This version is the accepted manuscript. The final version is available at:
https://doi.org/10.1016/j.trd.2019.01.019

Citation: Tovar, B.; Tichavska, M. (2019): Environmental cost and eco-efficiency from vessel emissions under diverse SOx regulatory frameworks: A special focus on passenger port hubs Transportation Research Part D: Transport and Environment 69, pp. 1–12. https://doi.org/10.1016/j.trd.2019.01.019

Environmental cost and eco-efficiency from vessel emissions under diverse SOx regulatory frameworks: a special focus on passenger port hubs

Beatriz Tovar*
Tourism and Transport Research Unit
Institute of Tourism and Sustainable Economic Development
Dept. Applied Economics, University Las Palmas de Gran Canaria. Campus de Tafira, Modulo D, Despacho 2.20. 35017 Las Palmas de Gran Canaria, Spain; Tel: (0034) 928 45 17 94
beatriz.tovar@ulpgc.es

Miluše Tichavska
MarineTraffic, London, UK.
miluse.tichavska@marinetraffic.com

(*) Corresponding author: Beatriz Tovar

Beatriz Tovar de la Fé. Departamento de Análisis Económico Aplicado. Campus Universitario de Tafira, 35017. Modulo D. Despacho 2.20. Las Palmas de Gran Canaria. España. Phone: +34 928 45 17 94; Fax: 928 45 81 83

Acknowledgements
The authors are grateful to Dr. Jukka-Pekka Jalkanen, Mr. Lasse Johansson and the Finnish Meteorological Institute (FMI) for the support and assessment provided. Also, they would like to thank Dr. Ernestos Tzannatos and Dr. Su Song for the valuable inputs that enabled the improvement of this work. A special acknowledgment is also extended to MarineTraffic (www.marinetraffic.com) for their daily efforts and the wide support provided to the AIS global community of academics and researchers. Any remaining errors are those of the authors. Financial assistance for this work was provided by Grant ECO2015-68345-R (MINECO/FEDER) from the Spanish Ministry of Economy and Competitiveness and the European Regional Development Fund (FEDER).

Abstract

Emissions related to economic activities including shipping and its contribution to the degradation of air quality, health and built environment in port-cities increasingly raise attention. Sustained market growth and shipping, also deriving into pollution concentration and an exposure increase over residents and visitors, stresses the need to identify and internalize environmental impacts. In order enhance abatement actions towards shipping sectors, this paper estimates for the first time the environmental cost and eco-efficiency performance indicators from vessel traffic in general and passenger sub−sectors in particular under diverse geographical and regulatory contexts. Emission assessment (NOx, SOx, PM2.5, CO and CO2) of EU (Las Palmas), non-EU but SECA (St. Petersburg) and non-EU non-SECA (Hong Kong) ports is based on the full bottom-up Ship Traffic Emission Assessment Model (STEAM) and messages transmitted by the Automatic Identification System (AIS) over a twelve-month period. Environmental cost is obtained from a top-down approach and the latest seaport-related cost figures. At last, eco-efficiency performance indicators are presented as the ratio of product/service impacts (externality costs) its added value (port profiles). Results present a first approximation to the externality cost of shipping traffic by sea and in port. Conclusions support international and regional policy design within the selected harbours and ports under similar traffic conditions.

Keywords: vessel emissions, environmental cost, port-city, eco-efficiency, Automatic Identification System, diverse geographical and regulatory contexts, SECA.

1. INTRODUCTION

Ports constitute the nodes of maritime transport where all shipping journeys ultimately converge. Thus, they are particularly exposed to the burden of ship emissions. In response to this problem and in addition to the International Maritime Organization (IMO) and (European Union) EU regulatory framework (Tichavska et al., 2017), ports have been collectively or individually active in adopting voluntary measures to improve air quality and reduce the release of greenhouse gases[1] (CO_2) and also SO2 and primary/secondary particulate matter[2]. Economic incentives (i.e. environmentally differentiated port dues) or the undertaking of infrastructural investments, aim to encourage ship operators to make use of environment friendly services (such as shore-side electricity (Ports of Auckland, 2017), liquefied natural gas (LNG) bunkering (Tzannatos et al, 2015), automated mooring systems, the use of scrubbers (Tzannatos, 2010a) to name a few).

Population located in port-cities, also experience air quality detriments associated to vessel traffic and the atmospheric concentration of air pollution (Viana et al 2014; Merico et al, 2017). These result in urban and rural externalities[3] that can be monetised as external costs[4]. Emission inventories are a necessary step within the estimation of external costs. These, are increasingly addressed in shipping literature but limited harbour studies may be found.

[1] There are a number of climate-change adaptation and mitigation initiatives that are being implemented by ports across the world. An analysis of these initiatives is out of the scope of this paper but can be found in Nursey-Bray (2016).
[2] See for example Contini et al. (2015).
[3] Accounted urban externalities include health issues, increased mortality rates and the degradation of built environment. Rural externalities relate to crop damages.
[4] External cost is also often referred as externality, social or environmental cost.

A recent review of the methodological and empirical state of the art of external costs from vessel emissions at port (Tichavska and Tovar, 2017) reflects that the representative approach to estimate emissions[5] is a bottom-up approach either based on port calls (and an approximation to vessel operative at port) or, on vessel tracks based on real vessel operative transmitted by the Automatic Identification System (AIS). The later avoids assumptions and the use of average figures (such as speed, distance) when calculating the released pollutants although some uncertainties remain[6]

The present paper extends the vessel emission research in Tichavska et al (2017) to the estimation of its associated cost and the eco-efficiency of ports[7]. Results provide a first approximation to externality costs based on emission results from a full bottom-up approach (STEAM model). This enables a comprehensive assessment on emissions cost patterns from vessel traffic in general and passenger sub-sectors in particular.

To the authors knowledge, the present research is the first one to estimate externality costs and eco-efficiency at ports derived from full bottom-up-obtained vessel emissions of cruise and ferry vessels navigating under a 12-month period in harbour areas under a diverse geographical and regulatory framework. Although our main interest is on the

[5] Knowledge on the resulting air pollution from the operative performance of vessels (main and auxiliary engine loads) at port is limited. Indeed, most inventories use conventional port arrival and departure data to describe ship movements and base emission estimations for each individual vessel with operative assumptions. This is an issue that grows significance as regulatory frameworks, and control over fuel sulphur content increase over time and refined estimations are required to sustainable policy design. A good example of this effort can found in some projects in the Mediterranean area, financed by the European Union, such as APICE (http://www.apice-project.eu/), CESAPO (http://www.cesapo.upatras.gr/index.php/en/) or POSEIDON (http://www.medmaritimeprojects.eu/section/poseidon) projects.
Several manuscripts arise from these projects: Donateo et al (2014); Contini et al (2011, 2016) Merico et al (2016, 2017).

