IS NATURAL GAS THE SOLUTION FOR PORT POLLUTION AVOIDANCE IN SPANISH SSS PORTS?

(Maritime air emissions / Port technologies)

JUAN JOSÉ Usabiaga Santamaría[1], Department of Nautical Sciences and Engineering, UniversitatPolitècnica de Catalunya, Barcelona, Spain, jusabiaga@cen.upc.edu, (0034) 934017921

MARCEL·LA Castells i Sanabra, Department of Nautical Sciences and Engineering, UniversitatPolitècnica de Catalunya, Barcelona, Spain, mcastells@cen.upc.edu, (0034) 934017939

F. XAVIER Martínez de Osés, Department of Nautical Sciences and Engineering, UniversitatPolitècnica de Catalunya, Barcelona, Spain, mcastells@cen.upc.edu, (0034) 934017942

ABSTRACT

Sustainability of transport is nowadays becoming more prevalent in the political agenda. Modes of transport are obliged by national and international governing bodies to improve their emission performances overall, making this requirement more acute in the case of the ports because of traffic density and port-city closeness. This paper assesses Short Sea Shipping (SSS) air pollution performance at Spanish ports, its major environmental weakness considering port calling high frequency. The paper analyses possible alternatives to reduce the generated impact, in particular feasibility and benefits of using natural gas instead or in combination with carbon fuels, such as diesel or oil. Four virtual scenarios are built up using different combinations of carbon fuels and methane, and when results are compared the outcome clearly reflects a more ecofriendly performance of those scenarios using methane gas together with carbon fuels. The impact valuation in the different considered scenarios presents savings of up to the 76% in air pollution external costs.

The paper is divided into following sections: Section 1. Introduction. The problem and the existing background are introduced; Section 2. Assessment model. Related research is discussed, determining the state of art and explaning the methodology to be followed; Section 3. Case study. Provides a practical development of the developed model based on SSS services in Spain; Section 4. Results. Analyses the results obtained; Section 5. Conclusions. Presents main findings.

Keywords: Short Sea Shipping, Environmental performance, Air pollution, Externalities

[1] Author for correspondence and Author for presenting

IS NATURAL GAS THE SOLUTION FOR PORT POLLUTION AVOIDANCE IN SPANISH SSS PORTS?

1. INTRODUCTION

Numerous are the Short Sea Shipping (SSS) lines calling at Spanish ports today. Their development has been favoured by the geographical location of Spainand by European transport policies seeking a balanced and more sustainable transport system.

Short Sea Shipping line operators often seek well located (close to industrial areas) and connected (infrastructures) ports, which are often located next to densely populated urban areas. Since SSS lines call frequently at sea ports, significant local air pollutants are expected in urban areas as a result of manoeuvring, hotelling and load/unload activities at ports.

Faced with this scenario, some policy instruments aimed at reducing local air pollution at ports are necessary, especially in those located close to urban areas where air pollution impact is more acute.

Ship air pollution externalities may be addressed through a variety of policies and measures, but these are not mutually exclusive. A general consensus exists in the literature pointing that several measures need to be implemented simultaneously to reduce air pollution externalities effectively. From one side, there are different technical alternatives existing to accomplish the current international regulations. Modification on board ships are not needed for sulphur emissions reduction as this is achieved using low sulphur fuels. However, slight changes in engines are needed for nitrogen oxides emissions reduction.

This paper studies the feasibility and efficiency of the use of methane as an ideal fuel and alternative power source in terms of air pollution externalities reduction for SSS traffic calling at Spanish ports. Methane will permit ports located in Spain to comply with the currently more stringent regulations regarding air pollution from shipping. The paper builds up four virtual scenarios with different combinations of methane and carbon fuels, compares them with the current scenario and presents obtained improvements with regards to the environmental performance of SSS services.

1.1. Spanish SSS network

Spain has the longest coastline among the European Union (EU) member states, which is approximately 8000 kilometres long. To provide shelter and service along this vast shoreline, Spain has a state controlled port network composed of 46 ports managed by 28 port authorities. These facts together with the strategic geographical location, border region geography and EU willingness to achieve a better balanced transport system, has fuelled the development of numerous SSS lines calling at Spanish ports.

Four vessel types operate in SSS lines: container, Ro-Pax, Ro-Ro and car carrier ships (FundaciónValenciaport, 2010). Moreover for analytical purposes, these are classed in two groups: RoRo or wheeled cargo ships (Ro-Ro, Ro-Pax and car carrier ships) and LoLo or container ships.

In the second half of 2010, 26 of the aforementioned 46 Spanish ports hosted SSS lines, 14 ports were located in the Atlantic and 12 in the Mediterranean. Spain was connected with 89 international ports in 29 different countries through SSS services.

Table 1.Spanish SSS ports.

Atlantic	Mediterranean
A coruña	Algeciras
Arrecife	Alicante
Bilbao	Almería
Cádiz	Barcelona
Ferrol-S.Cibrao	Cartagena
Gijón	Castellón
Las Palmas G.C.	Ceuta
Marín	Málaga
Pasajes	Motril
Puerto Rosario	Sagunto
S.C. Tenerife	Tarragona
Santander	Valencia
Sevilla	-
Vigo	-

Source: FundaciónValenciaport. BoletínLineport nº4, December 2010.

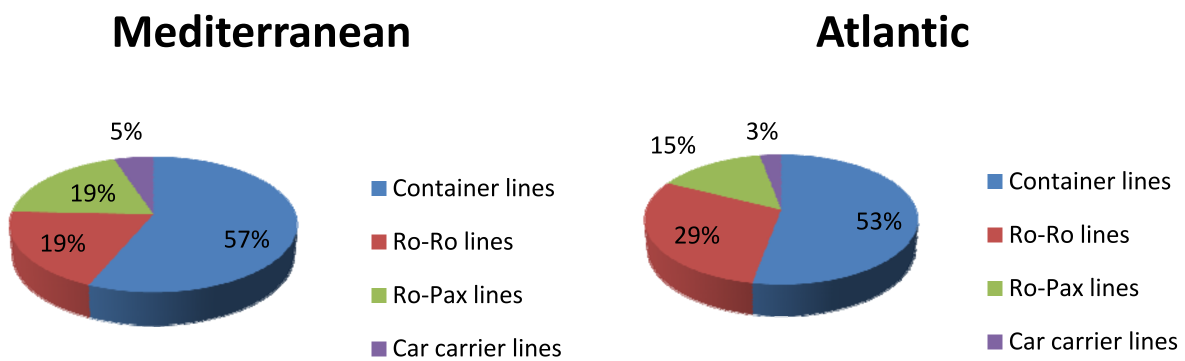
In terms of freight volume the most important ports within the Spanish port system are located in the Mediterranean. These are Algeciras, Valencia and Barcelona. Regarding SSS services is much the same, as reflected in the following table and graphics the Mediterranean predominance is notorious.

Table 2.Spanish SSS lines.

	Container lines	Ro-Ro lines	Ro-Pax lines	Car carrier lines	Total
Mediterranean	44	15	15	4	78
Atlantic	18	10	5	1	34
Both	9	1	-	2	12
Total	71	26	20	7	124

Source: FundaciónValenciaport. BoletínLineport nº4, December 2010.

Figure 1. Spanish SSS lines by ship type and service area.



Source: FundaciónValenciaport. BoletínLineport nº4, December 2010.

Shares are similar with regards to line types both in the Mediterranean and in the Atlantic; container lines are predominant in both. The most significant difference is the Ro-Ro share, which is ten percentage points higher in the Atlantic.

1.2. Short Seas Shipping air pollution

Although maritime transport is known due to its overall environmentally friendly performance, air pollution is its weak point. Air pollution accounts for the vast majority of the external costs produced by maritime transport, around the 90% (Usabiaga et al. 2011).

