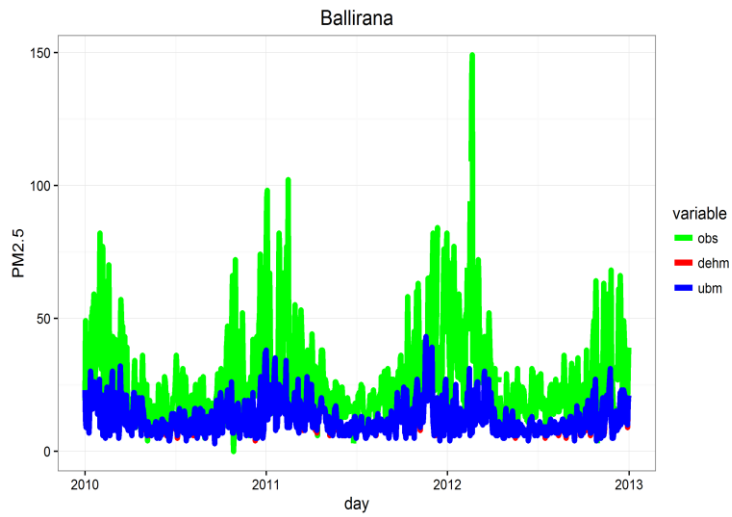




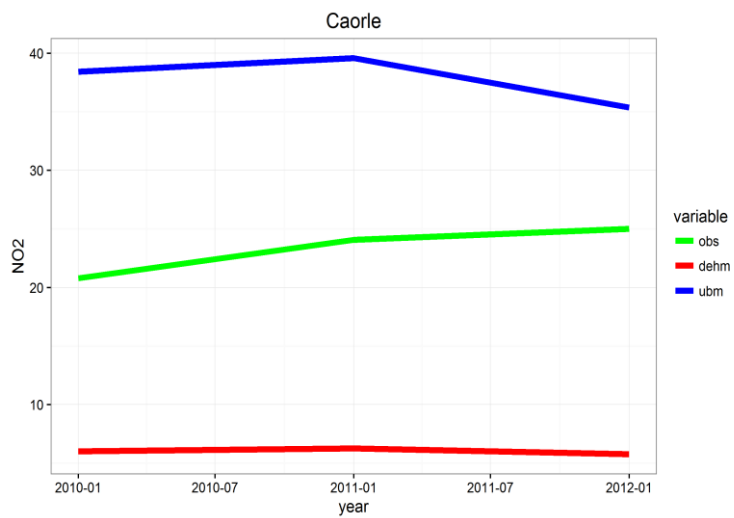
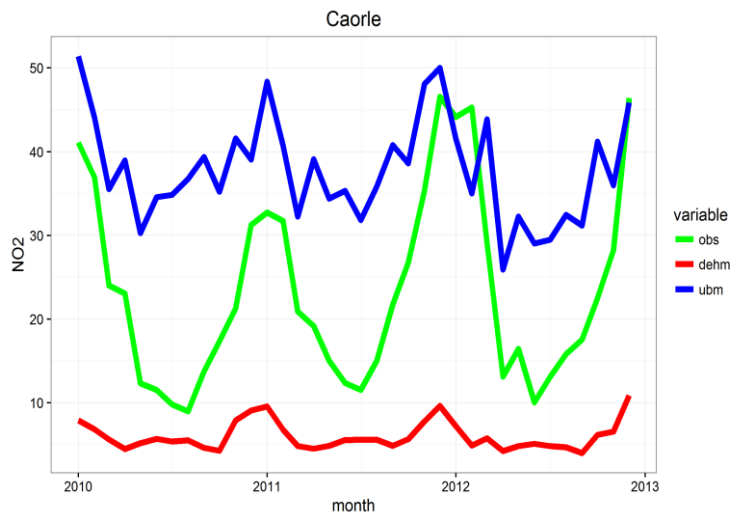
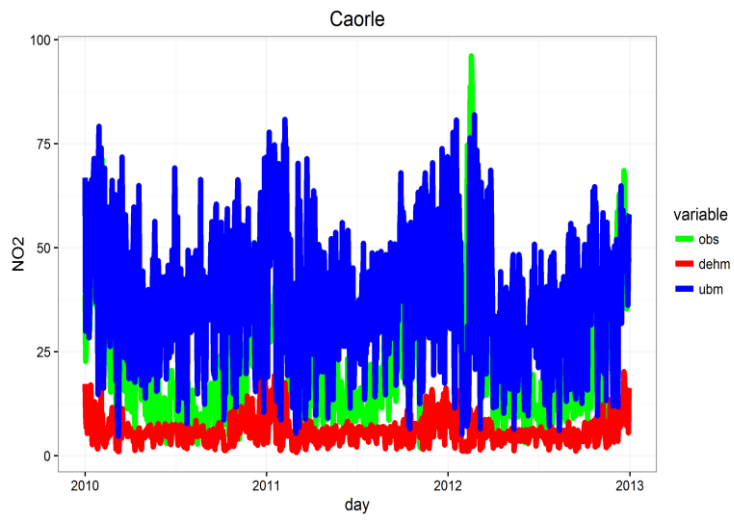


