Journal of Applied Science and Environmental Studies
JASES
http://revues.imist.ma/index.php?journal=jases

USING EMISSIONS OF PRECURSOR POLLUTANTS BY SHIPS IN DIFFERENT REGIONS TO CALCULATE YEARLY MORTALITY ATTRIBUTABLE TO MARITIME TRANSPORT: CASE FOR THE IMO TO DESIGNATE THE STRAIT OF GIBRALTAR AN ECA ZONE

H. ABIDA[1], J. MORENO-GUTIÉRREZ[1]

[1] College of Marine Nautical and Radio-electronics Engineering, University of Cádiz. Campus de Excelencia international del Mar.

* Corresponding author. E-mail address: juan.moreno@uca.es, hajar.abida@alum.uca.es

Received 12 December 2020; Revised 18 October 2021, Accepted 25 November 2021

Keywords
Shipping emissions, deaths from pollutants, greenhouse gases, Strait of Gibraltar.

Abstract
Emissions of exhaust gases from oceangoing ships are a significant and growing contributor to the total emissions from the transportation sector. Emissions by shipping, comprising both "greenhouse gases" and traditional pollutants, cause an estimated 87,000 deaths per year from lung-cancer, cardiopulmonary and other diseases, worldwide. In order to reduce air pollution from ships, the International Maritime Organization has officially designated certain zones as Emission Control Areas (ECAs). In this study, we estimate health impacts attributable to NO_x, SO_x and particulate matter ($PM_{2.5}$), emitted by shipping in the Strait of Gibraltar. This contamination causes many deaths that could potentially be prevented if the Strait were designated an ECA. In this case, the models devised by Krewski and Lepeule were applied. Both models use a direct relationship between mortality and the precursor pollutants, in tons, emitted from ships. Data for other areas are analysed for comparison. Comparing only the emissions by ships operating in the Strait of Gibraltar with the yearly total emissions from all sources in Europe, up to 0.81% of all NOx, 3.96% of all $PM_{2.5}$ and 0.51% of all SOx is emitted in the Strait of Gibraltar. Because these shipping lanes run at an average distance of only 13 km from the coast, the effects of pollutants on the resident population are almost immediate. To mitigate the adverse environmental and health outcomes from ship-sourced air pollution, and potentially to reduce premature deaths by 45%, it is recommended that the Strait of Gibraltar be designated an ECA by the IMO.

1. Introduction

The powering of maritime and land-based means of transport by the inefficient combustion of coal, oil, diesel and other fuels is a major contributor to air pollution and climate change emissions which ultimately can affect human health and environmental quality, and thus jeopardize global sustainability in the widest sense. Health impact assessments need to be an integral part of the design and implementation of global energy policies.

According to a recent assessment by the World Health Organization (WHO), whereas the deaths of around 6 million people each year are attributed to tobacco, approximately 4.3 million deaths per year can be attributed to air pollution [1]. In this latter context, the South East Asian and Western Pacific regions account for most of the total, with 1.69 and 1.62 million deaths, respectively. Almost 600,000 deaths occur in Africa, 200,000 in the Eastern Mediterranean region, 99,000 in Europe and 81,000 in the Americas; exposures are highest in and around developing cities [2].

The maritime transport sector, which is one of the least-regulated anthropogenic sources of emissions, contributes significantly to air pollution, particularly in coastal areas near major ports. In this sector, was estimated [3] that particulate matter ($PM_{2.5}$) emissions from maritime transport (MT) cause 60,000 cardiopulmonary and lung-cancer deaths yearly worldwide. More recently, was, estimated [4] that this global figure had increased to 87,000 deaths per year. Similarly, in a recent study [5] was estimated that MT emissions accounted for 3,500 premature deaths from $PM_{2.5}$ and O_3 across the USA in 2013. Another recent US study [6] estimated that emissions of $PM_{2.5}$ by the MT sector were associated with a health risk of 520-1,200 premature deaths per year. European Union [7] estimated that 1,000 premature deaths per year are attributable to MT emissions. In the East Asia region [8] was estimated that MT emissions cause 14,500-37,500 premature deaths per year. Finally, for Australia [9] was estimated that MT emissions were responsible for 90-300 premature deaths per year.

Pollution from ships is thus a significant contributor to global air pollution; this occurs not only in ports and along coastlines - pollution is also carried long distances across the sea and over land. Direct emissions from ships (known as precursor pollutants) are mainly constituted by CO_2, NO_x, SO_X, CO and PM.

Many factors can influence air quality in port cities and coastal areas, including geography and climate, road, rail and maritime traffic, industrial and residential emissions, but very little is known about the magnitude and effects of air pollution due to marine vessels [10].