[6] More detailed information on vessel emission calculations and the model used for vessel emission inputs in this paper, may be found in (Tichanvska et al, 2017). Assumptions and limitations associated to the STEAM model are summarized in Jalkanen et al, (2013), (see Table 1)

[7]The case study in this paper sheds light into the methodological possibilities for externality cost calculation in diverse traffic and regulatory contexts. As such, regulatory and modelling considerations have been taken into account for the ports and years under study (Tichavska et al. 2017). Result figures shown in future case studies might reflect differences due to new traffic and regulatory contexts.

passenger subsector in order to offer a whole picture of port externality cost derived from ships and also to facilitate the comparison of the responsibility among the different port shipping sectors, we incorporate emissions results related to the others shipping sectors in Tichavska et al (2017) to calculate external costs derived from all.

Indeed, passenger transport by sea has noticeably transformed throughout history. It began as a core business for shipping companies operating luxury vessels, but its activity diminished into such extent that by the mid 60´s, it became with only a few exceptions, into a single form of transportation by sea. Competitiveness of aircrafts led to the demise of some companies and to the diversification of cruise services. However, short-distance passenger services have maintained as a competitive sector over time. Thus, passenger traffic by sea must distinguish passenger services oriented to a recreational segment (cruise) and short-sea transportation services offered to carry passengers and sometimes vehicles and cargo across bodies of water (ferry).

Cruise operators look for well-located and connected ports. This often leads to major harbours and densely populated areas. Also, port-cities attributed with touristic attractiveness of diverse nature, play an important role in the industry. An example of this is the fast evolution of the Mediterranean coast as the second largest market in this industry, where attractiveness of cities is determinant in consumer's choices. In this sense, and in addition to air connections; the share of facilities with ferry services, population density, and a minimum depth of water, have been identified as determinants of cruise traffic in the Spanish port system, attributing a positive relation to island locations due to the touristic attractiveness of Spanish archipelagos and the appeal of destinations not accessible overland (Castillo-Manzano et al., 2014). Ferry services on the other hand, supply transportation needs across channels, straits and archipelagos through regular services. Short distance routes by ferries and high-speed ferries (fast ferries) are offered with, or without capacity for vehicles. Typology of ferries varies according to accommodation facilities or size. Also, depending on the size of transhipment, vessels may be provided with cabins, which may strongly influence its size. Vehicles access and leave the ship if necessary, through ramps at port. These are generally ships engaged in national cabotage services or short-distance connections.

The results presented in this study aim to facilitate the assessment and design of mitigation strategies towards vessel traffic in general and passenger sub−sectors in particular. Moreover, results attempt to assist future cost-benefit analysis used for evaluating abatement policies in Las Palmas, St. Petersburg, Hong Kong and other port-cities under similar vessel traffic conditions. Finally, our results also contribute to port literature in vessel emissions, by describing throughout results of the case study, and the possible use of results by port communities and governments, as assessment tools.

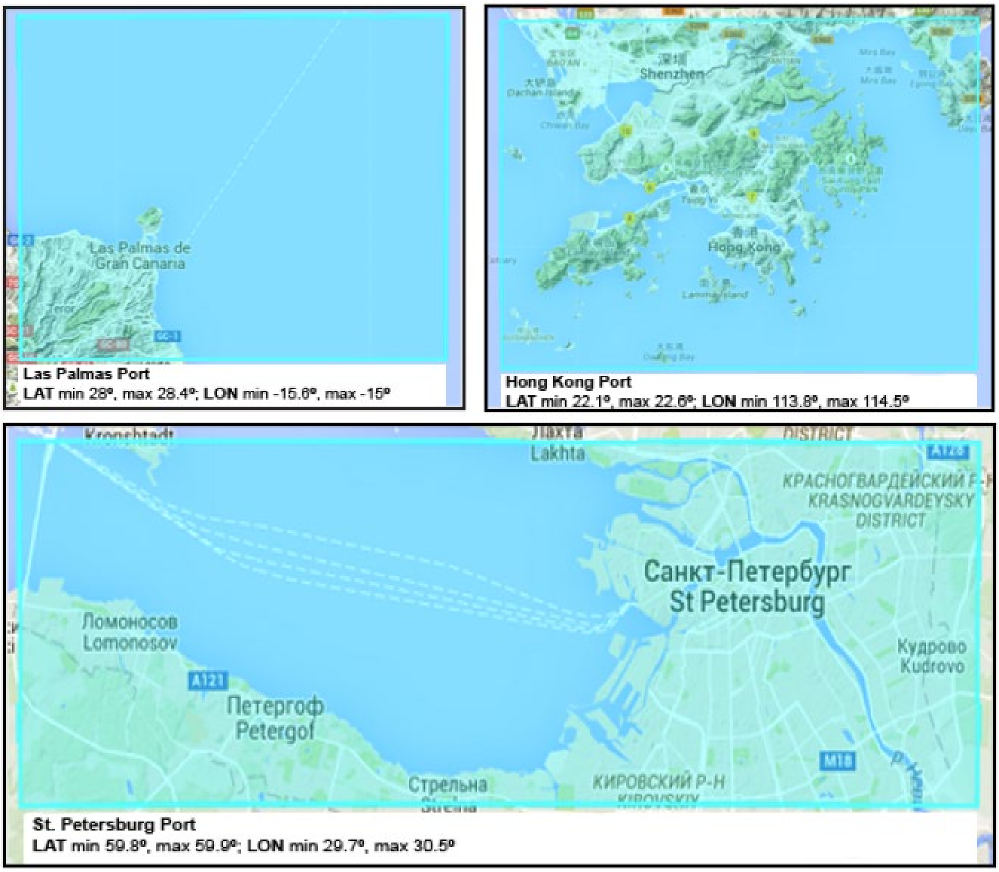
The structure of this document is as follow. Section 1 presents an introduction to the subject of research and the three-harbour case study; Section 2 provides a brief outline of the study areas; Section 3 describes the methodology followed and results for external cost and eco-efficiency performance is presented in Section 4.

2. STUDY AREAS

The selection of ports was based on their common attribute as cargo and passenger hubs with increasing cruise and ferry services under a diverse regulatory constellation (Figure

1). Namely, EU SOx regulations apply in Las Palmas, IMO SECA apply in St. Petersburg, and general IMO in Hong Kong.

