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Journal of the Air & Waste Management Association

ISSN: 1096-2247 (Print) 2162-2906 (Online) Journal homepage: https://www.tandfonline.com/loi/uawm20

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JOURNAL OF THE AIR & WASTE MANAGEMENT ASSOCIATION
2019, VOL. 69, NO. 4, 438–449
https://doi.org/10.1080/10962247.2018.1544178

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TECHNICAL PAPER

The economic benefits of fulfilling the World Health Organization's limits for particulates: A case study in Algeciras Bay (Spain)

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ABSTRACT
Algeciras Bay is an important industrial and port zone in the south of Spain whose pollution by particulate matter surpasses the threshold levels recommended by the World Health Organization (WHO) in its 2005 Guide on Air Quality. This study analyses the mortality avoided and the economic benefit which would be derived from a reduction of the pollution of PM2.5 and PM10 to the levels recommended by the WHO in Algeciras Bay in the period 2005-2015. The analysis carried out shows that the industrial zones, such as Los Barrios and San Roque, are those which have greater levels of pollution and in which the relative risk is greater. The calculations for Algeciras Bay between 2000 and 2015 show 182 deaths which would be avoided if the particulate matter pollution were reduced to the levels recommended by the WHO. Likewise, the economic valuation which this impact has on health is carried out through two concepts: the cost of illness and the Value of Statistical Life (VSL). The result shows that the economic benefit that would come out with the cost of illness valuation is 5,329,110€ and from the VSL is 414,787,113€.

Implications: $PM_{2.5}$ has a greater concentration in industrial localities and is linked to the industrial activity. When the particulate matter pollution is reduced to the levels recommended by the WHO in an industrialised area such as Algeciras (Spain), 182 deaths which would be avoided. The result shows that the economic benefit that would come out with the cost of illness valuation is 5,329,110€ and from the value of statistical life is 414,787,113€.

PAPER HISTORY
Received July 3, 2018
Revised October 20, 2018
Accepted October 30, 2018

Introduction

In 2005, the World Health Organization (WHO) established guiding values for specific pollutants. With the aim of guaranteeing human health, it was recommended not to surpass them (WHO 2006). In this guide, four groups of pollutants were identified, based on their impact on health. In the first group were particulate matter, sulfur dioxide, nitrogen dioxide, and ozone (WHO 2006). A recent report of the WHO (2016) stresses the need to include carbon monoxide in this first group, although a reference value has not been set. The European Union (2008), through the Directive 2008/50/CE, of May 21, 2008, established higher limits than the WHO (2006) for the different pollutants within the European territory. This greater laxity of the European legislation has been highlighted in recent reports concerning its negative impact on health (WHO 2013).

Environmental pollution affects human health in different ways. The most significant illnesses are the increase of the risk of suffering from acute respiratory illnesses (such as pneumonia), chronic illnesses (asthma), lung cancer, and cardiovascular illnesses (Kampa and Castanas 2008; WHO 2006). The basic evidence on the health effects of particulate matter is summarized by Kim, Kabir, and Kabir (2015). These illnesses have a more serious effect on people who are already ill or those in vulnerable groups of the population, such as children and the elderly (Ballester, Tenías, and Pérez-Hoyos 1999).

Some outstanding studies exist about the impact on health of particulate matter with a diameter of less than 2.5 microns ($PM_{2.5}$) or other pollutants in different European cities (Ballester 2005; Ballester et al. 2008; Díaz et al. 1999; Lanzinger et al. 2016; Schwartz, Laden, and Zanobetti 2002). These days, there are increasingly more studies at a global level for countries such as China (Wu et al. 2018; Zhang et al. 2016; Zhao et al. 2016) and Australia (Broome et al. 2015). In the case of Spain, there are prominent studies that focused on the impact of pollution on the health of specific population groups, such as children (Linares and Díaz 2009; Pablo-Romero et al. 2015). However, there is still

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Supplemental data for this paper can be accessed on the publisher's website.

little research about the economic benefits deriving from the reduction of local pollution (Linares and Díaz 2009; Pablo-Romero et al. 2015; Pérez, Sunyer, and Künzli 2009).

In the south of Spain, the zone called Algeciras Bay, located in the province of Cádiz (Andalusia), has a high industrial concentration and heavy port traffic. This has turned it into an economically significant zone but one that has high pollution. The petrol refinery industry, the chemical industry, and metallurgy are all located in this industrial zone. These three subsectors make up 93.48% of the zone's industrial production, according to the Association of Large Industries of Campo de Gibraltar (AGI) (2014). Other industries belong to the electric energy generation sector (in cogeneration and power plants), activities of packing and transferring petrol liquid gas, as well as the regasification of liquid natural gas. Altogether, the industrial site of Algeciras represents 7.3% of the gross value added of the province of Cádiz and employs 4.5% of its inhabitants (National Statistics Institute 2014).

Yet, the heavy maritime traffic and the waste disposal of the industries in the water of Algeciras Bay cause high pollution. In fact, some studies show that the waters of Algeciras Bay are more contaminated than the Galician coast after the Prestige disaster (Morales 2007). On the other hand, the air quality of this zone has been affected by the presence of oil refineries and chemical and metallurgical industries, given their high pollution according to the Spanish Register of Emissions and Pollutant Sources (SREPS 2014). Previous works, such as those of Cruz and Almisas (2009) and Cruz, Béjar, and López (2011), have shown the impact of pollution on the mortality and morbidity in Algeciras Bay in the 2001–2005 period.

The novelty of this paper is that, as far as is known, this is the first time that the mortality avoided and the economic benefits of reducing pollution (particle matter) to the levels recommended by the WHO (2006) have been studied in Algeciras Bay. These are annual mean limit values of 10 and 20 μg/m^3 for $PM_{2.5}$ and PM_{10} (particulate matter with an aerodynamic diameter <10 μm), respectively. This research allows a better understanding of the consequences of pollution in industrialized areas of Europe, where the limits of particle matter suggested by the European Union (EU) legislation are lower than those recommended by the WHO. The economic benefits of achieving the pollution levels suggested by the WHO provide additional information to EU policymakers in order to implement environmental policies to reduce pollution.

This paper contributes to the existing literature in the following aspects. Firstly, it carries out an analysis of the particulate matter (PM_{10} and $PM_{2.5}$) pollution in the four localities of Algeciras Bay (Algeciras, San Roque, Los Barrios, and La Línea de la Concepción), identifying its relation to the industrial activity between 2005 and 2015. This is an industrialized area, well known in Spain for its environmental pollution, but also for its lack of information on primary health data. Secondly, the paper analyzes the relation between high levels of particle pollution and mortality due to cardiovascular and respiratory problems in these locations. Thirdly, it carries out an economic assessment of the benefits that the reduction of the level of particulate matter pollution in Algeciras Bay to the levels recommended by the WHO (2006) would bring about.

The paper is structured as follows. After this introduction, the second section explains the databases used and develops the methodology applied. The third section presents the results obtained. The fourth section discusses the most relevant results. The fifth section sets out the main limitations of the research. And the final section synthesizes the paper's principal conclusions.