It is known that SOx emissions, together with NOx, exacerbate secondary formation of fine particulate matter, $PM_{2.5}$ [11]. NOx emissions from diesel engines also contribute to increasing ozone (O_3) regionally. All of these emitted and generated compounds represent a major threat not only to human health but they will also be deposited onto soils and water bodies to which the organisms living in those compartments are exposed. Apart from the scarcity of research of the contribution of oceangoing ships to air pollution, and the associated effects on human health, the environmental toxicology of this kind of pollution has been completely neglected to date. Hence, reductions of the various combinations of emissions that could influence public health are necessary. Moreover, these emissions are known to be related particularly closely to both mortality and morbidity in young children, and to the respiratory infections and asthma that affect them [2]. However, to our knowledge, the effects of these emissions on ecosystems and the organisms living in them have never been assessed. Pollutant-specific, location-specific, and source-specific models of health impacts are important and must be considered in the design of policies for the control of emissions to minimize health-risk; this has been demonstrated [12].

Breathing air with a high concentration of NO_2 can irritate airways in the human respiratory system. Such exposures, even over short periods, can aggravate respiratory diseases, particularly asthma, leading to respiratory symptoms (such as coughing, wheezing or difficulty breathing), hospital admissions and visits to emergency departments. Longer exposures to elevated concentrations of

NO_2 may contribute to the development of asthma and potentially increase susceptibility to respiratory infections. NO_2, together with other NO_x gases, reacts with other chemicals in the air to form both particulate matter and ozone. Both of these are also harmful when inhaled due to effects on the respiratory system. On April 6, 2018, based on a review of the full body of scientific evidence, the US EPA issued a decision to retain the current national ambient air quality standards (NAAQS) for oxides of nitrogen (NOx). The EPA has concluded that the current NAAQS protect the public health, including the at-risk populations of older adults, children and people with asthma, with an adequate margin of safety. NO_x in the atmosphere also contributes to the pollution of nutrients vital for marine life in coastal waters [13].
Cleaner marine fuels with low sulphur content will reduce ship-related premature mortality and morbidity by 34% and 54%, respectively, representing global reductions of about 2.6% in cardiovascular and lung cancer deaths and about 3.6% in childhood asthma, due to exposure to $PM_{2.5}$ [14].
In order to prevent and reduce the adverse impacts of air pollution from ships on human health, the International Maritime Organization (IMO) has adopted environmental regulations under the International Convention for the Prevention of Pollution from Ships (Annex VI MARPOL Protocol 1997, Marine Environment Protection Committee, MEPC). These regulations establish special Emission Control Areas (ECAs) that have been legally binding since May 2005, in areas that can demonstrate a need for prevention; in these designated areas emissions of oxides of nitrogen and sulphur, and particulate matter, are controlled and reduced.
The first ECA to come into effect was in the Baltic Sea in 2006, and in 2007 the North Sea was another. The east and west coasts of the United States and Canada, the Hawaiian Islands, and areas around the United States' Puerto Rico and Virgin Islands territories were also designated as ECAs by the IMO in 2012. Subsequently, the IMO has strengthened regulations both in ECAs and globally in non-ECA areas.
Outside ECAs, the current limit for fuel oil sulphur content by weight is 3.50%, and should be reduced to 0.50% on and after January 1, 2020. However, this date is subject to a review to be completed by 2018, which will consider the availability of the required fuel oil; depending on the review's outcome, this date could be delayed to January 1, 2025. In contrast the limit for sulphur content of fuel used in an ECA has been reduced in phases, and since January 1, 2015, has been 0.1%. Therefore, ships operating in an ECA must comply with regulations regarding the sulphur content their on board fuel that are 35 times more stringent than outside an ECA.
The regulation includes a global cap of sulphur fuel content (SFC) and contains provisions allowing for the establishment of special SO_2 and NO_x emission control areas (ECAs), i.e., a SECA (for Sulphur) and a NECA (for Nitrogen Oxide). Only the Baltic Sea, the North Sea, English Channel and the coastal waters around the US and Canada are designated as SECAs, for both gases, with the North American area as a NECA only. The U.S. government proposes to amend MARPOL Annex VI to designate certain waters adjacent to the coasts of the Commonwealth of Puerto Rico and the United States Virgin Islands, as a full ECA for the control of nitrogen oxides (NO_X), sulphur oxides (SO_X), and particulate matter (PM) emissions, the same as the Baltic Sea, the North Sea, English Channel and the coastal waters around the US and Canada.
Because these emissions are known to be particularly closely associated with both mortality and morbidity, and respiratory infections and asthma in young children (WHO, 2012), pollutant-specific, location-specific, and source-specific models of health impacts must be taken into account in the design of control policies to minimize health-risk emissions [12].
It is important that three new emission control areas are being established in China. They have been created to reduce the levels of ship-generated air pollution and mainly focus on the sulphur content of fuels. These areas are the Pearl River Delta, the Yangtze River Delta and Bohai Bay. It should be noted that these ECAs will be imposed under Chinese domestic law and will not be MARPOL Annex VI-designated ECAs. Details of these areas were first announced when the *"Ship and Port*