Figure 1. Bounding coordinates of study areas



2.1 Las Palmas

The port of Las Palmas is one of the largest ports in Spain (Tovar and Wall, 2012) and an important port of call and base for vessels traveling the Atlantic region. Due to its geographic location, connecting main trade routes across continents, it has become a logistics hub of importance. It has shipping links with 510 ports in 135 countries. Aside from handling cargo, the Port of Las Palmas is a hub for repairing ocean-going vessels and it plays an important role in vessel fueling in the Atlantic sea region. Moreover, it is also a major passengers' port, supporting over a million passengers every year including not only passengers using regular lines but also cruise passengers.

In order to serve the demand of regional mobility (passengers or passengers and goods), ferry routes are offered in a daily basis with hub operations set in both main Canarian ports[8]. Direct connections are regularly offered from Gran Canaria, and Tenerife in direction to other Canary Islands: Fuerteventura, Lanzarote, La Gomera and Spanish mainland (Huelva). There is also a permanent traffic between Spain and the island, of both passenger and cargo.

Since the1990´s cruise passengers in the Canary Islands have augmented progressively to up to 2,194.602 in 2017. Nowadays, the current docks in Las Palmas Port allow the simultaneous berthing of more than five cruise ships. Indeed, the brand "Cruise Atlantic Island" which includes Las Palmas port managed near 3 million tourists in 2015, proving the Atlantic corridor as one of the most important touristic cruise routes in the North Hemisphere, especially in winter.

The port of Las Palmas is regulated under the provisions of 2005/33/EC, which limits the sulphur content of fuel to 0.1% for berthed ships in EU ports and, 1.5% for ships serving regular passenger routes ports in European territory (Kalli, et al. ,2015). Also, it is compliance territory of the recently implemented EU Monitoring, Reporting and

[8] Main ports in the Canary Islands are namely Las Palmas port (located in Gran Canaria) and S.C. Tenerife port (located in Tenerife). Together, and in 2016 they sum up more than an 89% of the total freight moved from and to other geographical areas from the archipelago. They are managed by different Port Authorities. A detailed analysis of the port management model in Spain is beyond the scope of this paper but it can be found in Rodriguez-Álvarez and Tovar and Wall (2012, 2014).

Verification (MRV) system and implementation guidelines (EU 2015/757). Table 1 below shows its traffic profile in the year (2011) under study.

2.2 St. Petersburg

The Port of St. Petersburg is the largest port in the Baltic Sea, and one of the largest in Russia. It is a multipurpose port that has both cargo and passenger operations linked to ports all over the world by 24 shipping lines. In the recent past, shipping in the Port of St. Petersburg has increased dramatically with the construction of new facilities on both sides of the Gulf of Finland. The port has more than 200 berths, the mooring line length of about 31 km. Most of the berths can accommodate vessels with a draft of 9.8 m, some berths can accommodate vessels up to 11 m draft and 320 m length. Within its share of cargo, dry cargo, bulk and liquid bulk prevail with the most significant figures while containers play a minor role.

Moreover, cruise and ferry services calling at St. Petersburg have continuously increased since the 90's and represent an important asset for the economy of the city. Indeed, one of the most important sectors in the Port of St. Petersburg is the cruise industry. Sea Passenger Port of St. Petersburg has seven berths and it is located on the western area of Vasilevsky Island. The passenger port can handle up to seven cruise ships 340 meters in length per day and has two cruise terminals. Moreover, its ferry terminal is served by a number of ferry routes which sail west across the Baltic Sea to stops in Stockholm, Sweden; Helsinki, Finland, and North Estonia. Table 1 below shows its traffic profile in the year (2011) under study.

The harbour area of located in the Baltic, area enforced by IMO SECA under the International Convention for the Prevention of Pollution from Ships (MARPOL) Annex VI. Starting 1.1.2015, which limits sulphur levels in ship fuel to a 0.1% as max.

2.3 Hong Kong

The port of Hong Kong is the second busiest container port in the world. Advantageously located on trade routes in the far East, it has progressively become a world-class container, transhipment and passenger hub in the South East and East Asia region. (over 400 container liner services in a week to more than 500 unique destinations worldwide). Table 1 below shows its traffic profile in the year (2012) under study.

The Port of Hong Kong has nine container terminals in the Kwai Chung area, Stonecutters Island and Tsing Yi. The river trade terminal at Tsuen Mun handles the consolidation of containers, break bulk and bulk cargo operations. The mid-stream areas at the harbour handle the loading and unloading of cargoes. The Kwai Chung and Tsing Yi Container Terminals located in the north west part of the harbour include nine container terminals. The total area consists of 24 berths with 7,694 meters of deep-water frontage. The container handling facilities occupy a total terminal area of about 279 acres, and feature container yards and freight stations. The nine container terminals have a total handling capacity of more than 19 million Twenty-foot Equivalent Units (TEU).

With regard to passenger services in the region, ferry terminals Hong Kong-Macau and the China Ferry Terminal serve routes to eleven ports in the mainland in frequent services and, centralised routes to Macao. Taking a ferry is by far the most popular way to travel between Hong Kong and Macau, and one of the most convenient ways to travel between

Hong Kong and certain parts of China. In terms of cruise services, there are two terminals: the Ocean Terminal and the Kai Tak Terminal. The Ocean Terminal is located in Victoria Harbour at the southwestern edge of the Kowloon Peninsula. It was once a wharf pier that has been rebuilt and enlarged for use as a cruise terminal and which offers two berths accommodating vessels of up to 50,000 tonnes, it is in itself a major shopping complex. The Kai Tak Cruise Terminal, a refurbished airport, has two alongside berths, with support facilities to accommodate simultaneous berthing of two mega-cruise vessels (gross tonnage of up to 220,000).

The port of Hong Kong is only affected by a global sulphur cap of 3.5%, active since the 1st of January, 2012 (IMO MARPOL, Regulation 14 on Sulphur Oxides and Particulate Matter). Moreover, a harbour emission regulation for ocean going vessels has taken effect on the 1st of July 2015. The air pollution control regulation requires the use of fuel with a sulphur content that does not exceed a 0.5% while at berth in Hong Kong with the exception of the first hour after arrival and the last hour before departure.