In port cities maritime activity is often a dominant source of urban pollution, causing environmental problems affecting both human health and ecosystems (Miola et al. 2009). According to a European Commission study the amount of pollution emitted by vessels during manoeuvring, loading, unloading, and hotelling phases are respectively 4.5% of SO_2 and 6.2% of NOx of the total emitted (ESPO, 2010). In 2009, noise and air quality were the most relevant issues in European port environmental management over operational activities, such as port waste management, dredging, and port expansion (Shrooten et al. 2008).

Maritime transport entails different environmental impacts both at sea and in ports. The scope of this paper covers the externalities produced by air pollutant emission by ships at port though. Covering emissions of Particulate Matter ($PM_{2.5}$), Sulphur Dioxide (SO_2), Oxides of Nitrogen (NOx), and Volatile Organic Compounds (VOC-s), which are considered the most relevant.

$PM_{2.5}$ and SO_2 emissions are relevant for local impact, considering that they are able to cause damage in the original form in which they are released. Moreover, as related to health problems, local impact is proportional to the proximity between emissions sources and receptors and the population density around the emissions source.

As ozone and aerosol precursors, NOx, VOC-s and SO_2 need to be transported a certain distance (hundreds of kilometres) in the atmosphere while undergoing chemical processes before generating associated secondary pollutants (ozone, nitrate aerosols, and sulphur aerosols), thus being the cause of rural impact. These associated pollutants produce impact mainly in the form of sulphur deposition (acid rain), eutrophication (excess of nitrogen nutrient), and ozone formation.

1.3. Regulatory framework for air pollutant emission from ships

It is complex to design and implement policies in order to abate air emissions, because of the international feature of the maritime activity. Howeverthe sector itself and the governing regulatory framework are becoming more stringent.

The main regulatory body is the International Maritime Organization (IMO), the United Nations specialized agency with responsibility for the safety and security of shipping and the prevention of marine pollution by ships.

Moreover the International Convention for the Prevention of Pollution from Ships, MARPOL 1973/1978 (IMO, 1978), is the main IMO convention aimed at preventing and minimizing pollution from ships. Air pollutant emissions from ships are covered by Annex VI, in force since 2005. This annex sets limits on Sulphur Oxide and Nitrogen Oxide emissions from ship exhausts as well as Particulate Matter and prohibits deliberate emissions of ozone depleting substances. In 2008 the IMO Marine Environment and Protection Committee (MEPC) amended Annex VI, and the revised text introduced emission control areas (ECA-s) in which, due to air quality problems, more stringent emission policies are in force since 1 July 2010.

The IMO NOx emission standards are known as Tier I-III standards. The Tier I standards were established in 1997 when air pollution was introduced into the Annex VI, while Tier II and III standards were introduced in 2008 when Annex VI was amended by the MEPC.

MARPOL Annex VI seeks a progressive reduction in SOx emissions limiting the sulphur content in marine fuel oils. The actual sulphur cap of 4.5% shall be reduced to 3.5%, by January 2012 and furthermore down to 0.5% by January 2020. Since July 2010 the sulphur limit in the ECA-s is of 1% and will be further reduce to a 0.1% by January 2015 (EMSA, 2010).

Progressively restrictive policies regarding NOx emissions are also being enforced by Annex VI, for instance Tier III applicable for new constructions after January 2016.

Moreover the EU is going beyond IMO emission standards, and its EC Sulphur Directives 2005/33 and 1999/32 have established even more stringent sulphur standards limiting the sulphur content in marine fuels for use while at berth in EU ports to 0.1%. Ships spending less than two hours at berth and ships which switch off all engines and use shore-side electricity while at berth are exempt.

1.4. The Problem

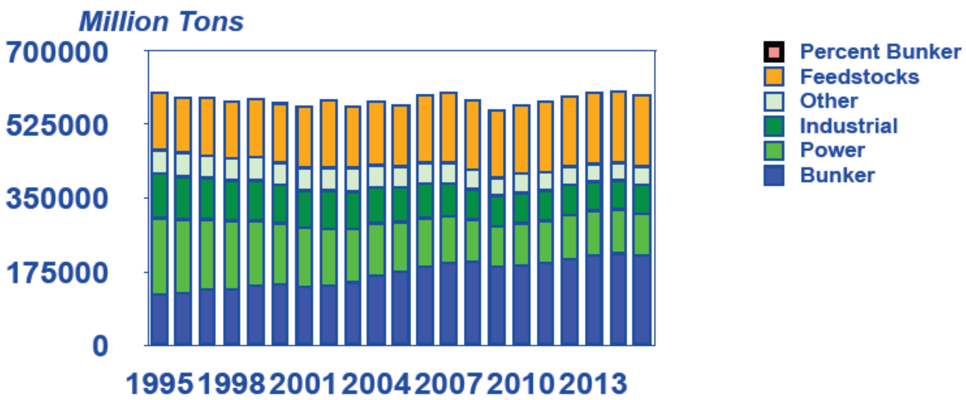
Several port cities are suffering from local air quality problems and are currently seeking appropriate instruments to correct them. Appropriate instruments need of comprehensive assessments and today there is no study attempting to quantify ship air pollution costs in port cities.

Due to their intrinsic characteristic of high frequency, hence spend long time berthed, SSS services are held responsible for a significant share of produced air pollution at their ports of call. Therefore alternative power supply for this traffic could result in improved eco-efficiency in terms of avoided pollution.

Policy instruments able to correct current air quality problems such as alternative power supply are expensive and require additional investment. Such investments are not executed if turnover and economic efficiency are not guaranteed. In this respect an extensive implementation for all ships and ports is not economically efficient. However if conceived for SSS traffic, efficiency is improved and its feasibility achieved based on a high utilization factor as well as a reduced initial investment upon servicing specific traffics in specific ports and terminals.

Furthermore, according to an IMO study, the use of heavy fuel oils will largely have to be abandoned once the 2015 SECA sulphur content limit is established. Transfer to low sulphur and thus cleaner fuels will increase fuel costs considerably as it is more expensive to produce cleaner fuels than heavy fuels. Besides fossil fuel resources are limited. These economic signals linked to existing and future restrictions on the use of fuels force to seriously address the energy conversion sector.

Figure 2.Total Bunker and Residual Fuel Demand.



Source: Refining and Bunker Trends to 2015, John Vautrain, 2009

1.5. Efficient Alternatives for Maritime Transport

Developments in ship structural design, achieving lighter ships, and technological innovation have reduced the engine average consumption and hence associated externalities. However this consumption still produces significant environmental impact and several alternative power supplies are being considered.

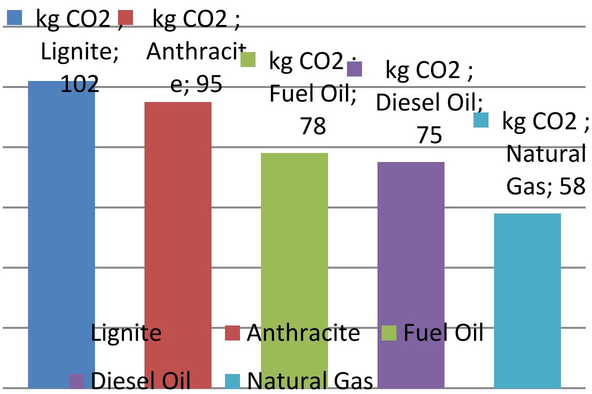
One of the efficient alternatives and the most widely used is "Fuel Switching ", which means the substitution of a high sulphur fuel, such as Heavy Fuel Oil (HFO), with a low sulphur fuel, such as Marine Gas Oil (MGO). This operation would occur as the ship approaches the port and here are certain ship requirements that must be in place before fuel switching can be considered. The ship must have a dual fuel system; the ship must have enough storage tanks, transfer pumps, separate piping, fuel treating equipment, and measuring equipment. In addition, ship's personnel must be trained to safely perform the fuel switching operation.