Materials and methods

In the case of the environmental data, the databases used are those provided by the Environmental Regional Government of Andalusia (2016), through two of its organisms: the Network of Environmental Information (REDIAM) and the General Management of Air Prevention and Quality. Specifically, PM_{10} and $PM_{2.5}$ pollution in the 2005–2015 period has been analyzed. The data come from the 20 air quality measurement stations owned by the Andalusian Regional Government and which make up the Air Quality Monitoring Network. The stations chosen are those located in the towns of Algeciras, San Roque, Los Barrios, and La Línea de la Concepción. In addition, 3 of the 20 stations offer meteorological data. The different stations offer daily information on the concentration (μg/m^3) of $PM_{2.5}$, PM_{10}, sulfur dioxide (SO_2), Benzene (BZ), carbon monoxide (CO), nitrogen dioxide (NO_2), nitrogen oxides (NO_x), ozone (O_3), and hydrogen sufide (H_2S) In turn, the meteorological data offered are the average daily temperatures and relative humidity in the period studied.

In 2005, by location the baseline concentrations of PM_{10} were 35.02 (Algeciras), 35.43 (La Línea), and 36 (Los Barrios) μg/m^3, and those of $PM_{2.5}$ were 20.42 (Algeciras), 18.62 (La Línea), 22.03 (Los Barrios), and 21.45 (San Roque) μg/m^3.

Statistical analysis of the air pollution data

A descriptive analysis of the particle pollution in Algeciras Bay has been carried out, identifying its correlation with the evolution of the industrial activity measured by the gross value added (GVA), which has been provided by the AGI (2014). The Pearson correlation coefficient has been obtained using eq 1 with the GVA data.

$$r_{X,Y} = \frac{E[(X-\mu_X)(Y-\mu_Y)]}{\sigma_X \sigma_Y} \quad (1)$$

where $r_{X,Y}$ is the value of the Pearson correlation coefficient, X are the GVA values of the study period, μ_X is the average of the GVA values, Y are the values of the pollutants studied in the period, μ_Y is the average of the pollution values, σ_X is the standard deviation of the GVA values, and σ_Y is the standard deviation of the pollution values.

Dose-response functions of air pollution on health

The study of the impact of air pollution on health has been performed via two methodologies. Firstly, the calculation of the relative risk for the population as a consequence of a change in the air pollution has been carried out. Secondly, the impact of air pollution on mortality has been worked out through dose-response functions.

The relative risk to which the population is subjected as a consequence of changes in the levels of PM_{10} and $PM_{2.5}$ pollution is a very common measure in the literature (Ballester et al. 2008; Cruz and Almisas 2009; Linares and Díaz 2009; Pope et al. 2002). The functions and coefficients applied are different, based on the pollutant studied, and have been taken from official reports for Algeciras Bay (Junta de Andalucía 2014a), These, in turn, have been previously used in Pope et al. (2002) and Ritz et al. (2000) in the case of children under 5 years old.

In this paper, the relative risk that occurs when the levels of pollutant particles existing in 2015 are reduced to the levels recommended by the WHO (2006) is calculated. To carry out the relative risk estimations, eqs 2 and 3 are used for the PM_{10} pollutant and the $PM_{2.5}$ pollutant, respectively.

$$RR_{PM10} = e^{\beta(C_{15}-C*)} \quad (2)$$

$$RR_{PM2.5} = \left[\frac{(C_{15}+1)}{(C^*+1)}\right]^{\beta} \quad (3)$$

C_{15} and C^* in eqs 2 and 3 are the pollution levels in 2015 and the levels of pollution recommended by the WHO (2006), respectively. Therefore, RR_{PM10} and $RR_{PM2.5}$ are the relative risks for long-term exposure to different causes associated with the β coefficients estimated by Pope et al. (2002) and Ritz et al. (2000), as shown in Table 1.

Secondly, the impact of a change in the PM_{10} and $PM_{2.5}$ pollution in terms of mortality has been analyzed, using dose-response functions. This method was chosen conditioned by the limited health data available for the localities and period analyzed. When complete serial data are available, it should be considered that there are alternative causal modeling methods as Cox (2017) suggests. Also, there are other methods for analyzing the premature mortality caused by these pollutants, such as the integrated exposure risk (IER) model, which has been recently applied (Maji et al. 2018).

The starting point for these estimations is the data proceeding from Cruz and Almisas (2009). Here, the rates of mortality per 100,000 inhabitants are shown according to different causes for 2005 in the localities of Algeciras Bay. So, eq 4 will be used to estimate the data referring to PM_{10} and eq 5 to estimate those referring to $PM_{2.5}$.

$$E_{15} = \frac{E_{05}}{e^{\beta(C_{05}-C_{15})}} \quad (4)$$

$$E_{15} = \frac{E_{05}}{\left[{(C_{05}+1)}/{(C_{15}+1)}\right]^{\beta}} \quad (5)$$

where E_{05} is the number of deaths in 2005, E_{15} is the number of deaths in 2015, and C_{05} and C_{15} are the average values of PM_{10} and $PM_{2.5}$ pollution in 2005 and 2015, respectively. In the case of eq 4, the mortality for all causes is analyzed, and in the case of eq 5 the mortality due to cardiovascular and respiratory causes is obtained. It is pointed out that to calculate the rate of variation of the mortality, the assumption is that the population has remained constant throughout the period.

Likewise, the β coefficients used in these estimations are those calculated by the official report for Algeciras Bay (Junta de Andalucía 2014a), obtained in turn from the relative risk functions of Pope et al. (2002). The data provided by these research analyses show 95% confidential intervals (CIs).

With the data estimated for 2015 in eqs 5 and 6, calculation has been carried out of the effect in terms of mortality of the reduction of PM_{10} and $PM_{2.5}$ pollution to the limits recommended by the WHO (2006) . Equations 6 and 7 show the methodology followed in the cases of the PM_{10} and $PM_{2.5}$ pollutants, respectively:

$$E^* = \frac{E_{15}}{e^{\beta(C_{15}-C^*)}} \quad (6)$$

$$E^* = \frac{E_{15}}{\left[{(C_{15}+1)}/{(C^*+1)}\right]^{\beta}} \quad (7)$$

Table 1. β coefficients used for the calculation of relative risks.

	β	CI (95%)
PM_{10}		
Correlation with the mortality for all causes and age groups.	0.0008	(0.0006–0.0010)
Correlation with the mortality for respiratory causes in children less than 5 years old.	0.00166	(0.00034–0.0030)
$PM_{2.5}$		
Correlation with the mortality in adults over 30 years old due to cardiovascular causes.	0.15515	(0.0562–0.2541)
Correlation with the mortality in adults over 30 years old due to pulmonary causes.	0.23218	(0.08563–0.37873)

Source: Regional Government of Andalusia (2014a).

where E^* is the mortality risk associated with the levels of pollution recommended by the WHO (2006) and C^* are the cited levels of pollution. Likewise, the β coefficients that are shown in Table 1 have been considered.