Pollution Prevention Special Action Plan (2015-2020)" was issued by the Chinese Ministry of Transport; this was followed by the implementation plan, released in December 2015.
The new Chinese regulations apply to all vessels entering or operating within the designated areas, with the exception of military, pleasure craft and fishing vessels, according to the following schedule:

- From 1 January 2017**:** Vessels at berth in a core port within an emission control area should use fuel with a maximum sulphur content of 0.5% - except during the first hour after arrival and the last hour before departure.
- From 1 January 2018: Vessels at berth in any port within an emission control area should use fuel with a maximum sulphur content of 0.5% - except during the first hour after arrival and the last hour before departure.
- From 1 January 2019: Vessels operating anywhere within an emission control area should use fuel with a maximum sulphur content of 0.5% at all times.

At a date which has yet to be advised after 31 December 2019 an assessment will be made by the Chinese authorities with a view to adopting one or more of the following measures:

- Reducing the maximum sulphur content to 0.1% for vessels operating in the ECA areas.
- Expansion of the geographical size of the ECA areas.
- Consideration of further initiatives.

IMO members have been reminded that, as of 1 January 2018, the requirement to use low sulphur fuel whilst visiting all ports within the Chinese ECAs is in force. **Low sulphur requirements in all ports within the previously-designated Zhejiang ECA, which** includes the ports of Ningbo, Zhoushan, Jiaxing and Taizhou, **came into force 1 September 2017.**
In Europe, the maximum sulphur content of the marine fuel used by ships operating in the sulphur emission control areas (SECAs) is restricted to 0.1% since January 2015; however, the EU sulphur directive has limited the sulphur content to 0.1% in harbour areas since January 2010. There are no NECAs in Europe yet.
Based on other studies, Johansson et al. report that, from 2009 to 2011, the emission limitations have had a significant effect on reducing the emissions of SOx measured in the ECAs in northern Europe. In contrast [15], report that sulphur emissions in sea areas outside the SECAs, and emissions of other species (especially NOx), in all sea areas around Europe have been increasing over the past few decades, while land-based emissions have been gradually decreasing.
Similarly, Volker Matthias et al., 2010, reported that sulphur emissions (low sulphur) in the North and Baltic Seas were reduced by 45% after these areas were designated ECAs.
If NECAs and SECAs were extended to all the EU's Exclusive Economic Zones, then health effects (from fine particles and ozone) would decrease by one third; and the area of marine ecosystems affected by acidification and eutrophication would be reduced by about 45% [16].
The benefits of designating the U.S. and Canadian waters an ECA are expected to include the prevention of as many as 14,000 premature deaths and the relief of respiratory symptoms for nearly five million people each year [17]. In addition to the determination of total premature mortalities, health damage functions (estimated as premature mortalities per unit of emissions) can be calculated to provide insight about sources and locations in which emissions reductions may be more or less efficient from a public health perspective [12].
Set against the benefits, however, ECA regulations can harm port efficiency, as reflected in the concerns expressed by policy-makers and industrial managers: it has been estimated that the average efficiency loss from an ECA designation amounts to 0.058–0.066 on a scale of 0–1, accounting for a 15–18% loss from the ECA ports' average efficiency scores [18]
The key question emerging from these considerations is how cruise shipping, ports and the related economic chain can operate efficiently, within a socially responsible and acceptable framework. The various environmental externalities refer to the handling of waste produced, water quality, air

emissions, noise, and soil contamination, whereas other issues (i.e. constructions that alter the natural or built environment, fauna, energy resources, etc.) are also part of the relevant agendas.
Addressing two key externalities produced by the provision of cruise shipping and the hosting of vessels and cruise passengers at cruise ports stand out today as priorities. The same externalities are illustrative of the need for discussion and conclusions on measures to be taken at international level. These externalities are waste management, and the various forms of emissions, including air and noise emissions. Air emissions in and near ports and other shipping-related emissions have attracted the serious interest of decision-makers in port-cities that experience the negative externalities of port and port-related operations. Without countermeasures, emissions of SOx and NOx by the shipping industry would exceed all other sources of emission in the transport sector, and would result in poor air quality in ports and their surroundings.
When emissions from shipping account for up to 50% of local emissions at seaport cities, the application of technology that already exists would decrease these emissions notably.
Cruise shipping is a source of relatively heavy emissions, due to the large hoteling load. Even though the average emissions in port account for comparatively small amounts, the fact that cruise terminals are often close to city centres means that the size of the population exposed to the polluted air is likely to be large.
There are over 51,405 merchant ships operating internationally, transporting every kind of cargo and passengers. Approximately 2,850 (i.e. 5.7%) are fast ferries propelled by waterjet; however, the emissions from ships of this type are not proportional. For example, although passenger and RoPax vessels only accounted for approximately 5% of the ships operating in the Baltic Sea in 2007, they were responsible for approximately 27% of all the emissions to air. Similarly, 4.7% of ships operating In the Strait of Gibraltar during 2007 were Fast Ferries [19]. It can therefore be stated that more than 27% of total emissions from maritime transport operations are now generated by Passenger and RoPax ship operations
In this study, we quantify premature mortalities from ships for each emitted pollutant across the Strait of Gibraltar and estimate the benefit per ton of reducing $PM_{2.5}$, NO_x and SO_x, based on the Technical Support Document issued by the U.S. EPA in 2011. This work presents an analysis that quantifies the deaths per year by applying different methods, and demonstrates the regional health benefits to be expected from the IMO designating the Strait of Gibraltar an ECA.