Table 1. Traffic profiles and regulatory framework

Ports (year under study)	Traffic Profile								Regulatory Frameworks	% Fuel sulphur content allowed in the year and port under study		
	Tanker	General Cargo	Container	Container	Rest	Ferry	Cruise	Port calls		Berthing for more than 2 hours	Manoeuvring and in transit	
	000 ton	**000 ton**	**000 ton**	**TEUs**	**000 ton**	**pax**	**pax**	**number**	**SOx Regulation**	**All**	**No passeger**	**Passenger**
Las Palmas (2011)	3,188.25	2,393.47	13,766.25	1,285,586.00	5,214	798,771	427,592	16,345	EU	0.1	2.7	1.5
San Petersburg (2011)	15,739.20	13,963.20	21,978.00	2,365,174.00	8,309	122,000	405,000	11,517	non-EU SECA	0.1	1	1
Hong Kong (2012)	17,721.00	12,029.00	203,964.00	23,117,000.00	35,569	26,000,000	1,382,296	22,094	non-EU non-SECA	2.7	2.7	2.7

Note: Regulation in force for Hong Kong in 2012 (year under study) is 3.5%. Nevertheless, we use 2.7% as limit since during the modelled years (2011–2012) the HFO fuel sold globally had 2.7% or less sulphur. This is why 2.7% is commonly used for global shipping emission studies. For more details regarding the gasses estimation please see Tichavska et al. (2017).

Source: adapted from Tichavska et al. (2017)

.

3. METHODOLOGY

Vessel traffic in general and passenger services in particular (although sharing positive effects and economic benefits) contribute to the atmospheric dispersion of exhaust gases and derived impact on air quality, health and environmental degradation in port-cities. The estimation of emission and derived cost profiles enable the internalization of impacts and supports policy design and externalities bound to prevail. In this sense, methodological approaches used to estimate vessel emissions and its derived cost (urban and rural) may capture transportation technology in an aggregated (top-down) or disaggregated form (bottom-up). In both emission and external cost estimation, top-down approaches use aggregated economic variables while bottom-up approaches consider refined and disaggregated information, mostly based on technical performance[9].

For the estimation of external costs, a bottom-up approach is preferred as it enables a refined assessment based on disaggregated information (marginal external costs). Nevertheless, costly and complex methodological requirements retrain the use of this approach. Thus, the use of a top-down approach is suggested and widely accepted when bottom-up studies cannot be performed or are not available. Indeed, in a context of seaports and shipping and due to the complexity and high cost of generating bottom-up external cost studies, literature relies and accepts the use of cost factors (top-down approach) from major bottom-up European reports (BeTa, CAFE, HEATCO and NEEDS).

[9] The application of approaches varies according to the subject of study. A detailed analysis about the methodological and empirical state of the art on external cost estimation from harbor emissions released by vessels is not considered within the scope of this article but can be found on the recent review by Tichavska and Tovar (2017).

A comprehensive assessment on the methodological and empirical state of the art on the estimation of external costs from vessel emissions by Tichavska and Tovar (2017) identifies ten harbour studies which address the urban and rural economic cost of gases and particles released by vessels (Miola et al., 2009; Tzannatos, 2010b; Tzannatos, 2010c; Berechman and Tseng, 2012; Castells et al., 2014; McArthur and Osland, 2013; Song, 2014; Maragkogianni and Papaefthimiou, 2015; Tichavska and Tovar, 2015b and Dragovic et al., 2018). From these, six out of ten also include CO_2 estimations. For emission estimation, the representative approach in the harbour studies identified was a bottom-up approach either based on port calls and approximation to vessel operative at port (all) or on vessel tracks (only Tichavska and Tovar, 2015b). In regional studies, bottom-up and top-down approaches have been used (Castells et al., 2014; Tzannatos, 2010c). On the other hand, when calculating externality costs and in each study revised a top-down approach was followed, on the basis of euro per tonne factors in BeTa (Berechman and Tseng, 2012); CAFE (Miola et al., 2009); NEEDS (Dragovic et al., 2018; BeTa and CAFE (McArthur and Osland, 2013; Castells et al., 2014); BeTa and HEATCO (Tzannatos, 2010b,c) NEEDS and CAFE (Maragkogianni and Papaefthimiou, 2015) or, BeTa CAFE and NEEDS (Tichavska and Tovar, 2015b). In addition to this Song (2014) uses the meta-analysis of international literature and its weighted average in a twelve-month study of Yangshan harbour. Moreover, every study addresses exhaust emissions associated to the detrimental effects in coastal areas but only a few comprehend CO_2 in their inventories and final results (Miola et al., 2009; Tzannatos, 2010c; Berechman and Tseng, 2012, Tichavska and Tovar, 2015b).

3.1. Environmental cost estimation from vessel emissions at port

With the aim of calculating the cost of vessel emission externalities and after revising the most recent publications, cost factors categorised as urban and rural for NOx, SOx and $PM_{2.5}$ from BeTa have been used (NETCEN, 2004). This is the only available report that specifically dedicates to seaports and allows a first approximation to the economic cost of ship emissions over the three harbours under study[10]. Namely, EU port of Las Palmas (Spain) and non-EU ports of St. Petersburg and Hong Kong. BeTa provided country-specific cost factors for European ports. In the case of non-European ports, the use of EU15[11] average has been considered as an appropriate approximation [12].

Moreover, and for external costs not included in BeTa (CO and CO_2) calculations are based on cost figures used in port and in shipping literature. Specifically cost factors obtained from Denisis (2009) and Delft and Infras (2011) as used by Tzannatos (2010b), Berechman and Tseng (2012) and Heinbach (2012) and Tichavska and Tovar, (2015b). In the case of CO_2 and due to the global effect of damages caused by the greenhouse gas effect, there is no difference on how and where in Europe CO2 emissions are released into the atmosphere. For this reason, the same cost factors are commonly used in estimations for all countries although these are dependent on time since emissions released in future years will have greater impacts than emissions today and have to be addressed separately. Based on transport studies that include two different CO2 prices concerning climate change costs, we also present a lower value and an upper value. These

[10] EU reports used to calculate externality costs (top-down approach), provide diverse unit cost factors due to technical/methodological refinements, changes in receptor characteristics and year of reference (among others). For additional details on the application of BeTa (dedicated to seaports), CAFE and NEEDS in vessel emissions and harbour studies, the reader is referred to Tichavska and Tovar (2017).

[11] BeTa provide external cost factor by tonne of different pollutant (SO2, NOx, PM2.5, and others) for the following European countries: Austria, Belgium, Denmark, Finland, France, Germany, Greece, Ireland, Italy, Netherlands, Portugal, Spain, Sweden, UK. EU-15 average is the average external cost factor regarding all these countries.

