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ASSESSMENT OF THE HEALTH IMPACTS FROM AIR POLLUTION IN RAVENNA (ITALY) USING THE EVA MODEL

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Abstract This study assesses the health impacts of air pollution in Ravenna, which is a small Italian city located in the Pianura Padana, where the environmental pressure due to air pollution is aggravated. Because of the meteorological conditions and the intensive industrial emissions, there is alarming levels of air pollution giving public health concern in Ravenna. In the present study, we assessed the effects of air pollution on the human health and evaluate the related external costs using the EVA (Economic Valuation of Air pollution) system. The EVA system was applied to do a detailed analysis of the impacts from the four major emission sectors in Ravenna (industrial, agricultural, road traffic and residential/commercial) and their relative contributions to air pollution and health impacts. In the present study, the EVA system included two air pollution models; the Danish Eulerian Hemispheric Model (DEHM) that describe atmospheric long-range transport of pollutants and all the processes that take place during their transport, and the Urban Background Model (UBM) that is coupled to DEHM to calculate the urban air pollution on a 1 km spatial resolution. The emissions in Ravenna were compiled using source-specific data from the local authorities. The main results show that among different health impacts, air pollution was responsible for 310 premature deaths in Ravenna in the year 2011, leading to an external cost of 240 million Euros. The major contributor to human health and related external costs was $PM_{2.5}$, contributing approximately 75% of the total external costs, while O_3 is responsible of about 25% of the external costs in Ravenna. While the sector that mainly contributes is the residential and commercial sector, which contributes 6% of external health costs and 8% of premature death.

Key words: *air pollution, health impact, external costs, Ravenna*

INTRODUCTION

The considerable increase of the industrial, commercial and agricultural development, and all human activities connected with the production of goods and service, have brought as a result different stresses of environmental pollution. The main effect of air 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 quality. Air pollution constitutes a severe problem for the environment and, consequently, for the human health. Epidemiological studies have shown that there are effects highly correlated with outdoor air pollution. On the base of short-term studies it has been shown that air pollution causes morbidity (cardiovascular and respiratory symptoms, decrease in lung function, chronic bronchitis, etc.) and mortality. 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.

A large portion of the European population lives in areas where the emission limits [4], as defined by Directive 2008/50/CE, are exceeded. According to the European Commission [5], every year more than 400.000 people in the EU die prematurely as a consequence of air pollution. Another 6.5 million people fall sick because air pollution causes disease. According to the World Health Organization (WHO) more than 90% of European citizens are exposed to annual amounts of air pollution which exceed the limit established by the WHO guidelines. Therefore illness and premature death caused by air pollution not only damages public health, but also costing Europe about 1.463 billion euro every year. According to WHO, this cost is associated with about 600 thousand premature deaths caused by air pollution. In 2012, 63.400 premature deaths have been attributable to exposure of fine particulate matter ($PM_{2.5}$), Ozone (O_3) and nitrogen dioxide (NO2), in Italy. 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.

The purpose of this work is to evaluate the effects of air pollution on the human health and economy in the city of Ravenna. Ravenna is located in the Emilia Romagna Region (NE Italy) on the Adriatic Sea, including a large industrial area and one of the most important commercial harbors of Italy. Ravenna is located in the Pò Valley, which is the most industrialized area in Italy. In addition, it is enclosed by mountains on three sides and is characterized by continental-temperate climate with high relative humidity, and presence of fog and wild lulls due to frequent thermal inversion during the winter. These conditions make this valley, and all the cities like Ravenna that are inside the valley, one of the worst areas in the world for air pollution, with large number of days exceeding air quality standards during the year, and some very strong pollution episodes.

In the present study, an integrated model system has been employed in order to make an assessment of the health impacts of air pollution and its economic valuation on the society, as well as to do a detailed analysis of the relative contributions of four major emission sectors.

MATERIAL AND METHODS

A detailed analysis of air pollution-related health impacts and their external costs associated with the major emission sectors and their relative contributions is performed using the EVA (Economic Valuation of Air Pollution: Brandt et al., 2013) model. In the current study, EVA uses air pollution concentrations from the offline-coupled air pollution system: the Danish Eulerian Hemispheric Model (Brandt et al., 2012) and the Urban Background Model (Im, U et al., 2017). In order to adopt these models for the region of interest, it is necessary to compile a local emissions database with all emission sources in the area of Ravenna. Four emissions sectors are considered in the present study: residential/commercial, industrial, agricultural and vehicular. In addition to the emission data, it is necessary to collect air pollution observations in order to evaluate the model performance and population data in order to calculate the exposure to air pollutants.