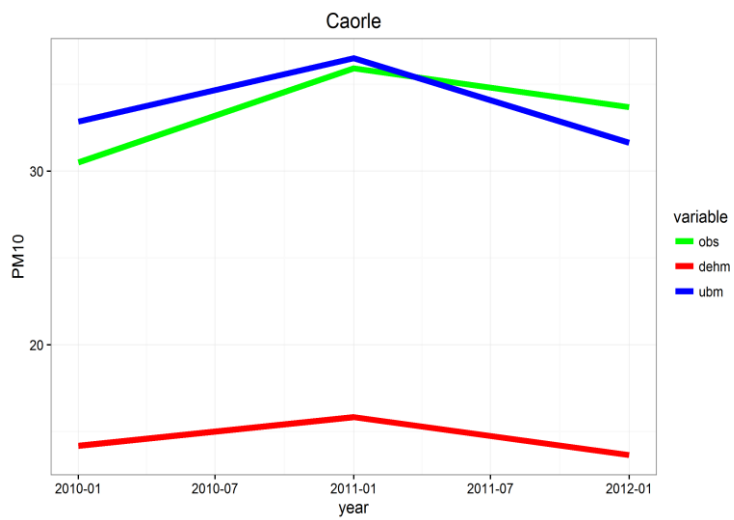
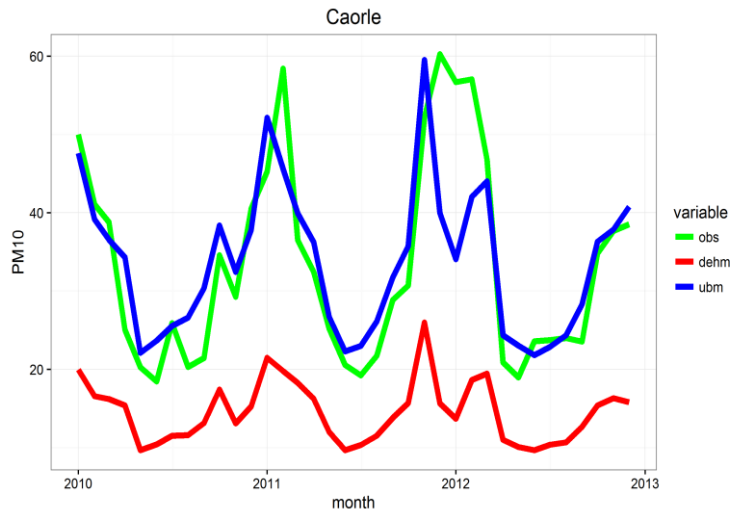
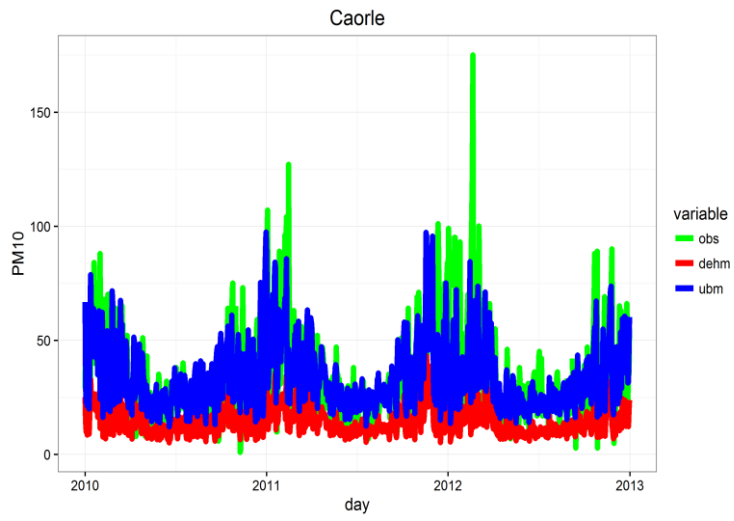


