HEALTH IMPACTS OF $PM_{2.5}$ AND NO_2 SHIP-RELATED AIR POLLUTION IN MATOSINHOS MUNICIPALITY, PORTUGAL

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ABSTRACT

Air pollution is considered the most significant environmental risk to health, causing substantial economic consequences. International maritime traffic has been identified as a major air pollution source, emitting nitrogen oxides (NO_x), sulphur oxides (SO_x) and particulate matter (PM). Thus, this work aimed to study the local health impacts of $PM_{2.5}$ and NO_2 ship-related air pollution in Matosinhos municipality, where Leixões port is located (one of the major ports in Portugal), in 2014. Hourly shipping emissions were obtained using STEAM model with a resolution of 250 × 250 m for a 50 × 50 km domain. The contributions of $PM_{2.5}$ and NO_2 concentrations in Matosinhos were modelled using the AERMOD model. The annual mean background concentrations of $PM_{2.5}$ and NO_2 were acquired from the fixed monitoring stations of the QualAr network. Log-linear functions based on WHO-HRAPIE relative risks (RR) for $PM_{2.5}$ and NO_2 all-cause natural mortality were used to calculate the excess of premature deaths. The costs associated with the health impacts were estimated as the product of the additional premature deaths and the value of statistical life (VSL). It was estimated that shipping emissions caused 15 additional deaths (95% CI 19–21), corresponding to 29 million € (95% CI 17–40) for the Matosinhos municipality in 2014. These results show that shipping emissions are an environmental concern that affects the Matosinhos municipality population.

Keywords: local impacts, shipping emissions, atmospheric modelling, health effects, monetary valuation.

1 INTRODUCTION

Ship engines have been recognised as a significant source of pollutants, mainly nitrogen oxides (NO_x), sulphur oxides (SO_x) and particulate matter (PM) and associated with environmental, health, economic and climatic impacts [1]–[3]. In the last decades due to new and more restrictive climate and air pollution policies, the emissions of NO_x, SO_x and fine particulate matter of the main land-based sources (traffic, industrial processes and power generation) decreased considerably in Europe. [4], [5]. Oppositely, for shipping only in recent years the technical and legislative control measures became more restrictive and to be released more often. Among the most recent measures, it is important to highlight the CAP2020 sulphur limit, the creation of new Nitrogen Emission Control Areas (NECAs) and the open debate to control black carbon (BC) emissions, especially in the arctic regions [6], [7]. Moreover, the European Union, in cooperation with the International Maritime Organization (IMO), has been establishing with the shipping industry an ambitious objective of reducing greenhouse gases, sulphur oxides and nitrogen oxides emissions and trying a "zero-waste, zero-emission" approach for maritime transport [8]. Despite this, it remains essential to study the health effects of shipping emissions and measure these effects in monetary terms. In the last years, the associated health effects have been almost exclusively reported for regional and global scales [1]–[3], [9]. In these regional and global scale studies, authors concluded that the most affected areas were the coastal ones and those close to

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maritime ports. Many case studies, where other anthropogenic emissions were considered, demonstrate the dominant influence of shipping emissions on the air quality of port cities. Using high-resolution local models is fundamental to analyse the air quality in more detail and make decisions at the local level to reduce the impacts caused by shipping emissions in port cities. To contribute to increase the study of the impacts of shipping emissions on human health in Portugal, because as far as known these studies are still scarce in Portugal, this study aimed to reduce this gap by estimating the local health impacts of $PM_{2.5}$ and NO_2 ship-related air pollution in Matosinhos municipality in 2014.