Shore-to-power or cold ironing alternative is also available, ships at berth are plugged via special wires to the shore-side power grid for electricity supply. Once plugged vessels shut down auxiliary engines. This measure implies low efficiency of primary energy production, pollutant emissions from electrical power plants, additional power from the grid (critical in peak hours) and low rate between annual running time and system costs. Ship shore to power connections enables a 90% reduction in SO_2, NOx and PM emissions (European Environmental Bureau, 2008).

Finally, ship engines can also operate on natural gas. This is an ideal fuel and alternative power supply in terms of air pollution externalities reduction to get compliment of the nowadays and even future, local and international regulations. In this way, the use of natural gas reduces SO_2emissions almost to zero since there is no sulphur on it. Emissions of NOx and PM are also significantly reduced.

There are also other proposals to improve ship environmental performance as nuclear power and the use of renewable energy in support of propulsion; in particular wind power, fuel cells and photovoltaic are on-going. However these are not developed enough.

Figure 3.CO_2 emission in the combustion.



Source: Ministerio de Industria, Turismo y Comercio de España

1.6.

1.8. Objectives

This paper studies the environmental performance, focusing in air pollution of wheeled cargo and container ships calling at Spanish mainland ports under the existing SSS services. Moreover it pursues the estimation of the overall benefit obtained in case of using natural gas as alternative power supply in port for Spanish SSS services in terms of avoided air pollution and derived externalities.

The attainment of the main objective requires of estimating both current SSS at port air pollutants emission as well as their impact in form of externalities. Scenarios in which natural gas is used are built to compare them with actual emissions and be able to estimate obtained benefits.

Finally this work tries to lay foundations for a comprehensive assessment methodology of natural gas projects implementation at ports, analysing the feasibility of natural gas usage as an alternative power supply for vessels when at port.

2. ASSESSMENT MODEL

This section describes the assessment model to evaluate air pollution of SSS in current Spanish ports and validates the viability of providing methane gas to ships while at berth. The developed model conceptualizes a means for analysis, in terms of port pollution avoidance, for port conversions in natural gas providers for berthed ships. This would be an alternavite solution for complying with the European directive 2005/33/EC on sulphur contents for fuels used at port.

2.1. Port and traffic identification

This paper studies SSS air pollution costs at Spanish ports, therefore the first task is to identify SSS services within the Spanish port network. In this respect SSS services must be perfectly defined and this definition is given by the European Commission in its COM(1999) 317 final. This communication defines SSS as *"the movement of cargo and passengers by sea between ports situated in geographical Europe or between those ports and ports situated in non-European countries having a coastline on the enclosed seas bordering Europe"*.

The Lineport bulletin published, every 6 months, by the FundaciónValenciaport is a data set gathering all SSS services operating in Spain. This work uses data given by this bulletin to identify all SSS services as well as the characteristics of the services (ports of call, frequency, vessel characteristics, etc.)

However this bulletin does not hold data on vessel's Main Engine (ME) and Auxiliary Engine (AE), and this information is necessary for air pollutants emission estimation. For this reason a study by Takashi H. et al. (2006) is used to be able to estimate the ME and AE power from ship main dimensions using regression models.

2.2. Scenarios

Five different scenarios are considered for the emission estimation. Scenario 1 represents the current and real scenario that using MGO with a maximum of 0.1% sulphur content when at port. Other virtual scenarios using a mixture of MGO/MDO/HFO and natural gas in different proportions are built to assess and compare total air emissions in terminal ports by using also natural gas fuelled ships in order to calculate the specific emission reductions potential in port operation. The following scenarios have been posed:

Table 3. Scenarios considered in the analysis.

Scenario	Fuel	Engine efficiency
Scenario 1 (current)	Marine Gas Oil (100%).	34.4%
Scenario 2	Mixture of Marine Gas Oil (20%) and Natural Gas (80%)	32.9%
Scenario 3	Mixture of Marine Gas Oil (5%) and Natural Gas (95%)	45%
Scenario 4	Mixture of Marine Diesel Oil (25%) and Natural Gas (75%)	32.9%
Scenario 5	Mixture of HFO/IFO (40%) and	34.4%

	Natural Gas (60%)	

Source: Gil Aizpuru (2011). Doctoral Thesis

Before analysing the emissions emitted by proposed scenarios, it has been necessary to calculate the sulphur contentof the mixture forscenarios 2, 3, 4 and 5 from the following formula:

$$S_{\%tot} = \frac{\sum_i CP_i \cdot S_{\%i} \cdot C_i}{\sum_i \%C_i \cdot CP_i} \quad (1)$$

%C Energetic percentage (%)
CP Calorific power (kJ/kg)
$S_{\%}$ Sulphur content percentage (%)
i Fuel type (Bunker Fuel Oil, Marine Diesel Oil, Marine Gas Oil, Natural Gas)

Results obtained are shown in table 4:

Table 4. Results of the sulphur content of the mixture of the proposed scenarios.

Scenario	Sulphur content ($S_{\%}$)
Scenario 2	0.034%
Scenario 3	0.027%
Scenario 4	0.24%
Scenario 5	1.97%

Source: Gil Aizpuru (2011). Doctoral Thesis

From the above results, scenarios 4 and 5 do not comply with sulphur content port regulation and have been rejected for this study.

2.3. Emission estimation and impact valuation

Once target traffic and ports have been identified, their current environmental performance regarding air pollution is assessed. Emissions from maritime transport need of a two dimension analysis, both quantity and quality of emitted pollutants and the place where the pollutants have been emitted must be assessed.

2.3.1. Emission estimation

Existing literature and authors' studies estimate ship emissions following two different methodologies: fleet activity-based emissions estimation methodology or fuel sales- based estimation methodology. Due to the limited geographical extent of this work, the fleet activity methodology is chosen as suggested by Winther (2008). This methodology uses detailed ship type and traffic data together with emission factors in order to obtain estimates.

In addition, a top-down approach is chosen for ship type and traffic data analysis. As different ship types have different particulars (gross tonnage (GT) and engine type) disintegration is needed. Therefore port calls are split into two groups formed by container and wheeled cargo lines. Port calls in each of these two groups are considered as a single activity with same characteristics (mean GT, mean engine power, mean auxiliary engine power, hotelling times, and emissions factors).

The methodology quoted as Tier III in the EMEP/EEA air pollutant emission inventory guidebook 2009 is used for the estimation of polluting emissions from ships. This methodology requires detailed ship movement data besides technical information on ships. Further focusing on the emissions estimation methodology demonstrates that this work follows the procedure using data on installed main and auxiliary engine power, load factor, and total time spent on each navigation phase. The Tier III method also employs specific polluting emissions factors for different engine types and fuel combinations, as well as for navigation phases (See table 12 and 13).

Emission factors differ between the different considered scenarios, those for the Scenario 1 are directly extrapolated from EMEP/EEA air pollutant emission inventory guidebook 2009, but those corresponding to the other two analysed scenarios, Scenario 2 and 3, are obtained from Gil J.M. (2011).

2.3.2. Impact valuation

The majority of air pollution externalities are site specific. That is, they are produced at a local scale just after the pollutants (PM and SOx primarily) have been released. In order to achieve a real estimation, great detail is required; therefore, a bottom-up approach has been chosen for the emissions' geographical characterization (Miola et al, 2010).