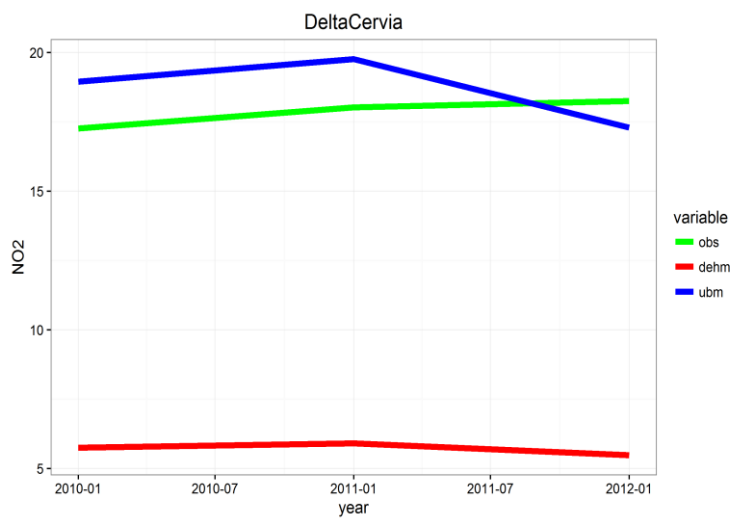
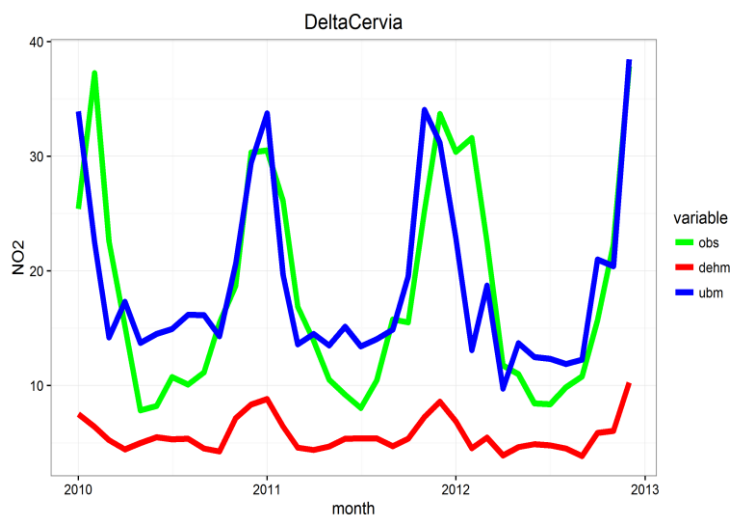
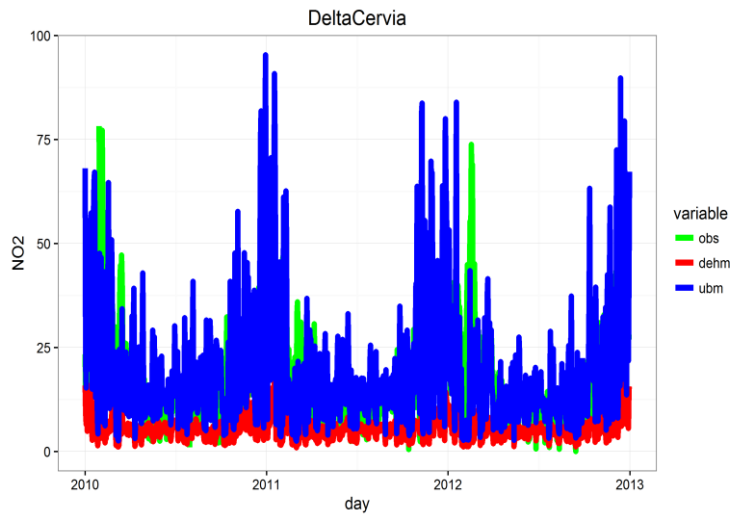