2. Methods

The primary objective of the study is to determine the optimum way to define the impact of ship emissions on urban air quality and human health in a particular region of heavy maritime traffic, the Strait of Gibraltar. The study uses a traditional framework for integrated impact assessment, as presented in Fig. 1.
In the case of MT, such assessments are based on air quality dispersion models in which the amounts of primary pollutants (CO_2, NO_x, SO_X, CO and PM) that are emitted directly into the atmosphere are calculated by a bottom-up approach (inventories compiled from ship activity records and activity-based emission factors for different ship types); these data serve as main input for the models [20].
We compiled shipping emissions inventories on the basis of 2015 data on shipping traffic obtained from the Automatic Identification System (AIS), which recorded 82,000 individual ship movements for the year along and across the Strait of Gibraltar.
In order to calculate the effects of emissions resulting from these movements, various air quality dispersion models are used. Examples of these models include ISCT3 and AERMOD v.5.2 [21], SMOKE [22], CMAQ-DDM and SILAM: a System for Integrated modeling of Atmospheric coposition [23].
These types of models use mathematical and numerical techniques to simulate the physical and chemical processes that affect air pollutants as they disperse and react in the atmosphere. Based on

inputs of meteorological data, (relative/real wind speed and direction, temperature, air pressure, relative humidity and water vapour mixing ratio, including clouds) and source information like emission rates and stack height, these models are designed to characterize primary pollutants that are emitted directly into the atmosphere from anthropogenic sources (from ships in this case). Some models also consider secondary pollutants that are formed as a result of complex chemical reactions within the atmosphere [17]. The problem is that both air quality models and ships´ emission inventories present many uncertainties.

An extensive epidemiology literature has also documented the association of fine particulate air pollution with mortality. Most of this research consists of time-series studies of the effects of particle exposures experienced over a relatively few days before death, but the estimated effect of particulate air pollution has been shown to increase as longer exposure periods (up to 7 weeks) are considered, indicating that exposures in the months before death may be important. Three follow-up cohort studies in the United States and a recent pilot study from Europe evaluated the effects of long-term average ambient concentrations of fine particles and other air pollutants over many years [24].

With respect to the operation of these models, they entail significant sources of errors from imprecisions in measurement; this is, for example, the case of $PM_{2.5}$ in epidemiological studies, as noted above [20]. Exposure assessment thus depends strongly on the accuracy of the emissions inventory and on the outcomes of the air quality model where a chemical transport model is included [10].

Spain has a very intense maritime traffic along its Mediterranean coast, especially in the Strait of Gibraltar (the North-western and Northern coasts are also subject to considerable traffic, including vessels on North Atlantic routes). The emission of NOx, SOx and PM from international shipping close to the Spanish coast is 10 times higher than from national shipping and much higher than emissions from aviation. In this study the model we apply is a recently preferred concentration–response (C–R) function by [25], in the Strait of Gibraltar. The linear C–R function reflects new understanding about the relationship between health impacts and exposure to increased air pollution concentrations and better describes the range of exposures to global shipping pollution across a long-tailed distribution of $PM_{2.5}$ concentrations.

The production of an emissions inventory is very important, but the production of an emissions inventory for each individual ship that is identified in the movements record is a much-debated issue; several contradictory papers have been published during the last 10 years reporting results following the application of emissions inventories in different areas. Other results published [26], confirm that the estimation problem is still a topic that is worth investigating because there are still no unified criteria for the methods to use (involving calculations of engine load factors, ship´s speed, specific fuel oil consumption, emissions factors, etc.). However, in the appraisal of possible strategies for the reduction of damage to the environment caused by the maritime transportation sector, it is crucial to know the total amount of emissions attributable to shipping activities, and the evolution of these data [27].

The issue of speed, for example, is especially complex for RoPax vessels (the type of ship that operates frequently in the Strait of Gibraltar), more than for other categories of ship. It is also evident that slow steaming in the RoRo/RoPax vessel category has received little attention from emissions researchers, compared to other segments of shipping industry operations [19]. This complex issue has not been taken into account by other autors[14], who have calculated global ship emissions using the Ship Traffic Emissions Assessment Model (STEAM). That model does not take into account significant parameters such as ship´s draught, sea current, speed and wind direction, and others. It is evident that debate on this issue is still on-going. Because we apply a direct relationship between pollutants emitted and mortality produced, it is very important to know the types and quantities of pollutants actually emitted as precisely as possible for this type of study.