For site-specific air pollution externalities cost calculation, two estimates are critical: on the one hand, the quantity of pollutants emitted ($PM_{2.5}$, SO_2, NOx and VOCs), and on the other hand, the impact of pollutants that are released. Well known projects already exist regarding both, for polluting emissions estimation as described in the EMEP/EEA Air Polluting Emissions Inventory Guidebook 2009, and for impact estimation, as described in the "Benefits Table Database: Estimates of the Marginal External Costs of Air Pollution in Europe (BETA)" and "Clean Air For Europe Program (CAFE)."

The Benefits Table Database (BETA) (European Commission, 2002), published in 2002, provides a straightforward estimation of air pollution's overall external costs, putting together both urban and rural externalities. However, once new air pollution's external costs were published under the CAFE program, in 2005 (European Commission, 2001), experts agreed that previous rural external costs given by BETA were under estimating actual costs.

This paper maintains the methodology given by BETA to list urban and rural external costs, but takes updated rural external costs provided by the CAFE program. The cost estimation done under the CAFE program considers human exposure to $PM_{2.5}$, human exposure to ozone, and exposure of crops to ozone. Although more impacts are known, there still is not sufficient information to evaluate them with guarantee. Moreover, in an attempt to achieve comprehensive results, the valuation done by the CAFE program considers four different sensitivity scenarios that lead to four different results for each geographical area being considered. Therefore, the emissions impact assessment model is composed of a top-down approach in the emissions evaluation aspect and a bottom-up approach in the geographical characterization aspect. In this manner, the model achieves a comprehensive assessment, taking into account the specifics of each emissions point as well as the details of the emitting vessel type.

Finally, the overall result is obtained through the aggregation of individual results for each geographical location being considered.

2.4. Comparative results

Once the impact for each of the considered scenarios, valuated in Euros (€), has been estimated results are directly compared. This comparison results evident and straight forward as estimations has been made using the same unit and consider the same area and period.

3. CASE STUDY

This section provides a practical development of the theoretical methodology explained in the above section. For this purpose SSS lines operating in Spain are studied.

3.1. Short Sea Shipping services: ports, lines and vessels

First, data provided by the Lineport Bulletin is studied, identifying Spanish SSS ports , number of lines operating in each of them and vessel types engaged. The following information is obtained:

Table 5. SSS lines in the Atlantic Spain.

Ports		SSS lines	Mean Frequency (weekly)	Ro-Ro/Ro-Pax lines	Container lines
Atlantic	A coruña	1	1.3	0	1
	Arrecife	2	1.3	0	2
	Bilbao	12	1.3	4	8
	Cádiz	6	1.3	1	5
	Ferrol-S.Cibrao	1	1.3	1	0
	Gijón	3	1.3	1	2
	Las Palmas G.C.	9	1.3	2	7
	Marín	1	1.3	0	1
	Pasajes	3	1.3	3	0
	Puerto Rosario	2	1.3	0	2
	S.C. Tenerife	8	1.3	2	6
	Santander	7	1.3	7	0
	Sevilla	1	1.3	0	1
	Vigo	14	1.3	4	10

Source: FundaciónValenciaport. BoletínLineport nº4, December 2010.

Table 6. SSS lines in the Mediterranean Spain.

Ports		SSS lines	Mean Frequency (weekly)	Ro-Ro/Ro-Pax lines	Container lines
Mediterranean	Algeciras	14	2.4	3	11
	Alicante	4	2.4	3	1
	Almería	3	2.4	3	0
	Barcelona	48	2.4	14	34
	Cartagena	4	2.4	3	1
	Castellón	13	2.4	3	10
	Ceuta	1	2.4	0	1
	Málaga	1	2.4	1	0
	Motril	1	2.4	0	1
	Sagunto	7	2.4	7	0
	Tarragona	9	2.4	4	5
	Valencia	40	2.4	9	31

Source: FundaciónValenciaport. BoletínLineport nº4, December 2010.

Four ship types operate in Spanish SSS services Container, Ro-Ro, Ro-Pax and car carrier ships. However the Lineport database, our data source, groups these four into two groups: container ships and wheeled cargo ships, therefore in this study also these two groups are considered.

Lineport database has no information on engine type and power. Instead information on average ship dimensions is given. This work uses this alternative data to estimate average engine power both for Main Engine (ME) and Auxiliary Engine (AE) in the considered two ship types.

Table 7. Average container ship dimensions by area.

Container ships	Length overall	Breath	Draft
Atlantic side	160	23.8	8.8
Mediterranean side	195.8	27.7	10.3

Source: FundaciónValenciaport. BoletínLineport nº4, December 2010.

Table 8. Average wheeled cargo ship dimensions by area.

Wheeled cargo ships	Length Overall	Breath	Draft
Atlantic side	160.6	24.3	6.8
Mediterranean side	125.4	22.4	5.8

Source: FundaciónValenciaport. BoletínLineport nº4, December 2010.

Regression models do not relate directly ship dimensions and engine power, but rather relate ship dimensions with gross tonnage (GT) and dead weight tonnage (DWT). The following regression models given by Takahashi H. et al. (2006) are used for GT estimation:

Table 9. Regression models used for container ship DWT and GT estimation.

DWT-LOA			
Ship Type	**Regression**	**Coefficients of determination (R^2)**	**Standard deviation (σ)**
Container ship (DWT<35000)	$LOA=5.6834.DWT^{0,3470}$	0.931	0.026
GT-DWT			
Container ship	GT=0.5285DWT	0.988	2.202

Source: own, based in Takahashi H. et al. 2006.

Table 10. Regression models used Ro Ro and Car carrier GT estimation.

GT-LOA			
Ship Type	**Regression**	**Coefficients of determination (R^2)**	**Standard deviation (σ)**
Ro-Ro ship <30000 GT	$LOA=5.9914.GT^{0,3487}$	0.906	0.07
GT-Breadth			
Car carrier<30000 GT	$GT=2.7742.B^{0,2195}$	0.897	0.024

Source: own, based in Takahashi H. et al. 2006.

Once GT for average ships is known, regression models given by EMEP/EEA air pollutant emission inventory guidebook 2009 are used to estimate ME and AE engine power.

Table 11. Installed main engine power as a function of gross tonnage and estimated average power vessel ratio of auxiliary engines/main engine.

Ship categories	Installed main engine power	Estimated average power vessel ratio of Auxiliary Engines/Main Engine
Container	$2.9165 \cdot GT^{0.8719}$	0.25
Ro-Ro Cargo	$164.578 \cdot GT^{0.4350}$	0.24

Source: Study for 2010 and 1997 world fleets: Entec (2007) for 2006 Mediterranean Sea Fleet.

Ship type disaggregation is important since ship characteristics (engine type, ME and AE power) and hotelling times are type-related.

The majority of vessels that form a part of wheeled cargo ships are equipped with Medium Speed Diesel (MSD) ME and MSD or High Speed Diesel (HSD) AE. On the other hand, the container ship fleet is on average equipped with Slow Speed Diesel (SSD) ME and MSD or HSD AE [16], being the emission factors different from wheeled cargo ships.

The following tables gather the emissions factors used for calculation. These have been updated for the year 2010 from emissions factors given by Entec for the year 2005. All of them correspond to Marine Gas Oil (MGO), as regulations in 2010 did not permit sulphur content above 0,1% at port.

Table 12. Emissions factors of ME burning MGO in hoteling phase.

Ship Type	**ME**	**$PM_{2.5}$ (g/kW·h)**	**SO_2 (g/kW·h)**	**NOx (g/kW·h)**	**VOCs (g/kW·h)**
RoRo cargo	MSD	0.774	0.45	9.88	1.5
Container	SSD	0.774	0.4	11.88	1.8

Source: own, based on Entec 2005.

Table 13. Emissions factors of AE burning MGO in hoteling phase.