The economic valuation of the impact of air pollution on health

The cost of illness (COI)

The first economic valuation criterion has been the cost of illness (COI). The COI calculates the cost of illness taking into account not only the health care but also the loss of productivity generated by the workers as a consequence of their convalescence or their death (Jo 2014). The COI is subdivided into two types of cost: the direct cost, derived from hospital care, and the indirect cost, generally measured in terms of unearned salaries (Hall, Brajer, and Lurmann 2006). The indirect cost can also be measured by the productivity lost due to premature mortality and morbidity (Cebr 2014).

$$COI = C_D + C_I = C_D \cdot M_P^{BA} \tag{8}$$

In this study, the direct cost (C_D) is an assessment of the cost of hospital care that could be saved if the atmospheric pollution were reduced to the levels recommended by the WHO (2006).

$$C_D = C_d \cdot \ (E_{15} - E^*) \tag{9}$$

where C_d is the health cost per person updated to euros of 2015 and $E_{15} - E^*$ is the number of deaths that could have been avoided if the air pollution of 2015 had been reduced to the levels recommended by the WHO (2006). To carry out this estimation, the cost of a hospital admission provided by Netcen (2002) for the year 2000 has been considered. This value has been updated to 2015, attaining values of 6,117€ and of 23,690€ for deaths due to respiratory and cardiovascular causes, respectively.

The indirect cost (C_I) shows the loss of labor productivity associated with deaths in people who are of a working age and that have been caused by air pollution over the levels recommended by the WHO (2006). To do so, firstly M_P^{BA}—the number of premature deaths in Algeciras Bay that could have been avoided in the case of reducing the levels of pollution existing in 2015 to the levels recommended by the WHO (2006)—is estimated, as is shown in eq 10.

$$M_p^{BA} = (E_{15} - E^*) \cdot \frac{M_p^E}{M_T^E} \tag{10}$$

where M_p^E is the premature mortality in Spain and M_T^E is the total mortality in Spain, both data for 2014 (National Statistics Institute 2014).

Secondly, the indirect cost per capita of premature mortality ($C_{I_{pC}}$) is estimated from the data of Cebr (2014) study for Spain via the following expression:

$$C_{I_{pC}} = \frac{C_I^E}{M_P^E} \tag{11}$$

where C_I^E is the loss of productivity or average incomes not earned caused by premature deaths in Spain in 2014 (Cebr 2014). The estimated $C_{I_{pC}}$ has been considered representative for the case of Algeciras Bay in 2015.

Value of statistical life

The criterion of the value of statistical life (VSL) is a measure of the cost of mortality that is derived from the aggregation of the individual willingness to pay (WTP) in a society (Hall, Brajer, and Lurmann 2006).

First of all, the function of expected utility (EU) of each individual is defined according to the following equation:

$$EU(y, r) = (1 - r)U(y) \tag{12}$$

where $U(y)$ is the utility function in a given period and r the risk of mortality in this period. It is thus obtained that the WTP is the amount that is willing to be paid in order to reduce the risk of mortality and which, therefore, enables the utility to remain constant, so that

$$EU(y - WTP, r) = E.U(y, r) \tag{13}$$

Therefore, the VSL is the marginal rate of substitution between a person's WTP and the risk of dying in the period given (r), following what is established in eq 14. The methodology used to find out the WTP value is via surveys.

$$VSL = \frac{\delta WTP}{\delta r} \tag{14}$$

The specific Spanish VSL value is obtained from the VSL value estimates for the USA in 2010 (WHO 2015), adjusting the inflation rates and applying the purchase power parity specified in this report. In the particular case of Spain, it is established that the WTP in 2010 was 30.6 USD for a reduction in the risk of mortality of 1 out of 100,000. This makes the VSL in Spain 3.06 (million USD, 2010 level).

Having obtained the VSL value for Spain in 2010, this value has been updated to 2015 and converted into euros, attaining a value of 2,275,848€. The individual VSL value estimated for Spain has been considered representative for Algeciras Bay and the total VSL has been calculated (VSL_T), taking into account the deaths that would have been avoided by reducing the pollution existing in 2015 to the levels recommended by the WHO (2006), as is shown in eq 15.

$$VSL_T = (E_{15} - E^*) \cdot VSL = (E_{15} - E^*) \cdot 2275848€ \quad (15)$$

Results

Results of the air pollution in Algeciras Bay

The concentrations of fine particles with diameters of 10 (PM_{10}) and 2.5 ($PM_{2.5}$) microns in all the localities of Algeciras Bay during the period analyzed are shown in Figures 1 and 2, respectively. The main descriptive statistics of the pollution due to particles is shown in Table S1 (see supplemental information).

The annual average concentration of PM_{10} pollution in the 2005–2015 period is above the threshold recommended by the WHO (2006) in all the localities. Although the annual concentration disparity of this pollutant was significant among the localities between 2006 and 2010, the annual concentration has been quite similar since then, around 30 μg/m^3.

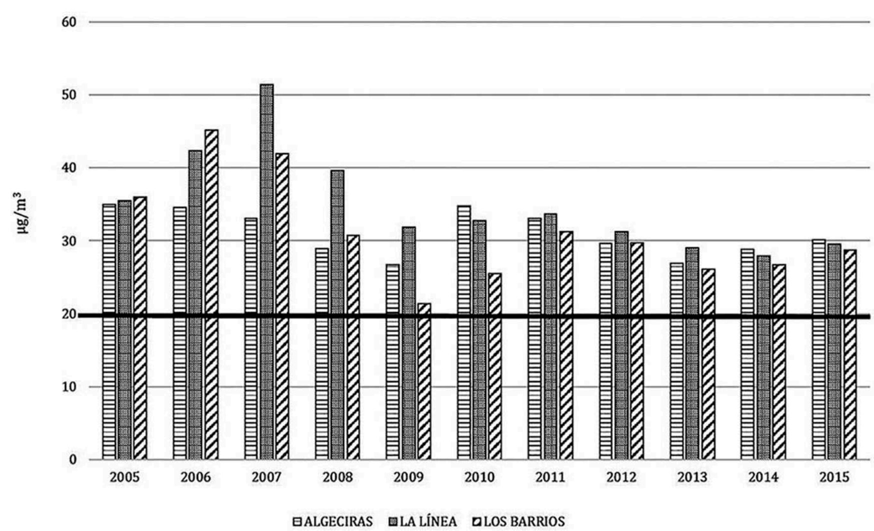

Figure 1. Evolution of the PM_{10} pollution in the localities of Algeciras Bay (2005–2015).

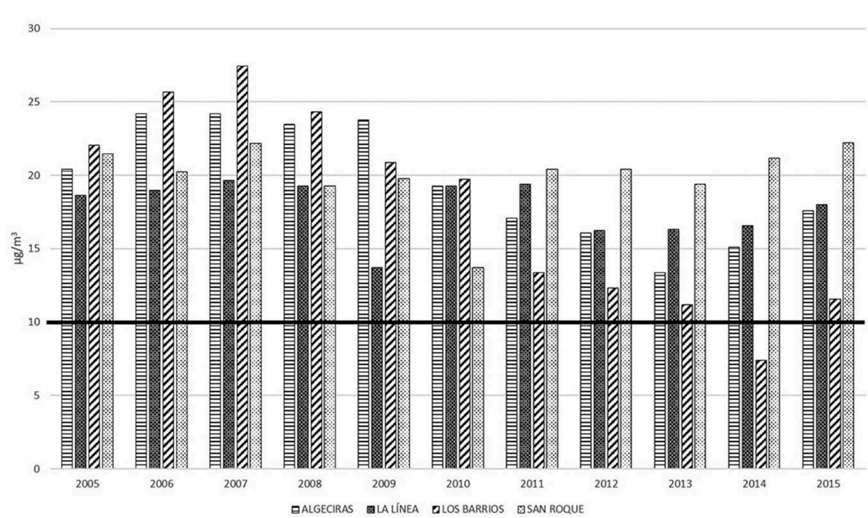

Figure 2. Evolution of the $PM_{2.5}$ pollution in the localities of Algeciras Bay (2005–2015).