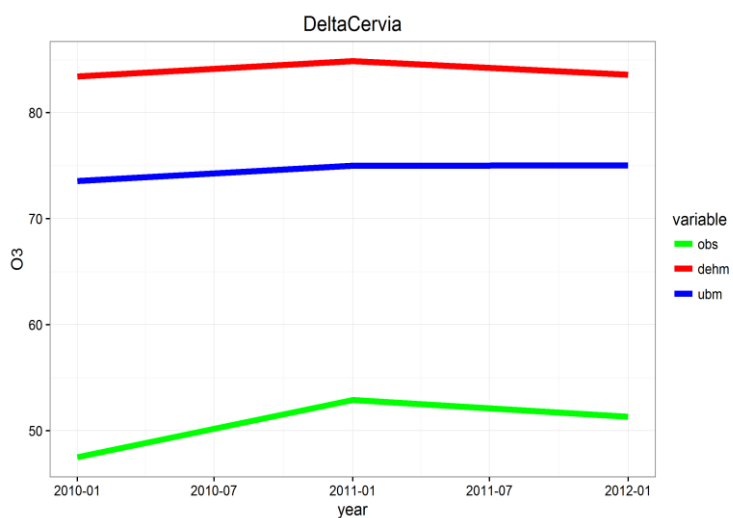
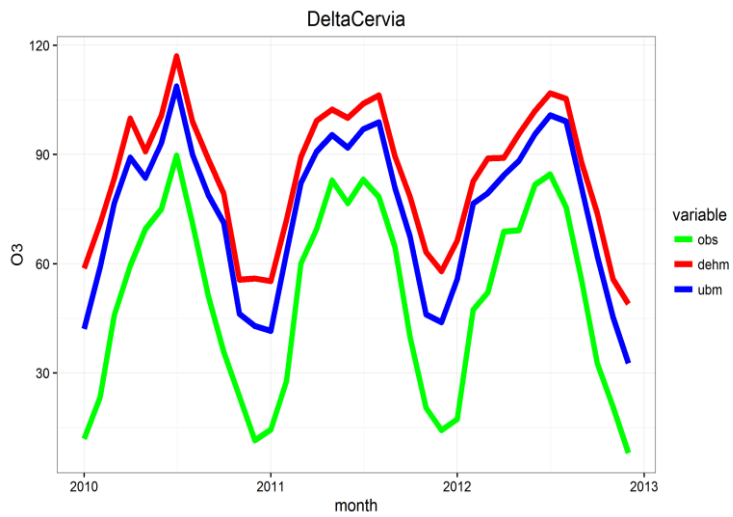
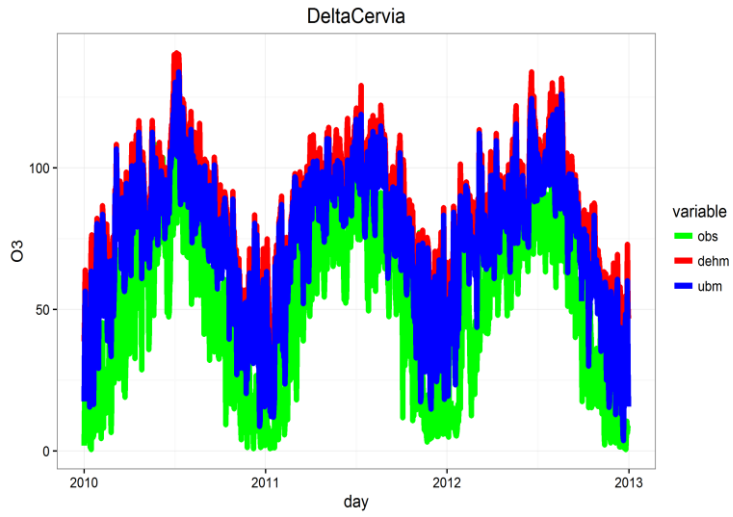