[12] Additionally, and as a sensitivity range, EU15 max and min cost factors have also been included. This way, any distinct features, such as the high-population density of H-K and the low population density of Russia can be accommodated through reference to the min or max.

suppose a high and a low scenario chosen according to the avoidance target scenario addressed[13].

In order to calculate the external costs of air emissions released close to shore, BeTa (NETCEN, 2004) suggests the use of EU (country or non country-specific) urban and rural cost factors. These are based, among others, on the adverted cost of damages and willingness-to-pay. Specifically, rural cost factors in BeTa are country-specific whereas urban factors are not (SOx and PM only). Urban cost factors of NOx and VOCs on the other hand, remain in the classification of country specific since BeTa expressly indicates to obtain its value from the corresponding rural (country specific) cost factors. In the case of CO in Denisis (2009) and CO2 in Delft and Infras (2011) cost factors are equally applied in all countries. Thus, these cost factors have also been considered as non country-specific.

With the aim of further adjusting estimations to the reality of the harbours (and year) under study it is considered appropriate to utilize the National Consumer Price Index (CPI) value (Tzannatos, 2010b). In line with this purpose, the present research adjusts country specific cost factor values (Table 2) to CPIs (Spain, 2011; Russia, 2011; and China, 2012) and non-country specific cost factors (Table 3) to the Global Consumer Price (GCP) of the year under study. CPIs and GCPs reflect the cost of remedial actions (such as health costs, resource generation costs, willingness-to-pay to prevent damages) and thus, should remain as a key parameter in similar research where estimated externality

[13] Following Delft and Infras (2011) our lower cost estimate is based on the avoidance factor calculated for meeting the EU GHG reduction target for 2020 and the higher climate cost factor is based on the cost for meeting the long term target of keeping CO_2 below 450 ppm in the atmosphere and global temperature rise below 2 centigrades.

costs relate to EU and non-EU harbours. Cost factors used in this case study have been summarized in Table 2 (country-specific) and Table 3 (not country-specific) below.

Table 2.- Country-specific cost factors (€/Tonne)

<table>
<tr><th rowspan="3">PORT</th><th colspan="4">NOx (€/tonne)</th><th colspan="4">SO_2 (€/tonne)</th><th colspan="4">$PM_{2.5}$ (€/tonne)</th></tr>
<tr><th rowspan="2">Spain</th><th colspan="3">EU15</th><th rowspan="2">Spain</th><th colspan="3">EU15</th><th rowspan="2">Spain</th><th colspan="3">EU15</th></tr>
<tr><th>Avg</th><th>Min</th><th>Max</th><th>Avg</th><th>Min</th><th>Max</th><th>Avg</th><th>Min</th><th>Max</th></tr>
<tr><td>Las Palmas urban</td><td>4700</td><td rowspan="4">4200</td><td rowspan="4">1500</td><td rowspan="4">8200</td><td></td><td></td><td></td><td></td><td></td><td></td><td></td><td></td></tr>
<tr><td>Non-EU ports urban</td><td></td><td></td><td></td><td></td><td></td><td></td><td></td><td></td><td></td></tr>
<tr><td>Las Palmas rural</td><td>4700</td><td>3700</td><td></td><td></td><td></td><td>7900</td><td></td><td></td><td></td></tr>
<tr><td>Three ports rural</td><td></td><td></td><td>5200</td><td>970</td><td>7900</td><td></td><td>14000</td><td>1400</td><td>22000</td></tr>
</table>

Note: All cost factors are refereed to year 2000 prices and they have been obtained from BeTa

Table 3.- Non Country-specific cost factors (€/Tonne)

	Source	Prices	SO_2 (€/tonne)	$PM_{2.5}$ (€/tonne)	CO (€/ton)	CO_2 (€/ton)
Las Palmas	**BeTa urban**	**2000**	23001	126503		
Non-EU ports	**BeTa urban**	**2000**	90000	495000		
Three ports	**Denisis, 2009**	**2003**			3	
Three ports	**Delft and Infras 2011 (low)**	**2008**				25
	Delft and Infras 2011 (high)	**2008**				146

4. RESULTS AND DISCUSSION

Vessel emission calculation in this study[14] is consistent across ports (vessel-position based, produced by the STEAM model) and results are obtained from two different stages. The first one relates to the three harbour areas with all ships and speeds allowed. The second, in order to enable a more refined comparison among ports (that does not include

[14] The emission inventories (NOx, SOx, PM2.5, CO and CO2) used in this paper to calculate the external cost are based on calculations in Tichavska et al (2017). Here we have included the minimum information about emissions needed for our issue, which is external cost calculation. For further details on the model and/or estimation of vessel emissions, readers are referred to Tichavska et al (2017).

distances travelled when arriving to port), is exclusive to the passenger vessel type under speeds that represents hotelling (0 knots) and manoeuvring (speed lower or equal to 5 knots) modes.

Results in Tichavska et al (2017), shed light to the effects of a stringent SECA regulation. Specially, when compared to the less stringent regulatory frameworks in the EU. Indeed, Hong Kong results (Non-EU, non-SECA) confirm the later assumption by showing that the tons of SOx (and PM2.5) per call to port exceed in nine and six times the results when compared, respectively, to Las Palmas (EU) and St. Petersburg (SECA). Their results are in concordance with the ones found by Contini et al (2015) and Merico et al (2017)

Table 4 presents the total estimated external cost for the port cities under study in millions of euros derived from the calculated emissions.

Table 4.- Total estimated external costs per year (million €)

	External cost (million €)											
Port	**NOx**			**SO_2**			**$PM_{2.5}$**			**CO**	**CO_2**	
	Total	**Min**	**Max**	**Total**	**Min**	**Max**	**Total**	**Min**	**Max**		**Low**	**High**
Las Palmas (EU15)	60	17	95	62	54	67	75	69	78	0.0022	6	34
St. Petersburg (EU15)	318	92	502	93	85	99	289	274	299	0.0025	13	78
Hong Kong (EU15)	650	187	1.025	2.867	2.763	2.933	3.486	3.416	3.530	0.0223	72	421
Las Palmas (SPAIN)	54			58			62			0.0018	5	32

Specifically, when using the EU15 avg. cost factor, the overall economic costs for NOx, SOx, PM2.5 and CO derive in a total of 196,938,807 € in Las Palmas Port (+28% and -22% when compared to the min. and max. EU ranges); 700,615,203 € in St. Petersburg (+36% and -28% when compared to the min. and max. EU ranges) and 7,002,459,857 €

in Hong Kong (+9% and -6% when compared to the min. and max. EU ranges). In terms of CO2 and for Las Palmas 5,849,189 € and 34,159,264 € were accounted as the low and the high cost ranges. Similarly, 13,425,615 € (low) and 78,405,593 € (high) were estimated for St. Petersburg and, 72,073,820 € (low) and 420,911,108 (high) for Hong Kong. As for the sensitivity case, where the externality costs of NOx, SO_2 and $PM_{2.5}$ in Las Palmas Port (estimated with EU15 values) are compared to calculations based on cost factors for Spain, the variation percentage of EU15 calculations over Spain reflect +10.61% for NOx, +7.6% for SOx, +20.37% for PM2.5 and +21.09% CO.