The annual average concentration of $PM_{2.5}$ pollution in the 2005–2015 period is above the threshold recommended by the WHO (2006) in all the localities, except in Los Barrios in 2014. In fact, the annual average value of the $PM_{2.5}$ pollutant in Los Barrios was above 25 μg/m³ in 2007, but this was reduced to close to 10 μg/m³ in 2015. Similarly, Algeciras increased its annual average of the $PM_{2.5}$ pollutant between 2005 and 2007, reaching almost 25 μg/m³ in 2007 and since then this was reduced to a value somewhat above 15 μg/m³ in 2015. La Línea shows an annual average value of the $PM_{2.5}$ pollutant close to 20 μg/m³ between 2005 and 2011, with the exception of 2009 when it was lower. Between 2012 and 2014, La Línea had an annual average value of $PM_{2.5}$ of around 15 μg/m³, but in 2015 the trend changed again and started increasing. Finally, San Roque was the only locality that did not reduce its annual average value of $PM_{2.5}$ during the period analyzed, with the exception of the 2007–2008 and 2009–2010 periods, reaching a value above 20 μg/m³ in 2015.

Table 2 shows the correlation coefficients between the pollutants by city and the GVA. The levels of significance are found in detail in Table S2. In those data that are significant, one can note a correlation between the economic activity and the pollution that surpasses 50%, and that attains values close to 90% in some localities.

In the next two subsections, the study of these pollutants is more thoroughly analyzed in order to identify the most harmful periods with regards to their concentrations.

Analysis of the PM_{10} pollutant in Algeciras Bay

The particles with a diameter of less than 10 microns have a cyclical behavior that is strongly linked to the industrial activity, with which it is correlated between 50% and almost 70% according to the locality (see Table 2).

Figure 3 allows us to distinguish three periods in the evolution of the PM_{10} emissions between 2005 and 2015. The 2005–2007 expansion period is characterized by a strong boost of the economic activity and an increase in the PM_{10} concentration in all the localities. The 2007–2013 recession period shows a fall in the economic activity that entrains the concentration of PM_{10} pollution in the localities studied. The annual average rate of pollution decreased between 18% and 43% in the total of the subperiod. Finally, the 2013–2015 subperiod started with an increase in the PM_{10} pollution in all localities that continued during the following years.

The heat maps show the change in PM_{10} pollution between 2005 and 2015 (see Figures S1 and S2). In spite of maintaining levels above those recommended by the WHO (2006), the figures show the relative reductions in the levels of PM_{10} pollution and, specifically, that the relative reductions between the years 2005 and 2015 were around 14% (Algeciras), 17% (La Línea), and 20% (Los Barrios).

Analysis of the $PM_{2.5}$ pollutant in Algeciras Bay

The particles with a diameter of less than 2.5 microns have a behavior similar to that of PM_{10} and are also very linked to the economic activity, with which they are correlated between 60% and almost 86% according to the locality (see Table 2).

Figure 4 shows the changes in $PM_{2.5}$ concentration in all the localities in Algeciras Bay between 2005 and 2015. San

Table 2. Correlation coefficients of the different pollutants with the gross value added (2005–2015).

Locality	PM_{10}	$PM_{2.5}$
Algeciras	63.97%**	52.08%***
La Línea	50.6%**	75.48%*
Los Barrios	69.33%***	59.60%***
San Roque	ND	87.26%*

Source: This study.
$^*P < 0.1$; $^{**}P < 0.05$; $^{***}P < 0.01$.

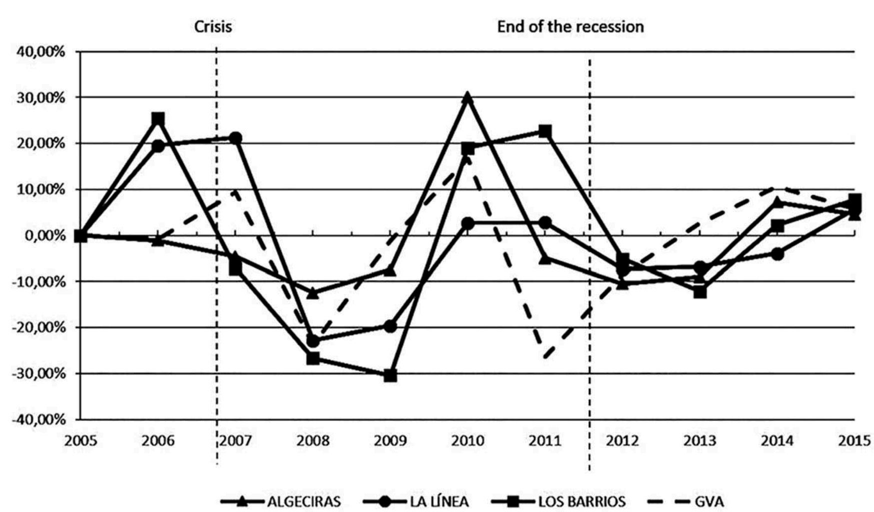

Figure 3. Evolution of the annual mean values of PM_{10} and GVA in Algeciras Bay (2000–2015).

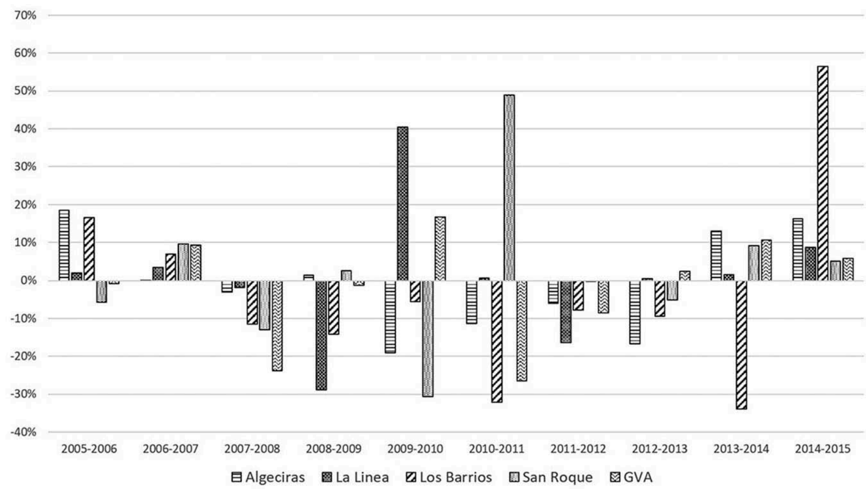

Figure 4. Evolution of the annual mean values of $PM_{2.5}$ in Algeciras Bay (2011–2015).

Table 3. Relative risks of PM_{10} for mortality according to cause.

	RR_{PM10}	
Locality	Mortality for all the causes and age groups	Mortality for respiratory causes (in children less than 5 years old)
Algeciras	1.0024	1.0051
La Línea	1.0080	1.0167
Los Barrios	1.0068	1.0142

Source: This study.