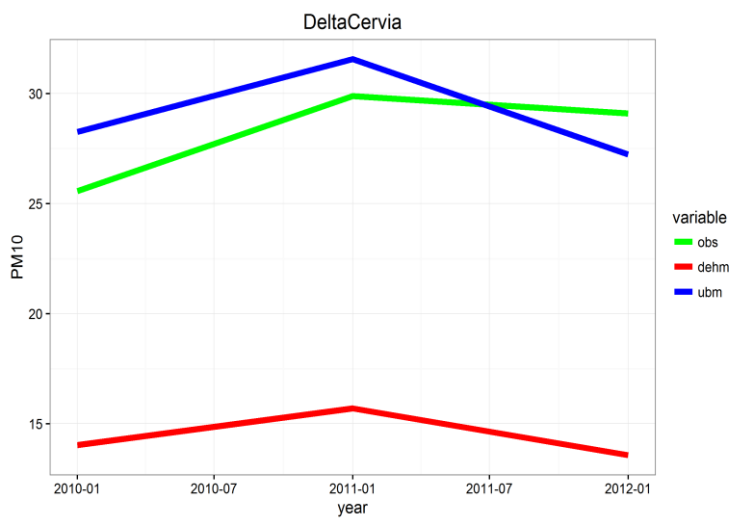
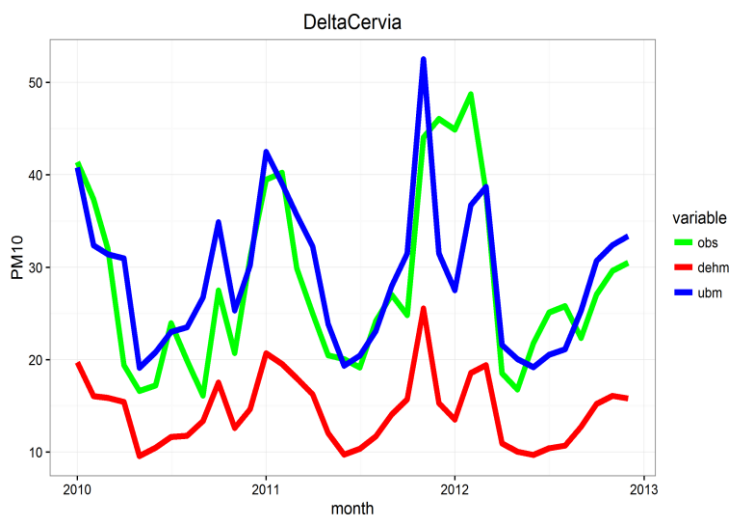
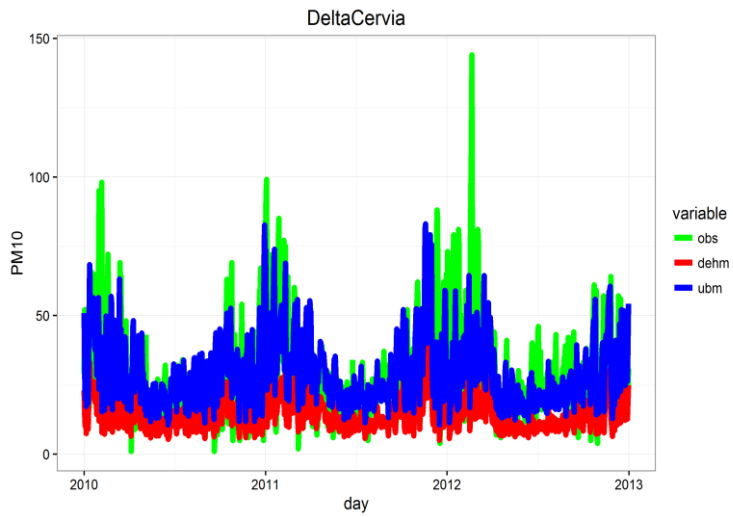
Attached B