2 MATERIALS AND METHODS

2.1 Ship emissions inventory

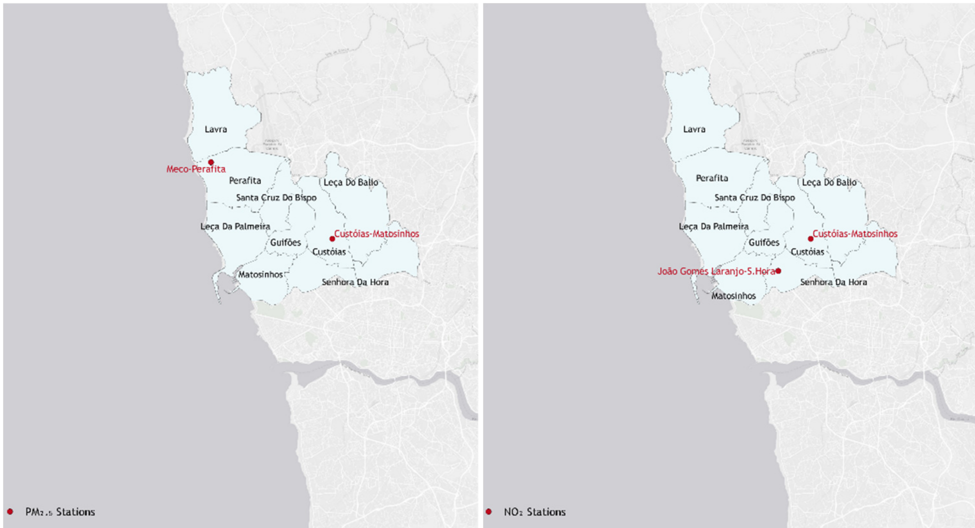
The hourly shipping emissions for 2014 were obtained using the Ship Traffic Emission Assessment Model (STEAM) with a resolution of 250 × 250 m for a domain with 50 × 50 km. Shipping emissions were estimated based on the messages reported by the Automatic Identification System (AIS), both terrestrial and satellite-based, which allows to know the position of each ship and on the technical characteristics of each ship (ship type, size, machinery type, operative mode and emission factors). STEAM considers these parameters and estimates the emissions based on water resistance calculations, predicting the main and auxiliary engines power and loads, as well as the fuel consumption of each ship [10].

2.2 Dispersion model approach

Atmospheric simulations have been performed with the AERMOD Modelling System for a domain of 50 × 50 km. AERMOD is steady-state, multiple sources, Gaussian dispersion model designed for short-range (up to 50 km) dispersion of air pollutant emissions. The AERMAP pre-processor was used to determine source and receptor heights using Shuttle Radar Topography Mission Global Coverage (~90 m) terrain elevation data [11]. Onsite hourly meteorological data was generated using Weather Research and Forecasting (WRF) model for 2014 with a resolution of 1 × 1 km [12]. The NO_x emissions from the emission input data were converted into NO_2 concentrations using the Ambient Ratio Method 2 based on ambient NO_2 and NO_x monitoring data from EPA's Air Quality System for a 10 year period (2001–2010) [13].

2.3 Background concentrations

Hourly concentrations of PM_{10} and NO_2 for the Matosinhos municipality were obtained from the QualAr Monitoring Network operated by the Environmental Portuguese Agency [14]. Fig. 1 shows the location of the background $PM_{2.5}$ and NO_2 air quality stations considered in the present study. According to the available data, two stations were considered with data for PM_{10} and two for NO_2. As there were no available data for $PM_{2.5}$ (pollutant considered for the assessment of the health effects), a conversion factor of PM_{10} to $PM_{2.5}$ was applied. A country specific conversion factor for Portugal was estimated as the mean ratio of $PM_{2.5}$ to PM_{10} of the country all stations for 2014 and applied for Matosinhos municipality. This ratio was calculated based on the methodology used in the WHO Ambient air pollution database [15]. After the conversion, annual average concentrations of $PM_{2.5}$ and NO_2 were calculated and assigned to each parish, applying the inverse distance weighting method.



(a) (b)

Figure 1: Location of the background. (a) $PM_{2.5}$ air quality stations in the Matosinhos municipality (red dot); and (b) NO_2 air quality stations in the Matosinhos municipality (red dot).