Roque shows a significant decrease in $PM_{2.5}$ concentration between 2007–2008 and 2009–2010, but experienced a very high increase in 2010–2011, not being correlated with the GVA trend, which was reduced during this same period. Since then, the relative importance of this locality in terms of $PM_{2.5}$ emissions change has not been relevant until 2013–2014 when it again increased. Los Barrios is also a locality where the $PM_{2.5}$ concentration was reduced between 2006 and 2014, especially in 2010–20111 and 2013–2014, but it experienced a significant increase in 2014–2015. Algeciras decreased its $PM_{2.5}$ concentration between 2007 and 2013 and since then it started increasing again. Finally, although La Línea follows a trend of diminishing its $PM_{2.5}$ concentration between 2008 and 2009, this increased considerably between 2009 and 2010, being highly correlated with the increase in GVA.

The heat maps show the change in $PM_{2.5}$ pollutant concentration between 2005 and 2015 (see Figures S3 and S4). The average concentration of $PM_{2.5}$ decreased between these two years, as can be seen in the maps, especially in Algeciras (14%) and Los Barrios (48%).

Table 4. Relative risks of $PM_{2.5}$ for mortality according to cause.

	$RR_{PM2.5}$	
Locality	Mortality for cardiovascular causes (in adults over 30 years old)	Mortality for pulmonary causes (in adults over 30 years old)
Algeciras	1.0847	1.1294
La Línea	1.0208	1.0313
Los Barrios	1.0886	1.1354
San Roque	1.1230	1.1895

Source: This study.

Results of the impact of air pollution on health

The data associated with the relative risk coming from the reduction of the PM_{10} and $PM_{2.5}$ pollutants are shown in Tables 3 and 4, respectively.

Specifically, Table 3 indicates the relative risks of mortality due to PM_{10} pollution in the zone of Algeciras Bay. The results show that they all are close to 1.0; therefore, according to Mengersen, Moynihan, and Tweedie (2007),

Table 5. Estimation of the number of deaths according to pollutant and cause.

	PM_{10} mortality (all causes)			$PM_{2.5}$ mortality (cardiovascular causes)			$PM_{2.5}$ mortality (pulmonary causes)		
Locality	E_{05}	E_{15}	E^*	E_{05}	E_{15}	E^*	E_{05}	E_{15}	E^*
Algeciras	1822	1821	1820	237	237	218	590	571	505
La Línea	1026	1026	1025	134	133	122	332	330	290
Los Barrios	330	330	330	43	39	38	107	93	90
San Roque	418	423	416	55	55	42	136	137	115

Source: This study.

Table 6. Variation of mortality according to pollutant and locality.

Locality	PM_{10} mortality (all the causes)		$PM_{2.5}$ mortality (cardiovascular causes)		$PM_{2.5}$ mortality (pulmonary causes)	
	Variation $E_{05} - E_{15}$	Variation $E_{15} - E^*$	Variation $E_{05} - E_{15}$	Variation $E_{15} - E^*$	Variation $E_{05} - E_{15}$	Variation $E_{15} - E^*$
Algeciras	−0.39%	−0.81%	−3.24%	−12.03%	−2.17%	−8.21%
La Línea	−0.47%	−0.76%	−3.94%	−11.61%	−2.65%	−7.92%
Los Barrios	−0.58%	−0.70%	−3.95%	−11.93%	−2.65%	−8.14%
San Roque	0.81%	−1.31%	−0.28%	−15.67%	−0.19%	−10.77%

Source: This study.

it cannot be concluded that the pollutant is a causal factor of mortality and consequently there exists only a relative risk linked to the PM_{10} pollutant in these localities.

When the data referring to the relative risks regarding $PM_{2.5}$ (Table 4) are analyzed, the differences in the relative risks among localities are evident. For example, in the case of Algeciras, in 2015, the probability of dying due to respiratory illness caused by $PM_{2.5}$ is 1.1294 times greater than if the levels recommended by the WHO (2006) had been reached. Also, the industrialized cities (San Roque and Los Barrios) have levels of risk above those noted for the other two cities. Specifically, San Roque stands out for the data of mortality risk due to both cardiovascular and respiratory causes, having death probabilities 1.12 and 1.18 times greater than if they had attained the $PM_{2.5}$ levels set by the WHO (2006).

However, these data on relative risk are few and it cannot be concluded that the $PM_{2.5}$ pollution is the direct cause of the respiratory and cardiovascular problems of the population living in the localities of Algeciras Bay (Lobdell et al. 2011).

Likewise, Table 5 shows the mortality registered according to the different causes observed and to the type of pollutant. The extended data are shown in Table S3. If the PM_{10} and $PM_{2.5}$ pollution levels between 2005 and 2015 are compared, there is a reduction in the mortality rates of all the localities (except in San Roque), oscillating between 0.5% and almost 4%. Specifically, the localities that relatively reduce the different rates of mortality more are Los Barrios and La Línea, whereas San Roque is the only locality where the estimations of mortality according to the different causes increase.

Second, the variation rate (Table 6) has been calculated considering the mortality that would exist if, setting out from the PM_{10} and $PM_{2.5}$ pollution levels in 2015, these were reduced to the limits recommended by the WHO (2006). In this case, the mortality would be significantly reduced, especially in the case of the $PM_{2.5}$ pollutant. San Roque is the locality that would have a greater reduction in mortality, although the data range in percentage points is, in the largest case, 1.

Table 7. Economic valuation of the impact of pollution in 2015.

Pollution	$E_{15} - E^*$	VSL	COI
PM_{10}, all causes	30	68,953,870 €	605,467 €
$PM_{2.5}$, respiratory causes	56	127,351,764 €	1,118,244 €
$PM_{2.5}$, cardiovascular causes	96	218,481,478 €	3,605,399 €
Total	182	414,787,112 €	5,329,110 €

Source: This study.

Results of the economic valuation of the impact of air pollution on health

The economic valuation on the basis of the COI and VSL criteria is noted in Table 7.

Firstly, the economic valuation is carried out on the number of deaths that arise when the pollution levels are higher than the values recommended by the WHO (2006). The estimates show that 182 deaths would be avoided, considering that 16 of these deaths would be premature, that is, people under 65 years old.

According to the COI criterion, the direct cost of health care (C_D) has been estimated at 6,117€ for hospital admissions due to respiratory causes and at 23,690€ for cardiovascular causes. On the other hand, premature deaths mean an indirect cost per capita ($C_{I_{PC}}$) of 156,463€ per person. Based on the different pollutants and the costs explained, a COI of 5,329,110€ has been estimated, derived from the action of the pollution of Algeciras Bay. The detailed calculation by locality, pollutant, and cause of illness is shown in Tables S4, S5, and S6.

The VSL_T value, due to the 182 deaths estimated because of environmental pollution, means a total cost of 414,787,113€, the VSL_T value being especially important due to the $PM_{2.5}$ pollution for respiratory causes.

Discussion

The results show that, in Algeciras Bay, the PM_{10} and $PM_{2.5}$ pollutants have concentrations above the values recommended by the WHO (2006), even though the average concentrations have been reduced between 2005 and 2015 by around 25% and 16%, respectively. During the period analyzed, the highest average concentration of PM_{10} is found in La Línea (35 μg/m^3): This is the locality of Algeciras Bay with the highest population density: 3,276.18 inhabitants/km (National Statistics Institute, NSI 2017). Also, the highest average concentration of $PM_{2.5}$ is found in San Roque (20 μg/m^3), which is one of the most industrialized localities of Algeciras Bay.