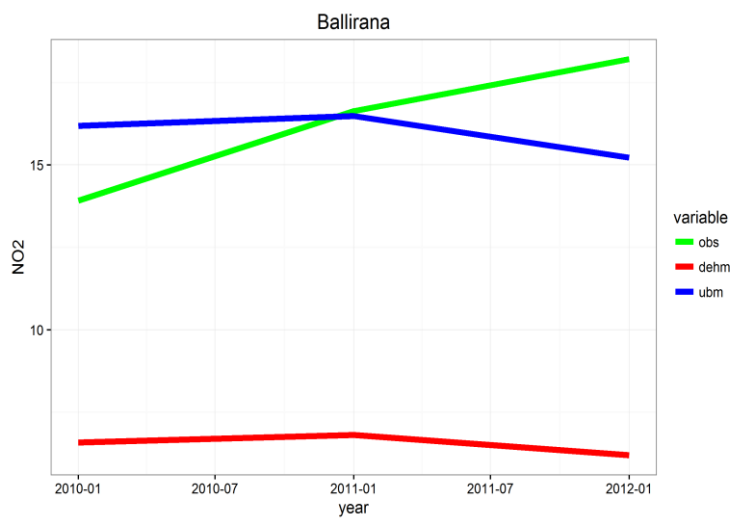
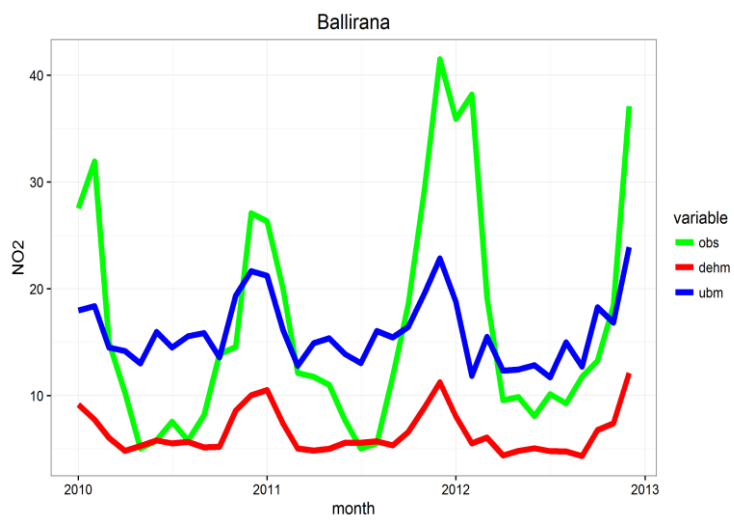
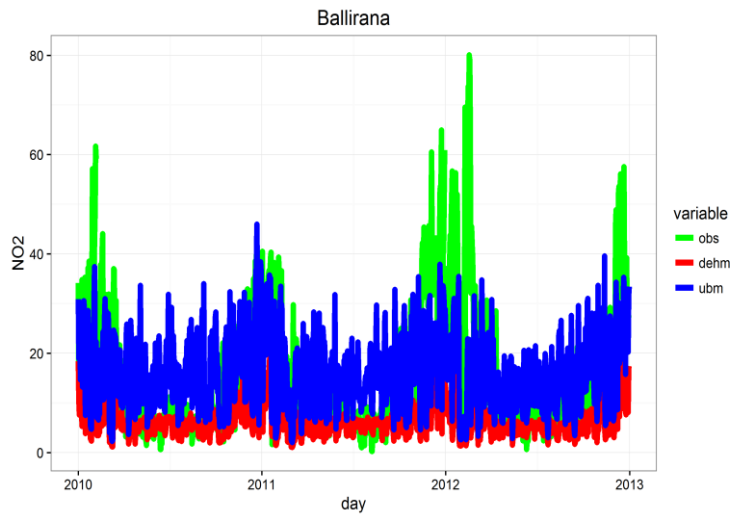