On the question of producing reliable emission inventories, the selection of the most appropriate method for calculating fuel consumption data and emission factors has been studied recently in the

Strait of Gibraltar [28], 2015, but that study did not include estimates of the impacts on human health of specific pollutants emitted, NO_x, SO_x and $PM_{2.5}$.

Health impacts of global shipping. Whereas the WHO in 2013 considered that the relationship between PM emitted as primary pollutant and deaths produced should be expressed as a supra-linear function, other authors [30, 12, 31 and 25] take this relationship as a linear function.
However, the WHO only considers the ratio between the concentration of PM_{10} (not emitted as primary pollutant) and daily mortality. For example, for PM_{10} an increase in concentration of 10 $\mu g/m^3$ is associated with a 0.6% increase in daily mortality for both the USA and the EU, and 0.7% for Canada. Other researchers [12] have estimated the concentration-response function to be a 1% increase in mortality associated with every 1 $\mu g/m^3$ increase in the annual average concentration of $PM_{2.5}$.
In the case of shipping, it is very important to take into account the emissions of the ship when anchored and at berth; in both situations a reduced quantity of PM is emitted as primary pollutant, compared with when the ship is under way. However, the resulting concentrations in the air are higher [8], because the ship remains for a relatively long time in the same place in port or close to the coast, and its auxiliary engine continues to emit a relatively large quantity of pollutants that are not so widely dispersed. The same argument can be applied for ships when operating close to land, as is the case of the Strait of Gibraltar, compared with when they are operating in the open sea.
On this point, other study [32], studied the impact of emissions on air-quality in Alaska's National Parks, both with and without ship emissions. They concluded that there is a significant effect of ships' emissions on air pollution during the tourist season in the study areas located downwind of the shipping lanes; these areas receive, on average, 75% of the total NOx and SO_2 emitted, and 35% and 10% respectively of the total $PM_{2.5}$ and PM_{10} mass concentrations attributable to shipping.
Recently the US EPA published a regulatory impact analysis of the incidence of avoidable mortalities and morbidities per ton of pollutants (NOx, SO_2 and $PM_{2.5}$) directly emitted as precursor pollutants in 2016 from the ocean-going vessels sector. That analysis utilized data [31 and 25] to determine that the incidence of avoidable mortalities per ton of directly emitted NOx in 2016 from the ocean-going vessels sector was 0.000210 [31] and 0.000490 [25]; for SO_2, the corresponding incidence rate was 0.0014 [31] and 0.0031 [25]; for $PM_{2.5}$ the rate was 0.0052 [31] and 0.012 [25].

3. Results

A summary of all articles and reports reviewed in this paper is given in table 1**.** This table shows the total emissions by ships in the respective ECAs and other areas studied, for each pollutant, in tons per year, and the estimated premature or avoidable deaths per year produced by these emissions. Comparing the deaths attributable to ships´ emissions with the total deaths attributable to all emissions, for the world and the regions studied, shipping accounts for the following proportions: 2% of the total world deaths; between 1.7% and 2.1% of the total US deaths; 2.6% of the EU total; between 0.8% and 3.1% of the East Asia total; and between 0.5% and 10% of the Australia total.
In the case of the Strait of Gibraltar the results are as follows: As proportions of the amounts of each pollutant emitted in the EU, shipping in the Strait accounts for up to 0.81% of NOx; 3.96% of $PM_{2.5}$; and 0.51% of SO_x. Because these shipping lanes are only 13 km from the coast on average, the effects of pollutants on the population are likely to be almost immediate.
Currently emissions from ships are responsible for 10% to 20% of sulphur deposition in coastal areas, and this proportion has been forecast to increase to more than 30% in much of Europe and up to 50 percent in coastal areas, by 2020 [15]. If this is the case for SO_x it can reasonably be assumed that the maritime zones of Europe not controlled as ECAs will suffer substantially increased emissions of NOx and $PM_{2.5}$, as well.

4. Discussion

As a general rule, the highest emissions generally take place along the busiest shipping lanes near the coast. In China, only a few port cities and provinces have begun to pay attention to emissions from ships and port activities. Hong Kong was the first to enforce strictly the use of low-sulphur fuel (500 ppm, or 0.05% sulphur content) by local vessels and will soon be the first in China to require Ocean-Going Vessels to use lower-sulphur marine fuel while docking [33].
In Australia, controls on fuel used within ports and harbours, such as a requirement for ships to use low-sulphur fuel while at berth, could potentially be implemented by state governments but controls on fuel use outside ports would require federal government regulation [30].
Currently in Spain, only the use of low sulphur-content fuels (EU Directive 2005/33/EC) is stipulated for ships operating at Spanish ports but no regulation is applied for ships cruising at sea within Spanish waters, such as the Strait of Gibraltar. This absence of regulation is of particular importance for the Mediterranean Sea, where many ships travelling between, say, the Suez Canal and the Strait of Gibraltar do not enter any EU port. To draw the attention to this situation, a study has been carried out recently to evaluate fuel usage and emissions in the Mediterranean Sea; it has been found that, over the period between 2007 and 2010, fuel consumption had increased in the area by 10%, and the resulting emissions were distributed principally along the Suez Canal-Strait of Gibraltar route [34]. In this situation the increased uncertainty regarding measurement is important because shipping in the Mediterranean Sea is responsible for an estimated 49% of the total European emissions of SO_x by ships; the possibility of proposing the Mediterranean Sea as a future ECA is currently being studied.