Ship Type	**AE**	**$PM_{2.5}$ (g/kW·h)**	**SO_2 (g/kW·h)**	**NOx (g/kW·h)**	**VOCs (g/kW·h)**
RoRo cargo	MSD/HSD	0.2592	0.45	12.94	0.4
Container	MSD/HSD	0.2592	0.45	12.94	0.4

Source: own, based on Entec 2005.

Once emissions factors of current scenario are known (scenario 1, MGO 100%), it is necessary to obtain emission factors of scenarios 2 and 3. For virtual scenarios only emission factors for PM2,5, SO2 and NOx are available. This lack of data does not endanger result validity as the impact produced by NMVOC-s can be considered negligible. NMVOC-s represent less than 1% of the total produced impact.

Table 14. Emissions factors of AE burning a mixture of MGO and NG in hoteling phase.

Scenario	**$PM_{2.5}$ (g/kW·h)**	**SO_2 (g/kW·h)**	**NOx (g/kW·h)**	**VOCs (g/kW·h)**
Scenario 2: MGO (20%)/NG (80%)	0.071	0.091	11.77	NA
Scenario 3: MGO (5%)/NG (95%)	0.024	0.022	11.06	NA

Source: Gil Aizpuru (2011). Doctoral Thesis

Auxiliary engines are operated both in maneuvering and hotelling phases, although contribute more while at berth (when the main engine is shut down). Hotelling times for each vessel category are based on average times and are reported in the following table:

Table 15.Average duration of port activities.

Ship categories	Hoteling time (h)
Container	14
Ro-Ro Cargo	5.5

Source: Entec 2002

ME and AE load factors at different navigation phases necessary for calculation are shown in the table below:

Table 16. Estimated % load Maximum Continuous Rating (MCR) of Main Engine (ME) and Auxiliary Engine (AE) for hoteling phase.

Phase	**% load of MCR of ME**	**% time all ME operating**	**% load of MCR of AE**
Hoteling	20	5	40

Source: Entec 2002

3.2. Air pollutant emission estimation

The Tier 3 approach calculates the emissions (E) on a single trip basis, considering the three different navigation phases of a journey.

$$Etrip = Ehotelling + Emaneuvering + Ecruising$$

Once all the necessary variables are known, the following formula corresponding to Tier 3 methodology is applied. As a result, emissions for each of the ports, ship types, and pollutants being considered are obtained.

$$E_{port,i,s,m} = \sum_p [T_p \sum_e (P_e \times LF_e \times EF_{e,i,s,m,p})] (2)$$

Eport emissions at port (tons)
EF emissions factor (tons/kWh)
LF engine load factor (%)
P nominal engine power (kW)
T time (hours)
e engine (main, auxiliary)
i pollutant ($PM_{2,5}$, SO_2, NOx, VOC)
s ship type (Ro-Ro and Container ship)
m fuel type (Bunker Fuel Oil, Marine Diesel Oil, Marine Gas Oil, Natural Gas)
p trip phase (cruise, maneuvering, hoteling)

In this case, hoteling phase for the evaluation of the emission impact of the different scenarios is considered.

3.3. Emission impact valuation

Last step is to evaluate the impact of the emissions, which are estimated using BETA and CAFE projects.

Both local and rural impacts are estimated. For local impact estimation, as set in the BETA project, urban externalities for $PM_{2.5}$ and SO_2 in a standard city with a population of 100,000 people are multiplied by the corresponding factors, depending on the population around the selected port. Then the country-specific rural impact is added. For this purpose, rural impact given for Spain in the CAFE project is used. The CAFE project lists four different types of rural impact, depending on different cases of sensitivity. Hence, four different final impact estimations corresponding to each of the four sensitivity scenarios used in the rural impact estimation are obtained.

Table 17.Local impact calculation factors.

Population	Factor	$PM_{2.5}$ (€/tm)	SO_2 (€/tm)
Standard city with a population of 100,000 people	1	33000 €	6000 €
500,000	5	165000 €	30000 €
1,000,000	7.5	247500 €	45000 €
Several million people	15	495000 €	90000 €

Source: Holland, M.R. and Watkiss, P. Benefits Table database: Estimates of the marginal external costs of air pollution in Europe, 2002.

Table 18. Rural impact per ton of pollutant emitted.

Scenario	$PM_{2.5}$ (€/tm)	SO_2 (€/tm)	NOx (€/tm)	VOCs (€/tm)
Sensitivity case 1	19000 €	4300 €	2600 €	380 €

Sensitivity case 2	29000 €	6600 €	3800 €	510 €
Sensitivity case 3	37000 €	8400 €	5200 €	920 €
Sensitivity case 4	54000 €	12000 €	7200 €	1100 €

Source: Holland M. et al. Damages per ton of $PM_{2.5}$, SO_2, NOX, and VOC-s emissions from each EU25 Member State (excluding Cyprus) and surrounding seas.

As mentioned previously, local impact is only produced by $PM_{2.5}$, and SO_2, NOx, and VOC-s are only relevant to rural impact.

(3)

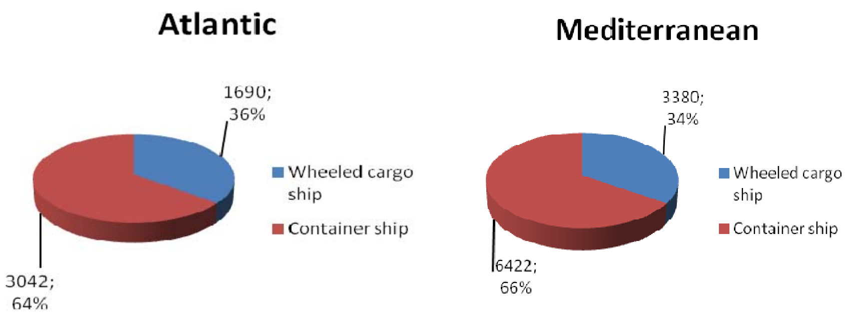
(4)

Ilport Local impact at the port being considered (€/ton)
It Total impact at the port being considered (€)
Ir Rural impact in the country being considered (€/ton)
Eport emissions at port (ton)
Si Standard impact in a city with a population of 100000 people (€/ton)
Pf Population factor at the port being considered
i pollutant ($PM_{2.5}$, SO_2, NOx, VOC)
s ship type (RoRo, Passenger, Container)
m fuel type (Bunker Fuel Oil, Marine Diesel Oil, Marine Gas Oil)

4. RESULTS

This section shows and analyses results obtained in the considered case study, Spanish SSS. Results are first split for the Atlantic and Mediterranean, and finally overall results are presented.

Figure 5.Port calls per year depending on area and ship type.



Source: Own.

Port call shares per ship types and areas result similar and average hotelling times are the same. However as average ship dimensions differ from the Atlantic to the Mediterranean emissions per port call are not the same in each of the considered areas. These are greater in the Mediterranean.

Table 19.Emissions obtained per port call and area.

		$PM_{2.5}$ (tm/portcall)	SO_2 (tm/portcall)	NOx (tm/portcall)	NMVOC (tm/portcall)
Atl.	**Scenario 1**	4.2E-03	6.2E-03	1.8E-01	7.2E-03
	Scenario 2	9.7E-04	1.2E-03	1.6E-01	N/A
	Scenario 3	3.4E-04	3.0E-04	1.5E-01	N/A
Med.	**Scenario 1**	6.4E-03	8.6E-03	2.7E-01	1.1E-02
	Scenario 2	1.5E-03	1.9E-03	2.5E-01	N/A
	Scenario 3	5.1E-04	4.6E-04	2.3E-01	N/A

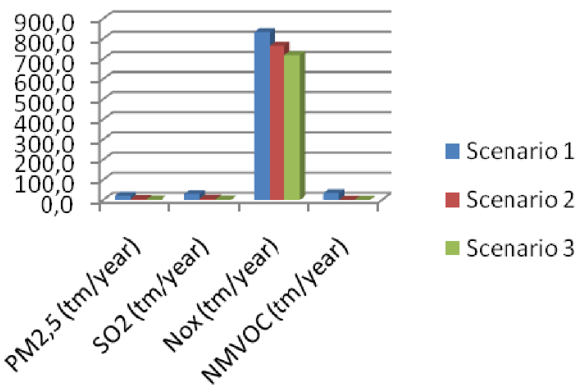
Source: Own.