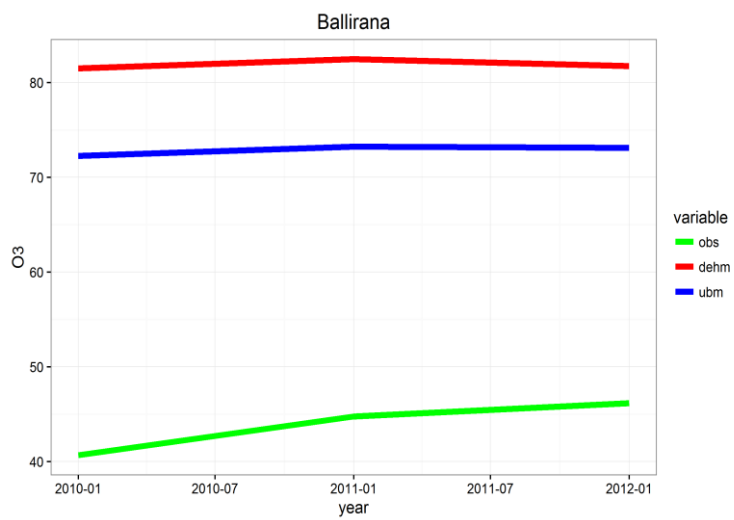
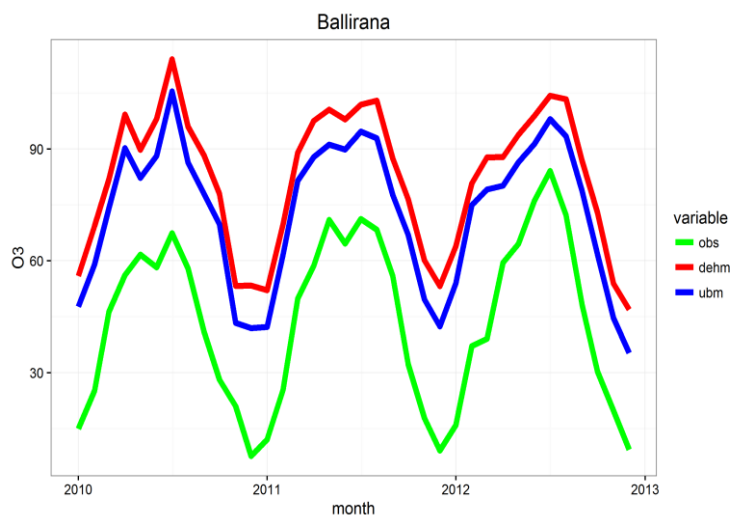
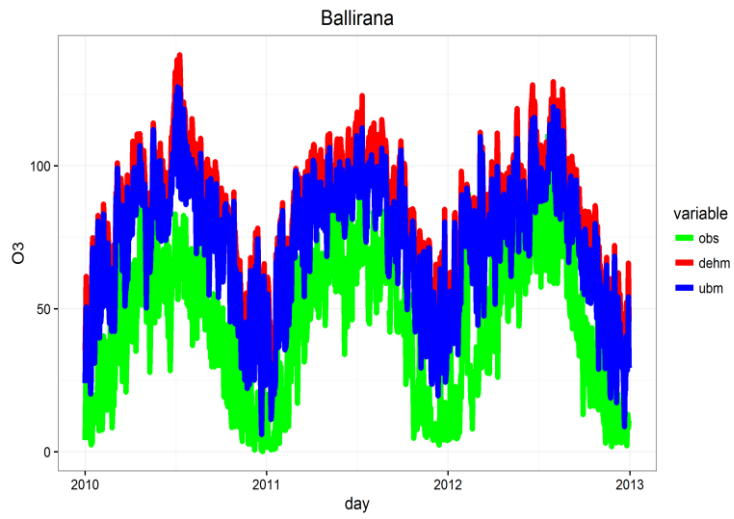