In this paper quantitative results from 17 different sources have been analysed and compared with the object of determining the most appropriate model for relating the amount of each main pollutant (NO_x, SO_x and $PM_{2.5}$) emitted by ships – usually expressed in tons weight per year – and the number of premature or avoidable deaths produced. Table 1 combines the data available on amounts of emissions by ships and numbers of deaths per year attributable to those emissions on a global basis and for the main geographical regions that have been studied.
For the world as a whole, it is estimated that 2% (87000 out of 4.3 million) of all deaths per year attributable to emissions of these main pollutants are accounted for by shipping. In the USA region only, this percentage ranges between 1.75% [5] and 2.1% [35]. For the European region, i.e. the 28 members of the EU, considering only international shipping was estimated [7] that 3.5% of total deaths per year due to emissions, i.e. 1000, were produced by shipping. In these cases, applying the relationship proposed by Lepeule to the emissions data is found to be more reasonable than the alternative proposed by another author [31].
For the case of the Sea of Marmara and its two Straits, a study [36] gives a total of 955 deaths per year produced by shipping emissions; this is practically 100% of the total for all of Europe estimated by Campling et al. However, by applying the [31] and [25] methods, the figures for deaths per year are 170 and 681 respectively; these represent 8% and 14% respectively of the total for Europe. In this case also, when the 31 and/or 25 methods are applied, the percentage seems more realistic. The Sea of Marmara is an area that also has very heavy maritime traffic. Since the region around the Marmara is highly urbanized, emissions from ships affect human health, but the overall regulation of the environment and emissions to the air from ships is virtually non-existent. As elsewhere, this situation requires the attention of the local, national and international authorities, to take appropriate action.
For the Mediterranean Sea, the European average value (2.6%) is applied to calculate deaths per year due to shipping emissions. However, applying both 31 and 25 models, the resulting figures are higher. For the case of Australia, the results from all the methods are similar, but for East Asia the results show very large differences.

In the case of Spain there is no equivalent data but by applying the same percentage, 3.5%, as estimated for Europe [7] to the total deaths attributable to these emissions, we obtain a figure of 79 deaths per year caused by shipping. However, from other study [37], 2007, for the Strait of Gibraltar only (as a part of Spain), a figure of 314 deaths per year from shipping emissions was reported; this is 30% of the total for all of Europe. Alternatively, based on emissions data study [28] and applying both [31 and 25 methods], figures of 57 (2.6%) and 130 (5.92%) deaths per year respectively, are obtained.
In this case, when both methods are applied, the percentage seems more realistic. The Strait of Gibraltar, in the extreme south of Spain, is second only to the English Channel among the world's busiest shipping lanes: around 110,000 yearly transits are currently being operated by ships in this channel, which is only 15 km wide at its narrowest, between the African and European continents, that connects the Atlantic Ocean and the Mediterranean Sea. Despite this fact, neither the Spanish Government nor the IMO have taken any action to regulate ship emissions generally in the Mediterranean, particularly in the Strait of Gibraltar where it is clearly most needed. Spain has, however, begun to regulate land-side emissions, through Directive 1999/30/CE, and as long ago as 1999 established that the air is a public good to be protected.
It is hoped that this article serves to call the attention of local, national and international authorities to take action on emissions given the circumstances of this maritime zone that adjoins a Spanish zone with heavy industrial emissions (La Linea and Algeciras). The sum total of harmful emissions from both shipping and industry represent a very considerable health risk to the population.

For the USA, compliance with ECA standards could be expected to result in annual reductions, starting in 2020, of 320,000 tons less of NOx; 90,000 tons less of $PM_{2.5}$; and 920,000 tons less of SOx, i.e. reductions of 23%, 74% and 86% respectively, from levels predicted in the absence of an ECA [38]. If reductions of this scale could be achieved for the high-risk areas identified, the Strait of Gibraltar and Sea of Marmara, they should be designated as ECAs.