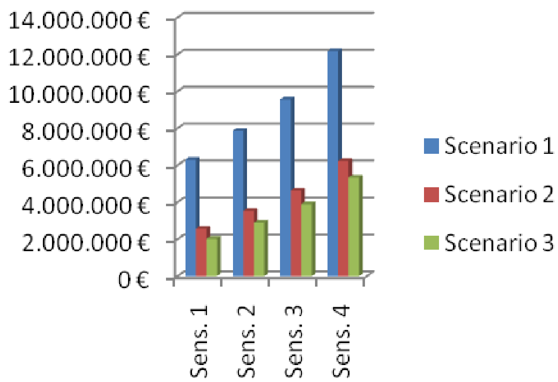
Table 20.SSS services emissions and overall impact in the Atlantic.

		Atlantic								Total
		PM_{25}		SO_2		NOx		NMVOC		
		(tm/year)	(€/year)	(tm/year)	(€/year)	(tm/year)	(€/year)	(tm/year)	(€/year)	
Scenario 1	**Sens. 1**	19.9	3008714 €	121.9	5184368 €	3479.0	9258600 €	142.2	70756 €	36798927 €
	Sens. 2	19.9	3297714 €	121.9	5474168 €	3479.0	13531800 €	142.2	94962 €	42401133 €
	Sens. 3	19.9	3528914 €	121.9	5700968 €	3479.0	18517200 €	142.2	171304 €	48501675 €
	Sens. 4	19.9	4020214 €	121.9	6154568 €	3479.0	25639200 €	142.2	204820 €	57836291 €
Scenario 2	**Sens. 1**	4.6	498749 €	24.7	941990 €	3193.0	7564700 €	N/A	N/A	12466198 €
	Sens. 2	4.6	545749 €	24.7	993510 €	3193.0	11056100 €	N/A	N/A	16185118 €
	Sens. 3	4.6	583349 €	24.7	1033830 €	3193.0	15129400 €	N/A	N/A	20439538 €
	Sens. 4	4.6	663249 €	24.7	1114470 €	3193.0	20948400 €	N/A	N/A	26638378 €
Scenario 3	**Sens. 1**	1.6	159562 €	6.0	227268 €	3000.4	7109440 €	N/A	N/A	8670817 €
	Sens. 2	1.6	175562 €	6.0	239688 €	3000.4	10390720 €	N/A	N/A	12024517 €
	Sens. 3	1.6	188362 €	6.0	249408 €	3000.4	14218880 €	N/A	N/A	15910397 €
	Sens. 4	1.6	215562 €	6.0	268848 €	3000.4	19687680 €	N/A	N/A	21500637 €

Source: Own.

Figure 6.SSS services emissions and overall impact in the Atlantic





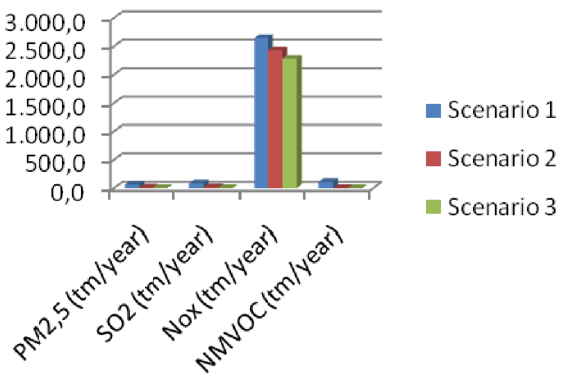
Source: Own.

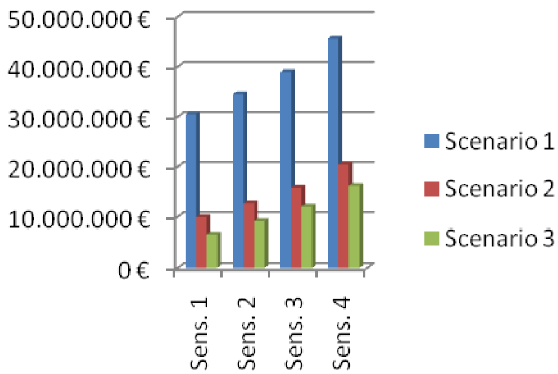
Table 21.SSS services emissions and overall impact in the Mediterranean.

		Mediterranean								Total
		$PM_{2.5}$		SO_2		NOx		NMVOC		
		(tm/year)	(€/year)	(tm/year)	(€/year)	(tm/year)	(€/year)	(tm/year)	(€/year)	
Scenario 1	Sens. 1	63.1	19276488 €	121.9	5184368 €	3479.0	9258600 €	142.2	70756 €	36798927 €
	Sens. 2	63.1	20002488 €	121.9	5474168 €	3479.0	13531800 €	142.2	94962 €	42401133 €
	Sens. 3	63.1	20583288 €	121.9	5700968 €	3479.0	18517200 €	142.2	171304 €	48501675 €
	Sens. 4	63.1	21817488 €	121.9	6154568 €	3479.0	25639200 €	142.2	204820 €	57836291 €
Scenario 2	Sens. 1	14.6	3460759 €	24.7	941990 €	3193.0	7564700 €	N/A	N/A	12466198 €
	Sens. 2	14.6	3589759 €	24.7	993510 €	3193.0	11056100 €	N/A	N/A	16185118 €
	Sens. 3	14.6	3692959 €	24.7	1033830 €	3193.0	15129400 €	N/A	N/A	20439538 €
	Sens. 4	14.6	3912259 €	24.7	1114470 €	3193.0	2094.400 €	N/A	N/A	26638378 €
Scenario 3	Sens. 1	5.0	1174547 €	6.0	227268 €	3000.4	7109440 €	N/A	N/A	8670817 €
	Sens. 2	5.0	1218547 €	6.0	239688 €	3000.4	10390720 €	N/A	N/A	12024517 €
	Sens. 3	5.0	1253747 €	6.0	249408 €	3000.4	14218880 €	N/A	N/A	15910397 €
	Sens. 4	5.0	1328547 €	6.0	268848 €	3000.4	19687680 €	N/A	N/A	21500637 €

Source: Own.

Figure 7.SSS services emissions and overall impact in the Mediterranean





Source: Own.

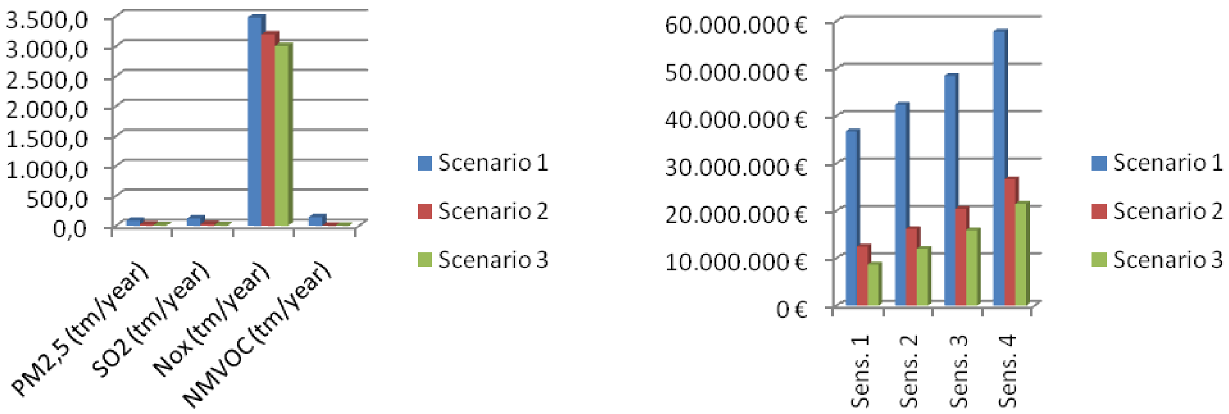
Obviously emissions in Mediterranean ports, due to higher emissions per call at port and heavier traffic, are higher than in the Atlantic. Registered emissions in the Mediterranean ports are almost three times higher than those in the Atlantic.