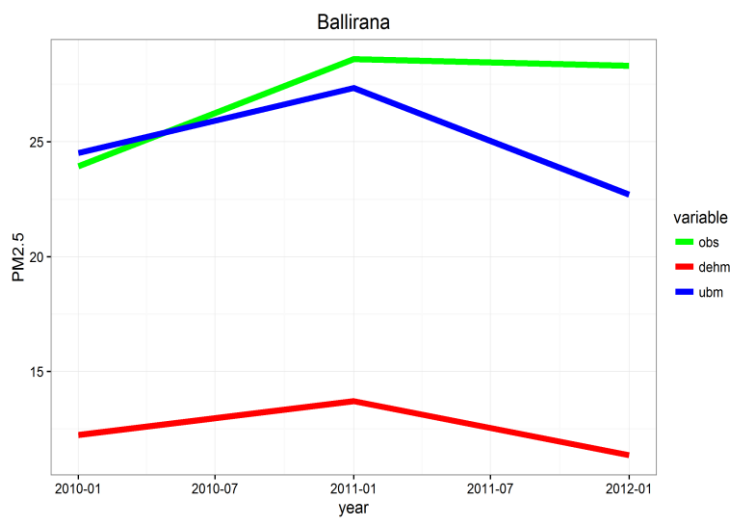
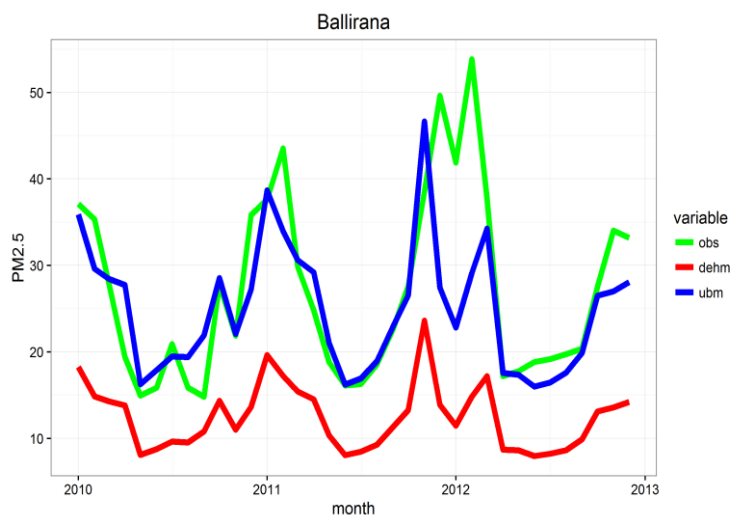
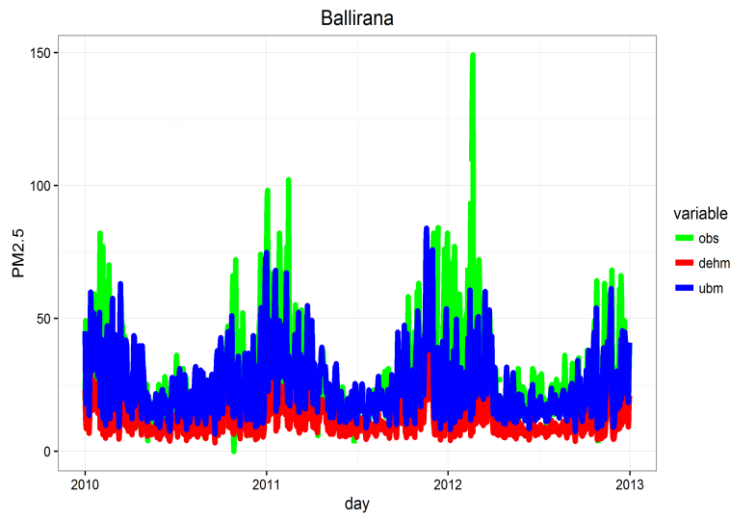












Attached C

Meteorological data

The meteorological information is very important to understand the behaviour of the pollutants and describe their processes of diffusion, transport and removal. In particular, parameters such as temperature, precipitation, pressure, fog, wind speed, wind direction, condition of stability of the atmosphere and the mixing height are important. These parameters are continuously measured by the meteorological stations located in the Province of Ravenna.

The meteorological data was collected, as concentration measurements data, to validate the UBM and DEHM models, but for different reasons was not handled. These data were obtained from ARPA web sites through the DEXTER system [28]. This system allows a direct access to the database of the meteorological service. This Service registers data about the traditional meteorological variables (e.g. temperature, pressure, precipitation), but also about water levels concentration of pollen and many other information regarding environmental, agricultural and health interest. The data reported come from measurements taken in real time, which constitute a regional monitoring network for urban meteorology, agro-meteorology and hydro-meteorology. The stations of the networks are linked to metadata that describe (identification and qualification) the single stations (kind of sensors). The number of sensor of the monitoring network is not the same in all Provinces. In the case of the Province of Ravenna there are in total 95 sensor [29]:

| Sensor | RA |
|--------------------|----|
| Precipitation | 25 |
| Water Level | 36 |
| Temperature of Air | 19 |
| Wind | 2 |
| Solar Radiation | 2 |
| Pressure | 2 |
| Relative Humidity | 9 |

Table 16. Meteorological sensors of Ravenna

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