2.4 Health impact assessment

The ship-related health impacts were evaluated based on two scenarios: (i) the baseline scenario (B-SCN) considering the background concentrations; and (ii) a non-shipping scenario (WTS-SCN) resulting of the difference between the background concentrations and the ship-related concentrations performed with AERMOD model, not considering the shipping emissions contributions.

The influence of shipping emissions on health was assessed comparing the differences between the B-SCN and WTS-SCN scenarios.

To assess the additional premature deaths attributable to $PM_{2.5}$ and NO_2 ship-related air pollution, relative risks (RR) were estimated using the log-linear functions derived from available epidemiologic studies, using the following expression [16]–[18]:

$$RR_{log-linear} = e^{\beta(C-C_0)}, \tag{1}$$

where C is the $PM_{2.5}$ or NO_2 concentrations (µg m^{-3}), C_0 is the endpoint-specific theoretical minimum-risk concentration, i.e. the concentration below which there are no additional health risks (No theoretical minimum-risk concentration was considered) and β-coefficient relates the change in the RR to an increase of the risk per 10 µg m^{-3}.

The attributable fractions (AF) were calculated following the attributable risk as:

$$AF = (RR - 1)/RR. \tag{2}$$

The excess burden of disease (EBD) was calculated as the increment in the number of deaths due to $PM_{2.5}$ and NO_2 ship-related air pollution in 2014, eqn (3):

$$\Delta EBDs = BI \times AF \times Pop, \tag{3}$$

where BI is the baseline incidence of the selected health endpoint for a given population and Pop is the population within the age group of interest. Population data by age (one year intervals) for Matosinhos at local administrative level (LAU) 2 level were obtained from ESS [19].

All-cause mortality for adults over 30 years' baseline rate and the population for each age group with intervals of four years until 85+ years were calculated using the number of deaths for Matosinhos in 2014 from the National Statistical System of Portugal [20]. The health endpoints and RR used in the present study are listed in Table 1.

Table 1: Health endpoints and relative risk used in the present study.

Pollutant	Health endpoints	Group of interest	Relative risk (95% CI)
$PM_{2.5}$	All-cause mortality	Adults (age ≥ 30 years)	1.062 (1.040–1.083)
NO_2			1.0027 (1.0016–1.0038)

2.5 Assessment of socio-economic external costs of the burden of disease

External socio-economic costs of the burden of disease were calculated with the results of the additional deaths for the two scenarios previously mentioned.

Unit health costs (cost per death) were used to estimate the economic value of the burden of disease. The exposure cost of the additional deaths was calculated as the product of the exposure-response function (ERF) and its unit health cost according to eqn (4)

$$Exposure\ cost = (ERF) \times (Cost\ per\ death). \tag{4}$$

The value of statistical life (VSL) was used to calculate the cost of the additional premature deaths [21]. The specific VSL, which is how much society is willing to pay to avoid an anonymous death, for Portugal for 2015 were taken from the Health Economic Assessment Tools (HEAT), and following the benefit transfer approach, the value was adjusted for 2014 considering the income growth and price inflation as recommended in OECD [22], [23]. VSL was adjusted according to eqn (5)