5. Conclusions

In this article we have associated the effects of contamination emitted as precursor pollutants with mortalities caused directly. Considering the influence of NO_x on PM formation, it is evident that NO_x emissions have a strong adverse impact on human health, as can be seen when the Krewski and Lepeule models are applied; both methods are based on the pollutants emitted as precursors by ships. For this reason, it is urgent and necessary that, for all maritime countries, ships´ emissions inventories that quantify the actual emissions of NO_x and other pollutants, are produced and published.
The main objective includes *reducing* scientific *uncertainties* in respect of emissions inventories. It is therefore concluded that an agreement is needed on the procedures both for producing emissions inventories and for the air quality model to be used.
It is recommended that the Strait of Gibraltar be designated an ECA zone, to help alleviate the adverse health and environmental outcomes from ship-sourced air pollution. Prior to the future entry into force of the proposed ECA, a change-over to the use of ECA-compliant fuel, for example, fuel oil as defined in MARPOL regulation 14.6, needs to be completed, and vessels need to have on board written procedures for how this is to be undertaken, and to implement those procedures.

Acknowledgments

This work is supported by "La influencia del transporte marítimo sobre la salud humana. Propuesta de un modelo de cálculo de predicción de muertes y hospitalizaciones anuales en la provincia de Cádiz. Consejería de Salud de la Junta de Andalucía. Project Cofinanced by Fondos FEDER. Work

within the project is also supported by the Master Plan for Spanish Ports 2015-EU-TM-0417 OPS,22 co-financed by the Connecting Europe Facility CEF -RET-T EU

References

1. Health Indicators of sustainable energy in the Context of the Rio+20 UN Conference on Sustainable Development Initial findings from a WHO Expert Consultation. **World Health Organization** (2012)
2. Burden of disease from Household Air Pollution for 2012. **World Health Organization** (2014)
3.- J.J.Corbet , J.J.Winebrake, , E.H Green,., Prasad Kasibhatla, , V. Eyring, Axer Lauer. Mortality from Ship Emissions: A Global Assessment. **Environ. Sci. Technol**, 41(2007), (24), pp 8512–8518.
4. J.J.Winebrake, J.J.Corbet, , E.H. Green, ALauer, , V. Eyring,. Mitigating the Health Impacts of Pollution from Oceangoing Shipping: An Assessment of Low-Sulfur Fuel Mandates. **Environ. Sci. Technol**. 43(13) (2009), 4776-4782.
5. F. Caiazzo, A. Ashok, A. Waitz, S.H.L. Yim, S. R.H. Barrett. Air pollution and early deaths in the United States. Part I: Quantifying the impact of major sectors in 2005.**Atmospheric Environment**.79 (2013) 198–208.
6. Estimating the Benefit per Ton of Reducing PM2.5 Precursors from 17 Sectors. **EPA**., 2013
7. P.Campling ,L. Janssen, K. Vanherle, J. Cofala, C. Heyes and Robert Sander.**VITO** (2013).
8. L. Huan , F.Mingliang , J.Xinxin , Y. Shang , S. Drew , G. Faluvegi , C. Shindell, K. He. **Nature Climate change**. (2016). doi:10.1038/nclimate3083.
9. A. Richard, A. Broome E. Martin, B. Cope, B. Goldsworthy, L. Goldsworthy, K. Emmerson, E. Jegasothy, G. Morgan D. The mortality effect of ship-related fine particulate matter in the Sydney greater metropolitan region of NSW, Australia. **Environment International** 87 (2016) 85–93
10. D. Mueller, S. Uibel, M. Takemura, D. Klingelhoefer and D.A. Groneberg. **Journal of Occupational Medicine and Toxicology** (2011). 6:31. http://www.occup-med.com/content/6/1/31
11. D. Cengiz, Y. Durmuşoğlu. Estimating shipping emissions in the region of the Sea of Marmara, Turkey. **Science of the total environment** 390 (2008). 255 – 261.
12. Stefani L. Penn, Saravanan Arunachalam, Matthew Woody, Wendy Heiger-Bernays, Yorghos Tripodis, and Jonathan I. Levy. Estimating State-Specific Contributions to PM2.5- and O3-Related Health Burden from Residential Combustion and Electricity Generating Unit Emissions in the United States. **Environmental Health Perspectives** (2016).125(3)
13. Review of the National Ambient Air Quality Standards for Oxides of Nitrogen, Final Decision. **EPA**, (2018).
14. Mikhail Sofiev, James J. Winebrake, Lasse Johansson, Edward W. Carr, Marje Prank, Joana Soares,Julius Vira, Rostislav Kouznetsov, Jukka-Pekka Jalkanen & James J. Corbett. Cleaner fuels for ships provide public health benefits with climate tradeoffs. **Nature communications**. (2018). DOI: 10.1038/s41467-017-02774-9.