As for local externality costs per shipping sector (see Table 5) passenger and container shipping are the most representative (measured as % from the harbour totals) in Las Palmas Port in terms of NOx (25% and 24%), of SOx (38% and 20%), of $PM_{2.5}$ (34% and 22%) and of CO (20% and 24%). This is different to results in St. Petersburg where the highest local externality costs (measured as % from the harbour totals) relate to cargo and container shipping in terms of NOx (23% and 29%) of SOx (21% and 25%), of PM2.5 (22% and 28%) but in terms of CO the highest costs relate to container (29%) and vessels classified as others (23%). Finally, in the case of Hong Kong the highest costs of all pollutants with local effects (NOx, SOx, PM2.5, CO) comes from container (46%, 55%, 52% and 58%).

Table 5.- External costs by shipping sub-sector per year (millions €)

	External cost (million €)											
Port	NOx			SOx			PM2.5			CO	CO_2 Low	CO_2 High
Las Palmas (EU15)	Total	Min	Max	Total	Min	Max	Total	Min	Max	Total	Total	Total
Passenger	15.2	4.4	23.9	23.5	20.4	25.5	25.0	23.0	26.2	0.00043	1.42	8.31
Cargo	5.3	1.5	8.3	4.9	4.3	5.3	6.0	5.5	6.3	0.00020	0.49	2.89
Container	14.4	4.2	22.7	12.6	10.9	13.7	16.1	14.9	16.9	0.00051	1.34	7.84

Tankers	9.4	2.7	14.9	8.1	7.1	8.8	10.4	9.6	10.9	0.00039	0.93	5.44
Others	13.8	4.0	21.7	10.5	9.1	11.4	14.1	13.0	14.8	0.00053	1.41	8.23
Unknown	2.0	0.6	3.2	2.5	2.2	2.8	2.9	2.6	3.0	0.00008	0.25	1.45
Total	60.1	17.3	94.7	62.2	54.0	67.4	74.6	68.8	78.3	0.00008	5.85	34.16
St. Petersburg (EU15)	**Total**	**Min**	**Max**	**Total**	**Min**	**Max**	**Total**	**Min**	**Max**	**Total**	**Total**	**Total**
Passenger	28.3	8.2	44.7	11.2	10.2	11.9	27.9	26.4	28.8	0.00025	1.19	6.96
Cargo	71.7	20.7	113.0	19.3	17.5	20.4	63.4	60.0	65.5	0.00049	3.05	17.80
Container	92.7	26.7	146.2	23.2	21.1	24.6	80.7	76.5	83.5	0.00072	3.91	22.86
Tankers	44.5	12.8	70.2	12.8	11.6	13.5	39.6	37.5	40.9	0.00027	1.89	11.04
Others	56.1	16.2	88.5	12.0	10.9	12.7	49.0	46.4	50.6	0.00058	2.28	13.34
Unknown	25.1	7.2	39.5	14.7	13.3	15.5	28.5	26.9	29.4	0.00019	1.10	6.40
Total	318.4	91.9	502.1	93.2	84.6	98.6	289.0	273.7	298.8	0.00250	13.43	78.41
Hong Kong (EU15)	**Total**	**Min**	**Max**	**Total**	**Min**	**Max**	**Total**	**Min**	**Max**	**Total**	**Total**	**Total**
Passenger	32.8	9.5	51.7	153.2	147.7	156.8	193.7	189.8	196.2	0.00244	4.67	27.27
Cargo	33.7	9.7	53.1	125.9	121.3	128.8	155.1	152.0	157.1	0.00079	3.42	19.98
Container	300.5	86.7	473.9	1.573.7	1.516.5	1.610.1	1.825.6	1.788.9	1.848.9	0.01300	30.45	177.82
Tankers	18.1	5.2	28.6	63.3	61.0	64.8	80.9	79.3	82.0	0.00045	1.91	11.13
Others	10.2	2.9	16.1	23.2	22.4	23.8	36.5	35.8	37.0	0.00025	1.18	6.89
Unknown	254.6	73.4	401.5	927.5	893.8	949.0	1.193.8	1.169.8	1.209.1	0.00538	30.45	177.82
Total	649.9	187.5	1.024.8	2.866.9	2.762.8	2.933.3	3.485.7	3.415.5	3.530.2	0.02232	72.07	420.91

In terms of costs estimated from CO_2 (see Table 5) in Las Palmas Port passenger and container vessels that represent a 57% from the total share while in St. Petersburg the highest numbers are attributed to container and cargo (29% and 23% respectively). At last, in Hong Kong, the largest cost shares from CO2 are attributed to container (42%) and unknown vessels (42%).

It should be noted that in Tichavska el al (2017) emission results, in the case of the passenger sector, have been based on traffic information of vessels navigating at a speed equal or below 5 knots (manoeuvring and berthing). This, to reduce emission calculation differences potentially due to differences in port fairway channels[15]. According to these

[15] When comparing the eco-efficiency of ports, it is important to remember that (apart from the regulatory differences) the influence of port call duration, port approach/departure navigational complexity, vessel utilisation, among others, have been taken into account.

results, the role of ferry vessels is the most representative in the port of Las Palmas while cruise overcomes in St. Petersburg and Hong Kong. This, regardless of the type of pollutant under assessment and the local or global contexts of its effects.

Obtained records suggest that this may not only hold relation to the size of the reported fleet but to the operative hours in harbour and also, and in terms of a specific valuation of SOx and PM2.5. due to the different regulation in force in the three ports (Tichavska et al 2017). External costs associated to cruise and ferry vessels emissions in the harbours under study are presented in Table 6.