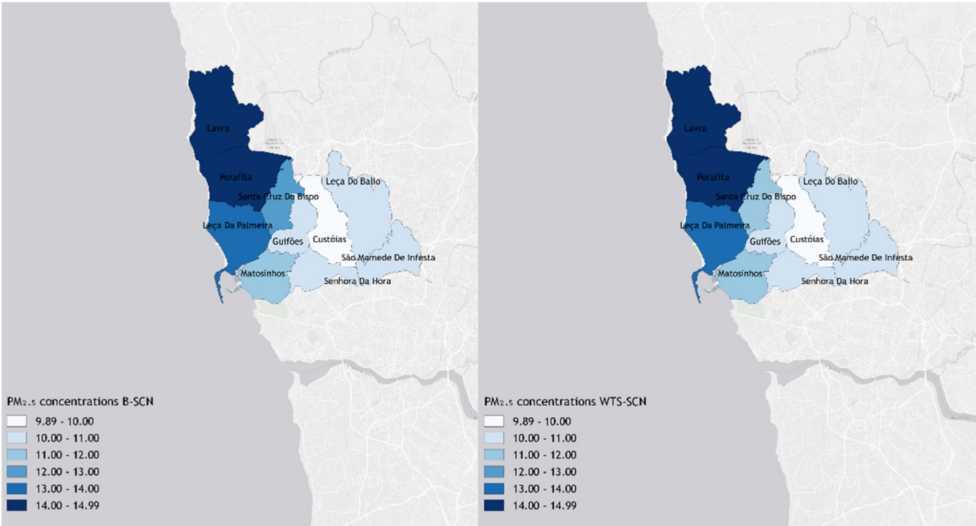
$$VSL\ PT\ 2014 = VSL\ PT\ 2015 \times (1 + \Delta P + \Delta Y)^{\beta}, \tag{5}$$

where: $VSL\ PT$ 2015 is the VSL for Portugal in 2015 obtained from HEAT; β is the income elasticity of VSL (the value of 0.8 was used as recommended by OECD); ΔP is the increase in consumer price from the year 2015 to 2014; and ΔY is the real change in real GDP per capita growth from the year 2015 to 2014. All values previously described were obtained from OECD [24]. The VSL used in the present study was 1.87 million €/death.

3 RESULTS AND DISCUSSION

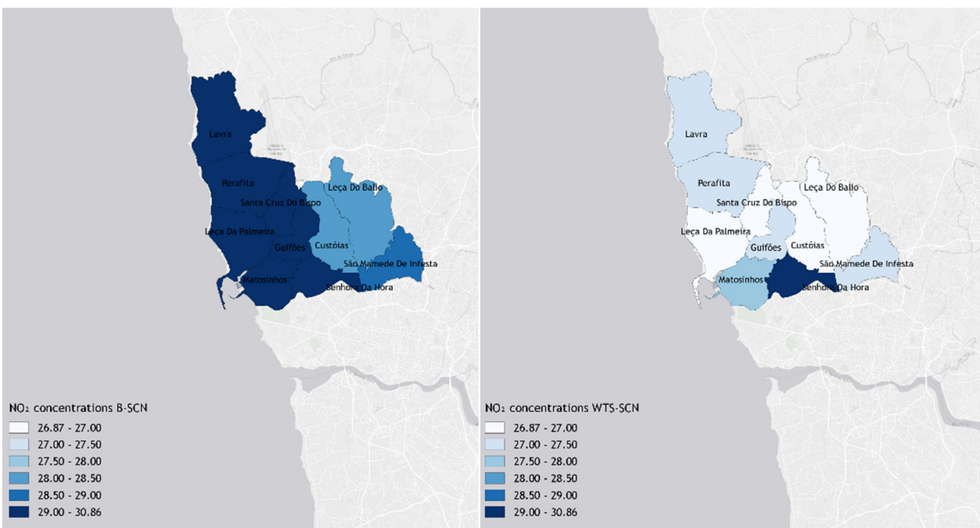
Figs 2 and 3 show the $PM_{2.5}$ and NO_2 concentrations respectively, for the B-SCN and WTS-SCN scenarios.

Table 2 shows the additional premature deaths associated with exposure to $PM_{2.5}$ and NO_2 ship-related air pollution for 2014 in Matosinhos municipality, as well as the external costs. It was estimated that shipping emissions caused 15 deaths (95% CI 19–21), which corresponded to 11% of premature deaths in Matosinhos municipality in 2014. Fig. 4 shows the spatial distribution of premature deaths associated with the exposure to $PM_{2.5}$ and NO_2 ship-related air pollution for 2014 in Matosinhos municipality. As can be seen, most mortality occurred in the parishes of Matosinhos (with the same name of the municipality) close to



(a) (b)

Figure 2: $PM_{2.5}$ concentrations (at LAU2 level) for (a) the baseline scenario (B-SCN); and (b) the non-shipping scenario (WTS-SCN).