Table 22.SSS services emissions and overall impact in Spain.

		Overall								Total
		PM 2,5		SO_2		NOx		NMVOC		
		(tm/year)	(€/year)	(tm/year)	(€/year)	(tm/year)	(€/year)	(tm/year)	(€/year)	
Scenario 1	Sens. 1	83.0	22285203 €	121.9	5184368 €	3479.0	9258600 €	142.2	70756 €	36798927 €
	Sens. 2	83.0	23300203 €	121.9	5474168 €	3479.0	13531800 €	142.2	94962 €	42401133 €
	Sens. 3	83.0	24112203 €	121.9	5700968 €	3479.0	18517200 €	142.2	171304 €	48501675 €
	Sens. 4	83.0	25837703 €	121.9	6154568 €	3479.0	25639200 €	142.2	204820 €	57836291 €
Scenario 2	Sens. 1	19.3	3959508 €	24.7	941990 €	3193.0	7564700 €	N/A	N/A	12.466.198 €
	Sens. 2	19.3	4135508 €	24.7	993510 €	3193.0	11056100 €	N/A	N/A	16.185.118 €
	Sens. 3	19.3	4276308 €	24.7	1033830 €	3193.0	15129400 €	N/A	N/A	20.439.538 €
	Sens. 4	19.3	4575508 €	24.7	1114470 €	3193.0	20948400 €	N/A	N/A	26.638.378 €
Scenario 3	Sens. 1	6.5	1334109 €	6.0	227268 €	3000.4	7109440 €	N/A	N/A	8.670.817 €
	Sens. 2	6.5	1394109 €	6.0	239688 €	3000.4	10390720 €	N/A	N/A	12.024.517 €
	Sens. 3	6.5	1442109 €	6.0	249408 €	3000.4	14218880 €	N/A	N/A	15.910.397 €
	Sens. 4	6.5	1544109 €	6.0	268848 €	3000.4	19687680 €	N/A	N/A	21.500.637 €

Source: Own.

Figure 8.SSS services emissions and overall impact in Spain.



Source: Own.

The environmental performance in both of the considered virtual scenarios improves significantly comparing it with the current and real scenario. Overall emission reductions in volume correspond to a 15% and 21% respectively for scenarios 2 and 3. However with regards to $PM_{2.5}$ and SO_2 is where the best results are obtained. The second scenario achieves a reduction of the 76.7% for $PM_{2.5}$, 79.7% for SO_2 and 8.2% for NOx. On the other hand the third scenario's even improves the achieved reduction by the second scenario: $PM_{2.5}$ emissions are reduced by 92.2%, SO_2 by 95.1% and NOx by 13.8%.

Regarding emission impact reduction, achieved results by the proposed two virtual scenarios are even better. $PM_{2.5}$ and SO_2 emissions are more damaging than NOx and NMVOC emissions, and as proposed alternative scenarios reduce more acutely emissions from the first set of pollutants obtained savings in emission impact outstrip notably the overall emission reduction in volume. Overall emission reduction in volume accounted for the 15% and 21% respectively for scenarios 2 and 3, when it comes to emission impact savings, reductions go from the 46% to the 66%

depending on the selected sensitivity scenario for the second scenario, and from the 62% to 76% for the third scenario.

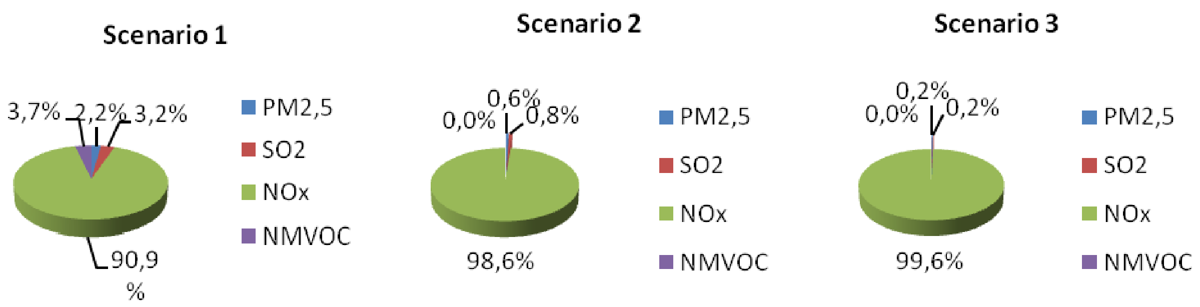
The following tables show the shares per air pollutant in the considered three scenarios. NOx emissions are predominant in the three of them, increasing its significance in each of the virtual scenarios as the main reductions are achieved for the other three pollutants. NMVOC emissions exist, although its impact comparing it with the overall impact is neglegible.

Table 23.Air pollutant share by scenario.

	$PM_{2.5}$	**SO_2**	**NOx**	**NMVOC**
Scenario 1	2.2%	3.2%	90.9%	3. 7%
Scenario 2	0.6%	0.8%	98.6%	N/A
Scenario 3	0.2%	0.2%	99.6%	N/A

Source: own.

Figure 9.Air pollutant share by scenario.



Source: Own.

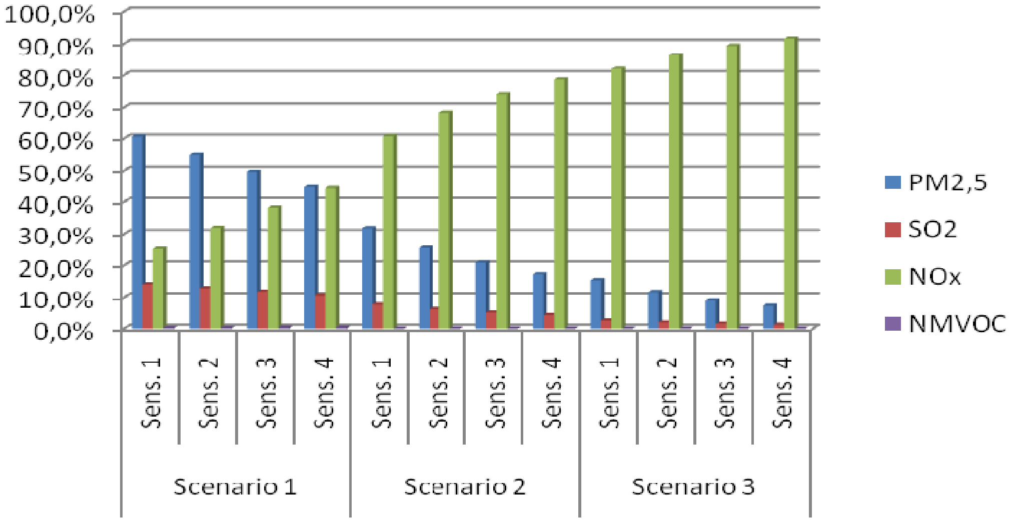
Table 24.Air pollutant impact share in the considered four sensitivity cases and three scenarios.