Estimations reflect that in terms of NOx and in Las Palmas Port the ferry category represents the highest share of costs for all gases. This is a 70% (3,336,096 €) from the passenger totals, while cruise account only a 30% (1,445,027 €). As for SO_2 the total that associates to ferries is of 485,186 € (69%) while 217,923 relate to cruise (31%). In terms of PM2.5 results of the ferry category sum a total of 1,904,085 € (69%) while for the cruise category the total is of 845,618 € (31%). Similarly, a 69% of externality costs derived from CO relate to ferry and a 31% to cruise. In terms of CO2 ferries account a 69% from the passenger totals while cruise represent a 31% from the costs. In St. Petersburg it is the cruise category that represents the largest share of costs. This is a 62% (5,175,133 €) of costs related to NOx, a 61% (600,362 €) related to SO_2, a 62% (2,908,071) to PM2.5 a 65% to CO and a 62% to CO2. In Hong Kong it is also the cruise category that associates with the largest share of results. It should be noted that when compared with Las Palmas and St. Petersburg, passenger totals are considerably higher. Specifically, for cruise as 4,568,679 € (86%) were accounted from NOx, 4,897,320 €

(90%) from SO2, 6,780,180 € (89%) from PM2.5, 94% from CO and an 86% from CO2 totals.

Table 6.- Externality costs by passenger shipping sub-sector per year (thousands €)

	External cost (thousands €)											
Port	**NOx**			**SOx**			**PM2.5**			**CO**	**CO_2 Low**	**CO_2 High**
Las Palmas (EU15)	**Total**	**Min**	**Max**	**Total**	**Min**	**Max**	**Total**	**Min**	**Max**	**Total**	**Total**	**Total**
Cruise	1445	417	2279	218	189	236	846	780	887	0.036	160	934
Ferry	3336	962	5261	485	421	526	1904	1756	1998	0.081	362	2117
Total	4781	1379	7539	703	611	762	2750	2536	2885	0.117	522	3051
St. Petersburg (EU15)	**Total**	**Min**	**Max**	**Total**	**Min**	**Max**	**Total**	**Min**	**Max**	**Total**	**Total**	**Total**
Cruise	5175	1493	8161	600	521	651	2908	2682	3051	0.119	579	3379
Ferry	3223	930	5082	376	327	408	1750	1614	1837	0.064	359	2095
Total	8398	2422	13243	976	848	1058	4658	4297	4888	0.183	937	5474
Hong Kong (EU15)	**Total**	**Min**	**Max**	**Total**	**Min**	**Max**	**Total**	**Min**	**Max**	**Total**	**Total**	**Total**
Cruise	4569	1318	7204	4897	4445	5186	6780	6420	7009	0.037	193	1127
Ferry	718	207	1133	515	467	545	873	827	902	0.002	31	182
Total	5287	1525	8337	5412	4912	5731	7653	7247	7911	0.039	224	1309

Eco-efficiency is normally taken as the key performance indicators for the measurement of the sustainability of economic development or a certain type of service (Song, 2017). Therefore, it is of interest to compare the eco-efficiency performance by shipping passenger subsector and ports related to emissions. This, since an eco-efficiency assessment may assist in an economically as well as ecologically sound decision through the examination and evaluation of environmental and economic factors (revenue, cost and so on) in one analysis and should be part of port management practices towards achieving sustainable port development[16].

[16] When comparing the eco-efficiency of ports, it should be desirable to include inland operations emissions (those related to harbour activities such as internal transportation, loading and unloading of ships, passenger transport and so on) in order to obtain and overarching insight of each port eco-efficiency. To the best of the authors knowledge there is no such research done in the present, maybe due to the difficulties associated to gather the data needed to do it. Effort

Following Tichavska and Tovar (2015b), we define our eco-efficiency indicators as the ratio between the impacts of the products or service (externality costs) and the added value of what has been produced (such as port profiles). Thus, Table 7 shows the external cost by unit of output by shipping subsector and ports according to the local (NOx, SO2, PM2.5 and CO) and the global (CO2) context of associated impacts. Parameters considered are, external costs per passenger (for cruise and ferry) and per tons of cargo (container[17], cargo, tanker, other and unknown).

Table 7 shows that the highest local externality costs relate to passenger subsector both in Las Palmas Port (51.91 €/pax) and in St. Petersburg (127.91 €/pax). Conversely, in Hong Kong the highest local externality costs relate to container subsector (18.14 €/Ton). On the other hand, Table 7 also shows totals including local and global (CO2 low and high) associated impacts.

Table 7.- Eco-efficiency performance by ports and shipping sub-sectors

Shipping Subsector	Units	Eco-efficiency performance								
		Local only			Local and global low			Local and global high		
		Las Palmas	St. Petersburg	Hong Kong	Las Palmas	St. Petersburg	Hong Kong	Las Palmas	St. Petersburg	Hong Kong
Passenger	€/pax	51.9	127.9	0.01	53.07	130.18	0.01	58.69	141.12	0.01
Container	€/TEUs	0.03	0.08	0.16	0.03	0.08	0.16	0.04	0.09	0.17
Container	€/Ton	3.13	8.95	18.14	3.24	9.13	18.29	3.74	9.99	19.01
Cargo	€/Ton	0.01	0.01	0.03	0.01	0.01	0.03	0.01	0.01	0.03
Tankers	€/Ton	8.77	6.16	9.16	9.06	6.28	9.27	10.47	6.86	9.79
Others	€/Ton	7.36	14.10	1.97	7.63	14.38	2.00	8.94	15.71	2.16

Note: this approximation to eco-efficiency has been based on AIS-STEAM-based vessel emission calculations which relate to the three harbour areas with all ships and speeds allowed in Tichavska et al. 2017. Also on EU15 BeTa cost factors only.

should be done to make it possible in future research.

[17] It is also expressed in TEUs.

As already mentioned, the vessel emission calculations carried out for the passenger sub-sector, allow more refined comparisons among ports. Table 8 shows eco-efficiency indicators by pollutant, passenger subsector and ports. It should be noted, that the highest indicators, represent the less environmentally efficient (eco-efficient) subsectors. Taking this into account, and by observing local effect pollutants (NOx, SOx, PM and CO results in Table 8), the least eco-efficient port would be Saint Petersburg (26.63€/pax) followed by Las Palmas (6.71€/pax) and with quite a significant distance, Hong Kong (0.68€/pax).