(a) (b)

Figure 3: NO_2 concentrations (at LAU2 level) for (a) the baseline scenario (B-SCN); and (b) the non-shipping scenario (WTS-SCN).

Leixões Port. These results appeared to be associated to a greater predisposition of this zone to shipping emissions (close to the port and coastline) and because these areas are densely populated. Regarding exposure costs, it was estimated a cost of 29 M€ (95% CI: 17 M€–40

M€) related to the additional deaths from $PM_{2.5}$ and NO_2 ship-related concentrations. Considering the Matosinhos city council budget for 2014, the costs calculated in the present study would represent almost a quarter of the total [25].

Table 2: Deaths and external costs related to shipping emissions in Matosinhos for 2014.

Health endpoint	Risk group	Deaths (95% CI)	External costs (95% CI)
All-cause mortality	Adults (age ≥ 30 years)	15 (9–21)	29 (17–40) M€

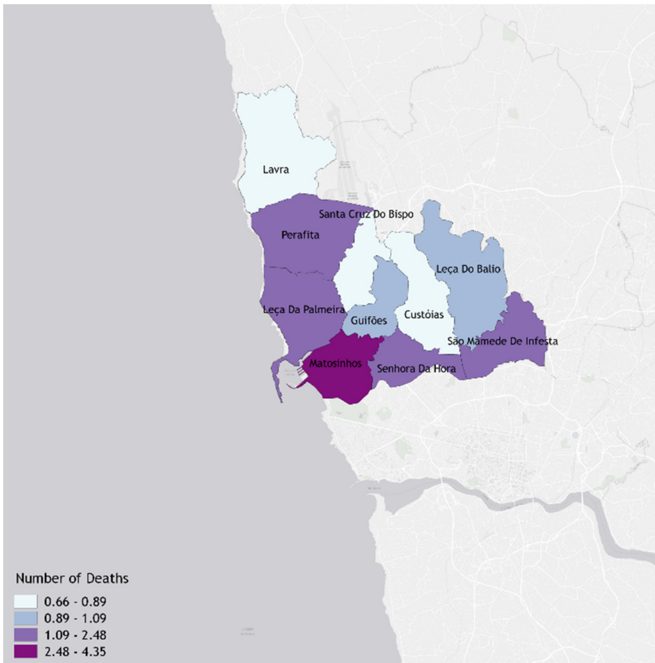


Figure 4: Spatial distribution (at parish level) of the number of premature deaths due to all causes associated with $PM_{2.5}$ and NO_2 ship-related air pollution in the Matosinhos municipality.

The results presented above demonstrate that Matosinhos municipality seems to be significantly affected by $PM_{2.5}$ and NO_2 ship-related air pollution, mainly by the proximity of the Leixões port with high shipping activity to highly populated areas.

4 CONCLUSIONS

In this study, local impacts of $PM_{2.5}$ and NO_2 ship-related air pollution in Matosinhos municipality for 2014 were assessed. Fifteen deaths (95% CI 19–21) related to shipping emissions were estimated, which corresponded to a cost of 29 M€ (95% CI: 17 M€–40 M€). Results show that the number of deaths reported in the present study represented 11% of premature deaths of the Matosinhos municipality and almost a quarter of the total Matosinhos city council budget for 2014. Most mortality occurred close to Leixões Port, which appeared to be associated to a greater predisposition of this zone to shipping emissions and residential densely populated areas close to the port. These findings contribute to understanding the local health impacts in the municipality of Matosinhos, highlighting the impact of the Leixões port presence close to highly populated areas. Moreover, the results could be used in the future to study mitigation measures to reduce shipping emissions contributions mainly close to the port area of Leixões. In the future the study of other major ports of Portugal and health endpoints should consider.

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