Data Collection

Population Data

A gridded data set was obtained from the GEOSTAT 2011 grid dataset covering all Italy on a 1km resolution. It is important to analyze the health outcomes as a function of age as different age groups respond differently to pollution.

Emission Data

Emission data for residential/commercial, agricultural and vehicular emissions as well as from each factory stack for industrial emissions, are collected from the AIE (Authorization Integrated Environmental) and allocated in the 1 km resolution grid using Q-Gis (Quantum Geographic Informatics System). UBM requires emissions of Nitrogen Oxide (NOx), Sulphur Oxide (SOx), Non Methane Volatile Organic Carbon (NMVOC), Carbon Monoxide (CO), Total Suspended Particulate (TSP), and Particulate Matter (PM_{10}, $PM_{2,5}$). The data is allocated in the model grid using the Q-Gis.

Measurement data
The observed air pollutant concentrations from different monitoring stations were obtained from the ARPA (Regional Agency for the Protection of Environment) network. These stations continuously measure hourly gaseous and daily PM concentrations. In this work, three stations (one urban, two rural stations) have been considered to evaluate the UBM model for the area of Ravenna.

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 setup used in this study includes two two-way nested domains, with the mother domain covering most of the Northern Hemisphere on a 150 km spatial resolution and the European domain that covers all Europe on a 50 km spatial resolution. The output of the DEHM model is used as boundary conditions for the UBM model.

UBM model

The Urban Background Model (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 NOx and O_3 on a spatial resolution of 1kmx1km. The UBM concentrations were used as input to the EVA model.

Model Evaluation

The model evaluation is conducted comparing simulated air pollutant levels of NO_2, O_3, CO, PM_{10} and $PM_{2.5}$ from the UBM and DEHM model with the observed levels for the three-year period (2010, 2011 and 2012) considered in this study

EVA model

The concept of the EVA system is based on the impact-pathway chain.

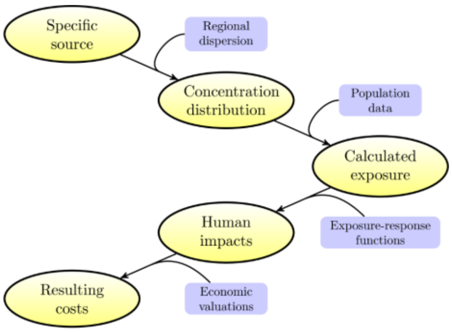

Figure 1. A schematic diagram of the impact-pathway methodology

Using exposure-response functions (equation 1) and economic valuations, the exposure can be transformed into impacts on human health and related external costs.

$$R=\alpha*\delta c*P \qquad (1)$$

where the response (*R*) depends by α that is an empirically determined constant for the particular health outcome typically obtained from the published cohort studies, δc is the concentration and *P* is the affected share of the population. EVA calculates the Years Of Life Lost (YOLL), that can be further converted to the chronic mortality, following the recommendation of the CAFE programme hat recommends to use a factor of 10.6. The total premature death is then calculated as the sum of the chronic and acute mortality. This factor allows to evaluate the number of PD in Ravenna through application of the following formula (equation 2):

$$PD = AY + (YOLL/10.6) \qquad (2)$$

RESULTS

The DEHM and UBM results were compared with the observations on hourly, daily, monthly and annual basis for NO_2, O_3 and SO_2, while for $PM_{2,5}$ and PM_{10}, comparisons were done on daily, monthly and annual basis. Figure 2 shows the observed and simulated (DEHM and UBM) monthly O_3 and $PM_{2,5}$, for the measurement station of Ballirana. As can be seen in the plots, both models largely overestimate O_3. DEHM overestimates O_3 by 87% and UBM by 66%. In contrast both models largely underestimate $PM_{2,5}$: DEHM underestimates $PM_{2,5}$ by 54% and UBM by 8%.

Table 1 presents the different health impacts and their external costs estimated by the EVA model for the years 2010, 2011 and 2012. These results are concerned with the cases of illness due to air pollution, but also about the restricted activity days, the mortality and the YOLL (Years Of Life Lost). The total external costs due to anthropogenic emissions in Ravenna, taken as a sum over the three species (CO, O_3 and $PM_{2,5}$), in 2010, 2011 and 2012 is around 300 million Euros and the highest contribution is from residential and commercial emissions.