15. Sebnem Aksoyoglu, Urs Baltensperger, and André S. H. Prévôt. Contribution of ship emissions to the concentration and deposition of air pollutants in Europe**. Atmos. Chem. Phys**. 16 (2016). 1895–1906, 2016.
16. A. Markandya, P.Wilkinson. Electricity generation and health. **Lancet**. 370 (2007) (9591):979-90.
17. EPA-420-F10-015. **EPA Office of transportation and Air quality** (2010)
18. Young-Tae Changa, Hyosoo (Kevin) Parkb,2018, Suhyung Leea, Eunsoo Kimc,d. Have Emission Control Areas (ECAs) harmed port efficiency in Europe? **Transportation Research Part D**, 58 (2018) pp-39-53
19. Vanesa Durán-Grados, Javier Mejías, Liliya Musina, Juan Moreno-Gutiérrez, The influence of the waterjet propulsion system on the ships' energy consumption and emissions inventories. **Science of the Total Environment**, 631–632 (2018), pp. 496–509
20. Volker Matthias, Ines Bewersdorff, Armin Aulinger, Markus Quante. The contribution of ship emissions to air pollution in the North Sea regions. **Environmental Polution**, 158 (2010), 2241-2250.
21. AERMOD model. **EPA**-454/R-03-004 ,2004.
22. F. Fung,Z. Zhu,R. Becque, B. Finamore. Prevention and Control of Shipping and Port Air Emissions in China. **Natural Resources Defense Council** (2014).
23. M. Sofiev, J. Vira, R. Kouznetsov, M. Prank, J. Soares, and E. Genikhovich.Construction of the SILAM Eulerian atmospheric dispersion model based on the advection algorithm of Michael Galperin. **Geosci. Model Dev**. 8 (2015), 3497–3522.
24. Francine Laden, Joel Schwartz, Frank E. Speizer, and Douglas W. Dockery. Reduction in Fine Particulate Air Pollution and Mortality. **Am J Respir Crit Care Med**. 15(2006); 173(6): 667–672.
25. Lepeule, J.; F. Laden; D. Dockery; J. Schwartz. Chronic Exposure to Fine Particles and Mortality: An Extended Follow-Up of the Harvard Six Cities Study from 1974 to 2009. **Environmental Health Perspectives**, 120(2012),965-70.
26. Dalsøren SB, Eide MS, Endresen Ø, Mjelde A, Gravir G, Isaksen I. Update on emissions and environmental impacts from the international fleet of ships. **Atmos Chem Phys,**9 (2009),2171e94
27. A. Miola, B. Ciuffo, M. Marra E. Giovine. **JRC European Comission National Environmental Research Institute** (2010)
28. Moreno-Gutiérrez, J. Durán-Grados, C.V. Methodologies for estimating shipping emissions and energetic consumption: A comparative analysis of current methods. **Energy**, 86(2015), 603–616.
29. Outdoor air pollution in cities [online database]. **World Health Organization**. Geneva (http://www.who.int/phe/health_topics/outdoorair/databases/en/index.html).
30. A. Richard, A. Broome E. Martin, B.Cope, B.Goldsworthy, L. Goldsworthy, K. Emmerson, E. Jegasothy, G. Morgand. The mortality effect of ship-related fine particulate matter in the Sydney greater metropolitan region of NSW, Australia. **Environment International** ,87 (2016) 85–93.

31. Krewski D.; M. Jerrett; R.T. Burnett; R. Ma; E. Hughes; Y. Shi. Extended Follow-Up and Spatial Analysis of the American Cancer Society Study Linking Particulate Air Pollution and Mortality. HEI Research Report, 140, Health Effects Institute, Boston, MA (2009).
32. Mölders, N., Porter, S.E., Cahill, C.F., Grell, G.A.Influence of ship emissionson air qualityand input of contaminants in southern Alaska National Parks and Wilderness Areas during 2006 tourist season.. **Atmospheric Environment**, 44 (2010), 1400-1413.
33. S. Kwng, L. Chubin, J.W. M Chan, A. C K Yip, A. K H Lau, J. C H Fung. Institute for the Environment the Hong Kong University of Science & Technology (2012).
34. T. W. P Smith, J. P Jalkanen, B. A Anderson, J. J Corbett, J. Faber, S. Hanayama, E. O'Keeffe, S. Parker, L. Johansson, L. Aldous, C. Raucci, M. Traut, S. Ettinger, D. Nelissen, D. Lee, S. Ng, S.A. Agrawal, J.J. Winebrake, M. Hoen, S. Chesworth, A.Pandey. **International Maritime Organization (IMO)** (2014).
35. U.S. EPA. Second Prospective Study — 1990 to 2020. **US EPA** 2011.
36. M. Viana, N.Fann,A. Tobias,X.Querol, D.Rojas-Rueda, A.Plaza, G.Aynos, J.A.Conde, L.Fernández and C.Fernández, 2015. **Environmental Science and Technology**. 49 (2015) ,3304-3313.
37. Matt Haber. US EPA. TPM Conference Air Enforcement Division. **Office of Enforcement and Compliance Assurance** (2013).
38. S. Begg, T. Vos, B. Barker, C. Stevenson, L. Stanley, A.D Lopez. The burden of disease and injury in Australia 2003.**The Australian Institute of Health and Welfare** (2007).