		$PM_{2.5}$ (impact)	**SO_2 (impact)**	**NOx (impact)**	**NMVOC (impact)**
Scenario 1	**Sens. 1**	60.6%	14.1%	25.2%	0.2%
	Sens. 2	55.0%	12.9%	31.9%	0.2%
	Sens. 3	49.7%	11.8%	38.2%	0.4%
	Sens. 4	44.7%	10.6%	44.3%	0.4%
Scenario 2	**Sens. 1**	31.8%	7.6%	60.7%	N/A
	Sens. 2	25.6%	6.1%	68.3%	N/A
	Sens. 3	20.9%	5.1%	74.0%	N/A
	Sens. 4	17.2%	4.2%	78.6%	N/A
Scenario 3	**Sens. 1**	15.4%	2.6%	82.0%	N/A
	Sens. 2	11.6%	2.0%	86.4%	N/A
	Sens. 3	9.1%	1.6%	89.4%	N/A
	Sens. 4	7.2%	1.3%	91.6%	N/A

Source: Own.

Both proposed scenarios achieved to reduced notably the sepecific weight of $PM_{2.5}$ and SO_2 within the caused impact and NOx turns into the most relevant are pollutant both in terms of quantity and caused externalities, impact.

Figure 10.Air pollutant impact share in the considered four sensitivity cases and three scenarios.



Source: Own.

Final figures are not the same in all sensitivity cases, not only with regards to the overall impact, but also regarding the impact share corresponding to each pollutant. The share of local impact decreases insofar as we change from sensitivity case 1 to 4. This could have been expected since sensitivity scenarios have only been considered for rural impact.

5. CONCLUSIONS

This paper has developed a “smart port and traffic identification model” to evaluate the impact of several types of pollutant emissions from maritime transport at Spanish SSS ports. The results from the model identifies 26 Spanish ports that hosted SSS lines, 14 ports are located in the Atlantic and 12 in the Mediterranean and two ship types (container and wheeled cargo ship).

Air pollution emissions have been quantified for selected ports in current scenario, accounting for over 3800 tons. The main pollutant in regards to quantity is NOx, representing 90.9% of the total, due to its high emission factor.

However with regards to air pollutants emission impact, $PM_{2.5}$ is the most damaging. Even though $PM_{2.5}$ emissions are the smallest in quantity, its high ratio between caused impact per tonne emitted makes of it the most damaging air pollutant of SSS services at port.

There are different measures that can be taken while at berth in order to minimise air pollution emissions and hence its externalities. In the study two virtual scenarios using a mixture of natural gas instead of pure oil derivates are presented. The minor emissions volume associated to natural gas, turns it an ideal fuel to be used at port.

Proposed two scenarios result really successful as they achieved to reduce significantly $PM_{2.5}$ and SO_2 emissions, which indeed are the most damaging pollutants per emited tonne. Even though NOx emissions are not significantly reduced. Results show that even though emissions in volume are not reduced more than the 20%, as NOx continues representing the vast majority of the emissions, the impact produced by the emitted air pollutants it is considerably reduced, up to a 76% in the best of the scenarios. Due to the significant reduction in $PM_{2.5}$ and SO_2 ,of up to the 92,2% and 95,1% respectively, in the proposed third scenario using a mixture of MGO 5% and natural gas 95%.

Dealing with air pollution impacts at seaports the most critical and decisive variable, external to the maritime activity itself, is the population exposed to it. The resulting impact from air pollution emissions increases exponentially as the exposed population grows. Population density around ports is crucial.

On the one hand the ship type, due to significant difference in hotelling times, and on the other hand the average ship dimension critically affect the emissions per call at port. These two are the main variables affecting overall emissions.

Moreover the local impact is more significant in the Mediterranean, as the population density around ports is higher. However in the Atlantic the share of the rural impact within the overall impact is higher. This is why the difference between the impacts in the four sensitivity cases are more acute in the Atlantic.

Finally, this paper highlights the fact that ship air pollution in port areas is already significant and its impact serious, even more ~~so~~ if ship traffic's growing trend is taken into account. A consensus exists in current literature promoting integrated measures and instruments as the best known method to reduce ship air pollution against single and independent policy instruments. Results show that a big budget exists for intervening actions. For instance, by taking action in the selected ports and traffic areas in the Spanish port network up toone third of the air pollution externalities at port areas could be reduced, achieving savings of around 36M€ per year in the most positive scenarios.

REFERENCES

[1] EMEP/EEA air pollutant emission inventory guidebook 2009. Technical report No 9/2009.

[2] EMSA (2010). The 0.1% sulphur in fuel requirements from 1 January 2015 in SECAs - An assessment of available impact studies and alternative means of compliance. Technical Report.

[3] ESPO (2010).ESPO-EcoPorts Port Environmental Review 2009. Executive Summary.

[4] European Commission (1999). The Development of Short Sea Shipping in Europe: A Dynamic Alternative in a Sustainable Transport Chain. COM (1999) 317 final. Second Two-yearly Progress Report.

[5] European Commission (2001). European Transport Policy for 2010: Time to Decide. COM(2001)370, Brussels.

[6] European Commission (2001). The Clean Air for Europe (CAFE) Programme: Towards a Thematic Strategy for Air Quality. COM(2001)245.

[7] European Commission DG Environment (2002). BETA Project. Benefits Table Database: Estimates of the Marginal External Costs of Air Pollution in Europe. Version E1.02a.

[8] European Environmental Bureau (2008). Air pollution from ships. Seas At Risk. Bellona Foundation. North Sea Foundation. Swedish NGO Secretariat on Acid Rain.

[9] European Union Directive (2006). 2005/33/EC of the European Parliament and of the Council of 06 July 2006 amending Directive 1999/32/EC, relating to a reduction in the sulphur content of certain liquid fuels.

[10]Fundación Valenciaport (2010). Boletín Lineport nº4, December. [www]<URL:http://www.fundacion.valenciaport.com/>[Accessed 17 July 2011].

[11] Gil Aizpuru, J.M. (2011). Análisis de la contribución del gas natural a la reducción de emisiones atmosféricas en el sector marítimo: Aplicación práctica en el litoral de Castellón. Doctoral Thesis. Directed by Dr. F.X. Martínez de Osés. Universitat Politècnica de Catalunya, July.

[12] Goldsworthy, L. (2010). Exhaust emissions from ship engines – Significance, regulations, control technologies. [www]<URL:https://maritimejournal.murdoch.edu.au/>[Accessed 02 June 2011]

[13] Holland, M.R. and Watkiss, P. (2002). Benefits Table database: Estimates of the marginal external costs of air pollution in Europe.

[14] International Maritime Organization (2008). Amendments to the Annex of the Protocol of 1997 to Amend the International Convention for the Prevention of Pollution from Ships, 1973, as modified by the Protocol of 1978 Relating Thereto (Revised MARPOL Annex VI), adopted 10 October 2008.

[15] Miola, A. et al. (2009). External Costs of Transportation. Case study: Maritime Transport. JRC Scientific and Technical Reports, pp.25–27.

[16] Miola, A. et al. (2010) Regulating Air Emissions From Ships. The State of Art On Methodologies, Technologies and Policy Options. JRC Reference Reports, European Union.

[17] Schrooten, L. et al. (2008). Emissions of Maritime Transport: A European Reference System. Science of the Total Environment 408, pp. 318–323.

[18] Takashi H. et al. (2006). Study of Standards for Main Dimensions of the Design Ship. Technical Note of National Institute for Land and Infrastructure Management, Japan.

[19] Usabiaga, JJ. et al. (2011). Port city closeness and turnaround time critical for Short Sea Shipping sustainable Performance, A case study: Spain. REACT Conference, Serbia.

[20] Vautrain, J. (2009). Refining and Bunker Trends to 2015.Bunker Asia 2009, Singapore.

[21] Winther, M. (2008). New National Inventory for Navigation in Denmark. AtmosEnviro.