The largest contribution to human health and related external costs is due to $PM_{2,5}$ because it includes different typologies of chemical species, originating from different kinds of human activities. $PM_{2,5}$ contributes approximately 75% of the total external costs, while O_3 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 O_3. While $PM_{2,5}$ causes a lot of health impacts, CO is the cause of just one illness, i.e., congestive heart failure.

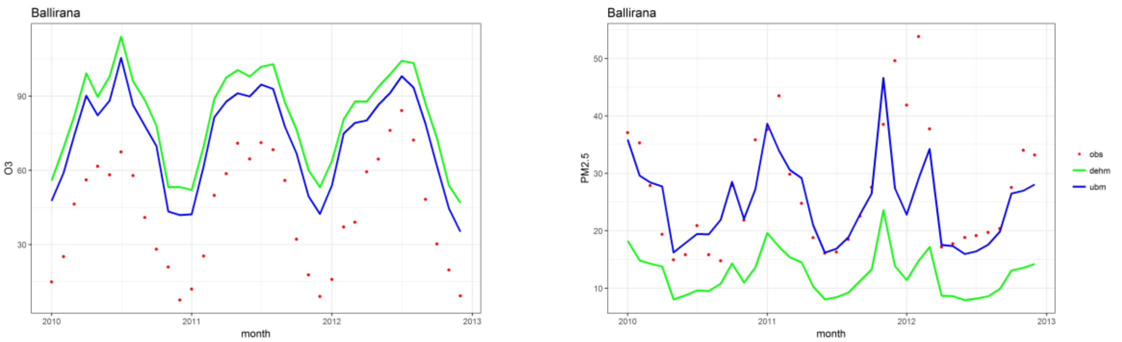

Figure 2. Observed and simulated monthly O_3 and $PM_{2,5}$ concenrations .

Table 1. Total number of cases and the health-related external costs, in million euros, in Ravenna related to the emission for the year 2010, 2011 and 2012

Health Impacts	Number of cases			External Costs		
	2010	2011	2012	2010	2011	2012
Chronic bronchitis (CB)	301	335	281	12	13	10
Restricted activity days (RAD)	307789	342114	286824	30	34	28
Respiratory hospital admission (RHA)	16	17	14	$82 \cdot 10^{-3}$	$91 \cdot 10^{-3}$	$77 \cdot 10^{-3}$
Cebrovascular hospital admission (CHA)	38	42	35	$254 \cdot 10^{-3}$	$282 \cdot 10^{-3}$	$236 \cdot 10^{-3}$

Congestive heart failure (CHF)	15	17	14	0	0	0
Lung cancer (LC)	46	51	43	$739*10^{-3}$	$821*10^{-3}$	$668*10^{-3}$
Bronchodilator use, children (BDUC)	7810	8680	7278	1	1	$995*10^{-3}$
Bronchodilator use, adults (BDUA)	58904	65473	54892			
Cough, children (COUC)	26982	29991	25145	3	3	2
Cough, adults (COUA)	60637	67399	56506			
Lower respiratory symptoms, children (LRSC)	10413	11574	9704	$291*10^{-3}$	$323*10^{-3}$	$271*10^{-3}$
Lower respiratory symptoms, adults (LRSA)	21873	24312	20383			
Acute mortality (AY)	50	52	51	77	80	78
Chronic mortality (YOLL)	2989	3322	2785	$172*10^{-3}$	191	160
Infant mortality (IM)	0	0	0	$606*10^{-3}$	$674*10^{-3}$	$565*10^{-3}$
Premature death (PD)	**282**	**313**	**263**			

CONCLUSIONS

Several experiments were done to simulate the models. In this research it is possible to see that there is a correlation between the models and the observations. From the plots it is possible to see that there is the same trend of the UBM and DEHM model with the observations. The final results of this work, obtained from the EVA model, suggest that the $PM_{2,5}$ contributes significantly to health impacts and related external costs, while the O_3 contribution is also significant. The main contributor of PD is residential and commercial emissions. This sector is also the highest contributor to the health related external cost. This is because this kind of emission include the highest concentration of all three pollution (O_3, CO and $PM_{2,5}$). 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.

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