If the pollution levels of Algeciras Bay are compared with those obtained by Ballester et al. (2008) in a study of 26 European cities, it is noted that they are similar to those recorded in Madrid, Marseille, and Vienna, having values that oscillate between 29 and 36 μg/m^3 for PM_{10} and between 16.5 and 22 μg/m^3 for $PM_{2.5}$. It should be highlighted that although the localities analyzed in Algeciras Bay do not surpass 12,000 inhabitants, their pollution levels are similar to those cities included in the above-mentioned research of Ballester et al. (2008), whose populations range from 300,000 to 3,000,000 inhabitants.

In turn, the study of the Instituto de Diagnóstico Ambiental y Estudios del Agua (Institute of Environmental Diagnostics and Water Studies;IDAEA 2013) shows that cities with a very different population size, such as Zaragoza and Avilés (650,000 and 85,000 inhabitants, respectively), have similar levels of pollution due to their industrial activity. This factor would explain why Algeciras Bay can reach levels of pollution similar to those of large capitals (Madrid and Vienna) or those cities with an industrial presence (Avilés or Ljubljana). The existence of the industrial zone of Algeciras Bay influences the concentration of pollution, specifically of particles in suspension.

Additionally, other studies for China or India show more significant levels of the PM_{10} and $PM_{2.5}$ pollutant concentration. For example, in the city of Agra in India, the average annual PM_{10} concentrations are between 140 and 300 μg/m^3 in the 2002–2014 period (Maji et al. 2017a). In China, the average annual concentration is 97.7 μg/m^3 and, in the case of $PM_{2.5}$ it ranges between 98 and 119 μg/m^3 (Maji et al. 2017a). These notable pollution levels in China and India are not comparable with those of European countries, as their population densities are higher and their industrial activities are more polluting.

An important correlation among the PM_{10} and $PM_{2.5}$ pollutant concentration levels and the population and/or economic activity is also found. On the one hand, there are very industrialized localities that show high levels of $PM_{2.5}$ pollutant concentration, such as San Roque. Table S7 shows the industrial activities located in Algeciras Bay, mainly in San Roque and Los Barrios, where the highest levels of $PM_{2.5}$ pollutant concentration were reached in 2005. On the other hand, there are localities characterized by a high population density, such as La Línea, where the levels of PM_{10} pollutant concentration are also high.

During the period analyzed, two environmental action plans have been implemented by the competent organization in the environmental area, the Ministry of the Environment of the Regional Government of Andalusia (2014b).

Firstly, in 2005, the Environmental Action Plan focused its efforts on the reduction of sulfur dioxide in the four localities of Algeciras Bay, as this pollutant had a significant presence in the zone due to the main emission source being the petrol refining industry. It is also a very harmful pollutant because it remains in the atmosphere for 3 to 5 days (being transported quite a distance) and its oxidation process forms sulfates, which are found in PM_{10} and, in the presence of humidity, creates aerosol acids producing $PM_{2.5}$ (Fundación para la Salud Geoambiental 2016). The implementation of this Environmental Action Plan did not achieve the desired effects. The concentrations of the PM_{10} and $PM_{2.5}$ pollutants increased from 2005, parallel to the economic activity that occurred during the expansion period.

Secondly, in 2011, the Plan of Improvement of the Quality of Air in the industrial zone of Algeciras Bay was implemented (Spanish Government 2011), focusing on reducing the PM_{10} pollutant concentration, establishing an objective value of 32 μg/m^3, instead of the limit of 40 μg/m^3 that the European standard sets. Our results show that from 2011, for the three localities for which data are available, the concentration of the PM_{10} pollutant decreased by 9% in Algeciras, 12% in La Línea, and 8% in Los Barrios. This can be due, on the one hand, to the efficacy of the measures implemented, but it ought to be considered also that between 2011 and 2014, the GVA diminished and the pollutant concentrations followed a similar path, increasing in the last period, 2014–2015, when the economic activity increased again.

Regarding the mortality data, our research shows that the highest number of relative deaths takes place in San Roque, this being the locality most benefited from reducing the particulate matter to the levels recommended by the WHO. As was mentioned before, San Roque is the most industrialized locality of Algeciras Bay and it has the highest levels of $PM_{2.5}$ emission. Of course, those studies carried out in China and India indicate a greater impact on health than the present study. Specifically, in the city of Agra, a range of between 649 and 789 deaths due to cardiovascular causes derived from exposure to PM_{10} is estimated (Maji et al. 2017b). In the case of China, a total of 722 deaths are established due to exposure to the $PM_{2.5}$ pollutant (Maji et al. 2017b).

As to the economic assessment, the results obtained are modest in comparison with other studies due to the lower population of the zone studied and the limited causes of illness analyzed (Pérez, Sunyer, and Künzli 2009; Zhao et al. 2016). For example, Pérez, Sunyer, and Künzli (2009) evaluate the metropolitan area of Barcelona and study the impact on mortality and morbidity for different causes and illnesses. In Zhao et al. (2016), the levels of pollution and population are quite high, and both mortality and morbidity for different causes are taken into account. On the other hand, in this study, only the mortality attributable to air pollution is noted.

Limitations of the study

The estimation of the effect that particulate matter pollution has on health in Algeciras Bay during the 2005–-2015 period, as well as its economic assessment, has been carried out based on some suppositions that limit the study's conclusions. These assumptions have been considered due to the lack of data available for all the variables of interest. They are, in brief, the following.

First, in light of the lack of data to calculate the β correlations of the illnesses due to the PM_{10} and $PM_{2.5}$ pollutants, the coefficients calculated by the Regional Government of Andalusia (2014a) have been used. Their calculations are in turn derived from the relative risk functions of Pope et al. (2002). These calculations are provided with 95% confidential intervals (CIs).

Second, for the estimation of health data, only mortality rates for different causes of illness and pollutants have been taken into account; morbidity has not been considered. The mortality data for the year 2005 have been obtained from Cruz et al.'s (2009) study, and they have been extrapolated until the year 2015.

Third, for the calculation of the direct cost (C_D), the mortality data have been borne in mind, considering that each person who has died has been previously admitted into hospital. It is assumed, therefore, that the health cost depends solely on the cost of hospital admission. Additionally, it has been considered that each person has been hospitalized once. To carry out this estimation, that provided by Netcen (2002) has been taken as a reference for the cost of a hospital admission. The health cost per person for respiratory causes is estimated at 4,320€ and for cardiovascular causes at 16,730€. These data are expressed in euros of the year 2000. For this reason, the value of this cost has been updated to 2015 through the data of the National Statistics Institute (2015), attaining values of 6,117€ and of 23,690€, respectively.

Fourth, in the estimation of the indirect cost (C_I), it was necessary to calculate the premature mortality (that is to say, the number of deaths of those under 65 years old) in Algeciras Bay. Given the lack of these data, the relation between the number of premature deaths and the total deaths for Spain in 2014 has been calculated from Cebr (2014) study. It has been assumed that this relation remains the same for Algeciras Bay and is maintained constant over time. In turn, to find out the indirect cost, it has been necessary to calculate the indirect cost per capita ($C_{I_{pC}}$), Comp: The math expression. Subscript roman pls.</AQ> which has also been obtained for the case of Spain, dividing the total loss of productivity between the number of premature deaths in 2014 and applying this to Algeciras Bay.

Fifth, in the case of calculating the value of statistical life (VSL), the base value of 3.06 million USD (2010) calculated for Spain has been considered (WHO 2015). This value has been assumed for the calculation of the VSL in Algeciras Bay, considering in turn that this value is extrapolated to the year 2015 and that therefore it has not undergone a substantial variation.

Sixth, although the relative risk data are lower than 2.0 and according to Mengersen, Moynihan, and Tweedie (2007), there is not a casual relation between pollutants and mortality, as the results are greater than 1.0, the authors have considered that these pollutants are worthy of being studied in order to provide a better knowledge for further research. It should be considered that the relative risk functions analyzed have no clinical significance, rather they are provided only for statistical significance (McCluskey and Ghaaliq 2007).

Seventh, the analysis is carried out including the total population of Algeciras Bay localities. Although this population figure is not very high, it was included because the final aim is to compare Algeciras Bay with other localities that have a similar industry and/or population in order to find out other risk factors.

Eighth, it is necessary to emphasize that this research paper is focused on the variation in mortality due to the population's exposure to PM_{10} and $PM_{2.5}$ pollutants. Other factors that may affect the conclusions of this work have not been taken into account, such as biological, socioeconomic, behavioral, and other environmental risk factors, for instance, temperature (Krstic 2012).

Conclusion

First, the conclusion is that the PM_{10} pollutant surpasses the values recommended by the WHO (2006) in all the localities of Algeciras Bay during the period analyzed, reaching levels of concentration of around 28.7–30.2 μg/m^3 in 2015. Likewise, the $PM_{2.5}$ pollutant also surpasses the reference value in all the localities during the period analyzed (with the exception of Los Barrios in 2014), having a greater concentration in 2015 in the most industrialized locality, San Roque (20 μg/m^3).

Second, it is concluded that after the implementation of the environmental measures in 2011, the levels of PM_{10} pollution decreased but did not reach the levels recommended by the WHO (2006). Our results allow us to conclude that if the particulate matter pollution, specifically $PM_{2.5}$, were reduced from the levels reached in 2015 to the levels recommended by the WHO (2006), the greatest change in rates of mortality would appear in San Roque. This result is significant, as San Roque is the only locality of Algeciras Bay whose levels of the $PM_{2.5}$ pollutant increased in the period analyzed (4%).

Third, it is concluded that the air pollution in Algeciras is linked to the economic activity and, in particular, to the industrial activity. Hence, the crisis period coincides with a clear downward trend of the levels of particle pollution, whereas the values for the final years of the period, which, as mentioned, show a growing trend, accompanying increases in the industrial zone's production. The high concentration of particle pollution in the industrial zones of Los Barrios and San Roque stands out.

Fourth, taking as a reference the year 2005, it is underlined that an estimated 182 deaths would have been avoided with a decrease of PM_{10} and $PM_{2.5}$ pollution to the threshold levels. Likewise, it is estimated that the benefits associated with this reduction would have been 5,390,110€ according to the cost of illness (COI) and more than 400 million euros based on the VSL criterion.

Acknowledgment

Rocío Román-Collado acknowledges the support from the Chair on Economics for Environmental and Energy sponsored by Universidad de Sevilla and Red Eléctrica España (REE) and from Universidad Autónoma de Chile (Chile).

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References

Asociación de Grandes Industrias del Campo de Gibraltar (AGI). 2014. Memoria anual. Accessed April 10, 2016. http://www.agicg.es.

Ballester, F. 2005. Contaminación Atmosférica, Cambio Climático y Salud. *Revista Española de Salud Pública* 79:159–75.

Ballester, F., J. M. Tenías, and S. Pérez-Hoyos. 1999. Efectos de la contaminación atmosférica sobre la salud. Una introducción. *Revista Española de Salud Pública* 73:109–21.

Ballester, F., S. Medina, E. Boldo, P. Goodman, M. Neuberger, C. Iñiguez, and N. Künzli. 2008. Reducing ambient levels of fine particulates could substantially improve health: A mortality impact assessment for 26 European cities. *J. Epidemiol. Community Health* 62:98–105. doi:10.1136/jech.2007.059857.

Broome, R. A., M. E. Cope, B. Goldsworthy, L. Goldsworthy, K. Emmerson, E. Jegasothy, and G. G. Morgan. 2015. The mortality effect of ship-related fine particulate matter in the Sydney greater metropolitan region of NSW, Australia. *Environ. Int.* 87:85–93. doi:10.1016/j.envint.2015.11.012.

Cebr. 2014. *Coste económico de las enfermedades cardiovasculares desde 2014 a 2020 en seis países europeos*. London: AstraZeneca.

Cox, L. A. 2017. Do causal concentration–Response functions exist? A critical review of associational and causal relations between fine particulate matter and mortality. *Crit. Rev. Toxicol.* 47 (7):609–37. doi:10.1080/10408444.2017.1311838.

Cruz, C., L. M. Béjar, and D. J. López. 2011. Ingresos hospitalarios en el área de la Bahía de Algeciras. Comparación con Andalucía y España (2001-2005). *Gaceta Sanitaria* 25 (5):403–11. doi:10.1016/j.gaceta.2011.04.003.

Cruz, C., and M. Almisas. 2009. Análisis epidemiológico de la mortalidad por causas en la Bahía de Algeciras (2001-2005). *Gaceta Sanitaria* 23 (5):388–95. doi:10.1016/j.gaceta.2008.10.004.

Díaz, J., R. García, P. Ribera, J. C. Alberdi, E. Hernández, M. S. Pajares, and A. Otero. 1999. Modeling of air pollution and its relationship with mortality and morbidity in Madrid, Spain. *Int. Arch. Occup. Environ. Health* 72:366–76.

Environmental Regional Government of Andalusia. 2016. La Red de Información Ambiental (REDIAM) y la Dirección General de Prevención y Calidad del Aire. onsejería del Medio Ambiente y Ordenación del Territorio. Junta de Andalucía.

European Union. 2008. Directive 2008/50/EC of the European Parliament and of the Council on ambient air quality and cleaner air for Europe, Official Journal of the European Union, Strasbourg, 21 May 2008.

Fundación para la Salud Geoambiental. 2016. *El dióxido de azufre SO2*. Accessed July 12, 2016. http://www.saludgeoambiental.org/dioxido-azufre-so2.

Hall, J. V., V. Brajer, and F. W. Lurmann. 2006. *The health and related economic benefits of attaining healthful air in the San Joaquin valley*. California, USA: Institute for Economic and Environmental Studies.

Instituto de Diagnóstico Ambiental y Estudios del Agua (IDAEA) e Instituto de Salud Carlos III. 2013. *Niveles, composición y fuentes de PM_{10} y $PM_{2,5}$ en*. España: Aragón, Asturias, Castilla La Mancha y Madrid. Barcelona: Subdirección General de Calidad del Aire y Medio Ambiente Industrial.

Jo, C. 2014. Cost-of-illness studies: Concepts, scopes, and methods. *Clin. Mol. Hepatol.* 20 (4):327–37. doi:10.3350/cmh.2014.20.4.327.

Junta de Andalucía. 2014a. Informe sobre los efectos en la salud asociados al plan de mejora de la calidad del aire de la zona industrial Bahía de Algeciras. Consejería de Salud. Secretaría General de Salud Pública y Participación.

Junta de Andalucía. 2014b. DECRETO 231/2013, de 3 de diciembre por el que se aprueban planes de mejora de la calidad del aire en determinadas zonas de Andalucía. *Boletín Oficial de la Junta de Andalucía., 10 de marzo de 2014, núm* 46: 1288.

Kampa, M., and L. Castanas. 2008. Human health effects of air pollution. *Environ. Pollut.* 151 (2):362–67. doi:10.1016/j.envpol.2007.06.012.

Kim, K., E. Kabir, and S. Kabir. 2015. A review on the human health impact of airborne particulate matter. *Environ. Int.* 74:136–43. doi:10.1016/j.envint.2014.10.005.

Krstic, G. 2012. A reanalysis of fine particulate matter air pollution versus life expectancy in the United States. *J. Air Waste Manage. Assoc.* 62 (9):989–91. doi:10.1080/10962247.2012.697445.

Lanzinger, S., A. Schneider, S. Breitner, M. Stafoggia, I. Erzen, M. Dostal, A. Pastorkova, S. Bastian, J. Cyrys, A. Zscheppang, T. Kolodnitska, and A. Peters. 2016. Associations between ultrafine and fine particles and mortality in five central European cities — Results from the UFIREG study. *Environ. Int.* 88:44–52. doi:10.1016/j.envint.2015.12.006.

Linares, C., and J. Díaz. 2009. Efecto de las partículas de diámetro inferior a 2,5 micras ($PM_{2,5}$) sobre los ingresos hospitalarios en niños menores de 10 años en Madrid. *Gaceta Sanitaria* 23 (3):192–97. doi:10.1016/j.gaceta.2008.04.006.

Lobdell, D., V. Isakov, L. Baxter, J. S. Touma, M. B. Smuts, and H. Özkaynak. 2011. Programs on a local scale: New haven case study. *Environ. Health Perspect.* 119 (4):487–93. http://ehp.niehs.nih.gov/1002636/.

Maji, K. J., A. K. Dikshit, M. Arora, and A. Deshpande. 2017b. Assessment of city level human health impact and corresponding monetary cost burden due to air pollution in India taking Agra as a model city. *Aerosol Air Qual. Res.* 17:831–42. doi:10.4209/aaqr.2016.02.0067.

Maji, K. J., A. K. Dikshit, M. Arora, and A. Deshpande. 2018. Estimating premature mortality attributable to PM2.5 exposure and benefit of air pollution control policies in China for 2020. *Sci. Total Environ.* 612:683–93. doi:10.1016/j.scitotenv.2017.08.254.

Maji, K. J., M. Arora, and A. K. Dikshit. 2017a. Burden of disease attributed to ambient PM2.5 and PM10 exposure in 190 cities in China. *Environ. Sci. Pollut. Res.* 24:11559–72. doi:10.1007/s11356-017-8575-7.

McCluskey, A., and A. Ghaaliq. 2007. Statistics IV: Interpreting the results of statistical tests. *Contin. Educ. Anaesth. Crit. Care Pain* 7 (6):208–12. doi:10.1093/bjaceaccp/mkm042.

Mengersen, K., S. A. Moynihan, and R. L. Tweedie. 2007. Causality and association: The statistical and legal approaches. *Stat. Sci.* 22 (2):227–54. doi:10.1214/07-STS234.

Morales, C. 2007. Caracterización de la calidad de sedimentos afectados por vertidos de petróleo: Comparación entre casos de vertidos accidentales (impacto agudo) frente a derrames continuos. (impacto crónico). PhD., University of Cádiz.

National Statistics Institute. 2014. Encuesta población activa. http://www.ine.es/.

National Statistics Institute. 2015. *Contabilidad Nacional de España*. Accessed December 21, 2015. http://www.ine.es/jaxi/menu.do?type=pcaxis&path=%2Ft35%2Fp008&file=inebase&L=0.

National Statistics Institute (NSI). 2017. Encuesta de población activa. http://www.ine.es/.

Netcen. 2002. Benefits table database: Estimates of the marginal external costs of air pollution in Europe. Accessed May 1, 2016. http://ec.europa.eu/environment/enveco/air/pdf/betaec02aforprinting.pdf.

Pablo-Romero, M., R. Román, J. M. González, and M. Praena-Crespo. 2015. Effects of fine particles on children´s hospital admissions for respiratory health in Seville (Spain). *J. Air Waste Manage. Assoc.* 65 (4):436–44. doi:10.1080/10962247.2014.1001499.

Pérez, L., J. Sunyer, and N. Künzli. 2009. Estimating the health and economic benefits associated with reducing air pollution in the Barcelona metropolitan area (Spain). *Gaceta Sanitaria* 23 (4):287–94. doi:10.1016/j.gaceta.2008.07.002.

Pope, C. A., R. T. Burnett, M. J. Thun, E. E. Calle, D. Krewski, K. Ito, and G. D. Thurston. 2002. Lung cancer, cardiopulmonary mortality, and long-term exposure to fine particulate pollution. *JAMA* 297 (9):1132–41. doi:10.1001/jama.287.9.1132.

Ritz, B., F. Yu, G. Chapa, and S. Fruin. 2000. Effect of air pollution on preterm birth among children born in Southern California between 1989 and 1993. *Epidemiology* 11:502–11.

Schwartz, J., F. Laden, and A. Zanobetti. 2002. The concentration-response relation between $PM_{2.5}$ and daily deaths. *Environ. Health Perspect.* 110:1025–29. doi:10.1289/ehp.021101025.

Spanish Government. 2011. *Real decreto 102/2011, de 28 de enero, relativo a la mejora de la calidad del aire.*

Spanish Register of Emissions and Pollutant Sources (SREPS). 2014. Conclusions - refining of mineral oil and gas. D 2014/738/UE BAT. http://www.prtr-es.es/Data/images/Decision_2014_738_UE_Refinerias_EN.pdf.

WHO. 2006. Air quality guidelines for particulate matter, ozone, nitrogen dioxide and sulfur dioxide. Global update 2005, WHO, Geneva.

WHO. 2013. Review of evidence on health aspects of air pollution – REVIHAAP. Copenhagen Ø, Denmark: WHO Regional Office for Europe.

WHO. 2015. *Economic cost of the health impact of air pollution in Europe: Clean air, health and wealth*. Copenhagen: WHO Regional Office for Europe.

WHO. 2016. Available evidence for the future update of the WHO global air quality guidelines (AQGs). Copenhagen Ø, Denmark: WHO Regional Office for Europe.

Wu, R., X. Song, Y. Bai, J. Chen, Q. Zhao, S. Liu, H. Xu, T. Wang, B. Feng, Y. Zhang, L. Zhong, X. Wang, F. Wu, and W. Huang. 2018. Are current Chinese national ambient air quality standards on 24-hour averages for particulate matter sufficient to protect public health? *J. Environ. Sci.* in press. doi: 10.1016/j.jes.2018.01.017.

Zhang, F., X. Liu, L. Zhou, Y. Yu, L. Wang, J. Lu, W. Wang, and T. Krafft. 2016. Spatiotemporal patterns of particulate matter (PM) and associations between PM and mortality in Shenzhen, China. *BMC Public Health* 16 (1). doi:10.1186/s12889-016-2725-6.

Zhao, X., X. Yu, Y. Wang, and C. Fan. 2016. Economic evaluation of health losses from air pollution in Beijing, China. *Environ. Sci. Pollut. Res.* 23 (12):11716–28. doi:10.1007/s11356-016-6270-8.