Table 8. Eco-efficiency performance by passenger shipping subsector and ports

Passenger Subsector	Eco-efficiency performance (€/pax)						
	Local only					Local and global	Local and global
	NOx	SOx	$PM_{2.5}$	CO	Total	Low	High
Las Palmas Port (EU15)							
Cruise	3.38	0.51	1.98	0.000084	5.87	6.24	8.05
Ferry	4.18	0.61	2.38	0.000102	7.17	7.62	9.82
Total	3.90	0.57	2.24	0.000095	6.71	7.14	9.20
St. Petersburg Port (EU15)							
Cruise	12.78	1.48	7.18	0.000294	21.44	22.87	29.78
Ferry	26.42	3.08	14.35	0.000528	43.84	46.78	61.01
Total	15.94	1.85	8.84	0.000348	26.63	28.41	37.01
Hong Kong Port (EU15)							
Cruise	3.31	3.54	4.91	0.000027	11.75	11.89	12.57
Ferry	0.03	0.02	0.03	0.000000	0.08	0.08	0.09
Total	0.19	0.20	0.28	0.000001	0.67	0.68	0.72

Note: this approximation to eco-efficiency has been based on AIS-STEAM-based vessel emission calculations in Tichavska et al. 2017. Emission calculations for passenger vessels include manoeuvring and berthing vessels navigating at a speed 0-5 knots, only. This allows a more refined comparability among ports (not with Table 7 since emission calculations are different) and uncertainty reduction in terms of fairway distances/differences within ports. Externality cost calculation has also been based on EU15 BeTa cost factors only.

However, the disaggregated figures, also allow the discovery of greater differences between sub-sectors: ferries and cruises. Thus, the ferry sub-sector is the least eco-efficient in Las Palmas Port (7,17€/pax, when compared with 5.87€/pax for cruise) and St. Petersburg (43,84€/pax, when compared with 21,44€/pax for cruise) whereas the opposite happens in the case of Hong Kong (11.98€/pax for cruise, when compared with 0.08€/pax for ferries).

What the above figures (see Table 8) highlight is that contrary to what one might think, it is not always the same sub-sector of passengers that gives rise to the greatest costs. Therefore, if one of the core principles of sustainable development: The Polluter Pays Principle is applied, more precise measurements and calculations should be required. Thus, if the total external costs were used to introduce eco-taxes to internalise local externality costs in St. Petersburg´s port, these would be 26,63€/pax, which would clearly imply a higher rate in the case of cruises (21.44€/pax) and lower in the case of ferries (43,84€/pax). All aligned with the externality cost generated by each one.

It is important to emphasize the importance of having these indicators and to register them periodically, since these will be of great assistance in the evaluation of the efficiency effectiveness or saving measures that could be potentially carried out. The lack of comparability in current indicators and tools can be also in itself, a disincentive for the market (or ports) to report, request or make use of emission, externality costs or eco-efficiency calculations, which can enable comparisons on equity conditions. This can potentially facilitate sustainability improvement of the port communities by fostering the design of incentive instruments according to detailed operative, polluting profiles and the externality costs calculated from them, to then develop mitigating policies for instance (Tichavska and Tovar 2015b).

Moreover, eco-efficiency indicators related with SOx (see Table 8), show higher external cost, that is a lesser performance, by the sub-sector of cruise in Hong Kong, followed by St. Petersburg and, finally by Las Palmas Port. This is something that is probably related to the more stringent sulphur regulation: Las Palmas (EU regulation), followed by St. Petersburg (Non-EU SECA) and Hong Kong (non EU, non SECA). The same can be said of the externality cost per passenger in the case of Las Palmas and St. Petersburg. Therefore, the lack of stringent regulatory measures gives rise to a higher external cost per passenger. And, if used to define eco-taxes, it may act as incentive of change to greener fuels. This, of course, as long as the total cost of implementing these measures is not higher than the eco-taxes.

5. CONCLUSIONS

Air quality has become a major concern for ports. This is continuously demonstrated by voluntary initiatives such as the World Port Climate Initiative promoted by the International Association of Ports and Harbours (IAPH) or by the European Sea Ports Organisation (ESPO). Also, the importance of air quality as an environmental priority for European Ports has increased considerably. It has evolved from not being ranked (1996), to being ranked in the sixth place (2004) and then since 2013, rank as a top priority (ESPO, 2016).

The present study contributes to the state-of-the-art in literature by presenting, for the first time, calculations on the economic costs and the eco-efficiency performance of vessel traffic in cargo and passenger ports under diverse geographical and regulatory frameworks (EU, Non-EU SECA and non-SECA). Also, by including port, sector and passenger sub-sector (cruise and ferry) totals. External costs totals are based on a top-down approach and the latest seaport-related cost figures in BeTa. At last, eco-efficiency indicators are also calculated.

The overall external costs (local and global high) derive in a total of 231,1 million € in Las Palmas Port; 779 million € in St. Petersburg and 7,423 million € in Hong Kong. Moreover, and when it comes to the environmental cost per shipping sector, the passenger sector in Las Palmas, and container in the case of St. Petersburg and Hong Kong remain as the most representative in each port. In the case of passenger (cruise and ferry) vessels, the overall external costs (local and global high) derive in a total of 11,3 (3,4 and 7,9 respectively) million € in Las Palmas Port; in a total of 19,5 (12,1 and 7,4 respectively) million € in St. Petersburg and in a total of 19,7 (17,4 and 2,3 respectively) million € in Hong Kong. Finally, eco-efficiency performance indicators show that the highest scores relate to the passenger sub-sectors both in Las Palmas Port (51.91 €/pax) and, in St. Petersburg (127.91 €/pax). This is different to results in Hong Kong where the highest scores relate to container subsectors (18.14 €/Ton).

In terms of the local effect pollutants regarding passenger, results reflect that the least eco-efficient port is Saint Petersburg (26.63€/pax) followed by Las Palmas (6.71€/pax) and, Hong Kong (0.68€/pax). The disaggregated figures, allow the discovery of greater differences between sub-sectors, such as ferries and cruises. For instance, and based on our results, the ferry sub-sector is the least eco-efficient in Las Palmas Port (7,17€/pax ferries, 5.87€/pax cruise) and St. Petersburg (43,84€/pax ferries, 21,44€/pax cruise) whereas the opposite happens in the case of Hong Kong (11.98€/pax cruise, 0.08€/pax ferries). Moreover, eco-efficiency indicators related with SOx, show a higher external cost by the sub-sector of cruise in Hong Kong, followed by St. Petersburg and, finally by Las Palmas Port. This is something that is probably related to the more stringent sulphur regulation. Therefore, the lack of stringent regulatory measures gives rise to a higher external cost per passenger.

At last, it should be stressed that ferry and cruise are industries very different in nature. Whereas cruise services are oriented to a recreational segment (cruise), ferry services supply transportation needs across channels, straits and archipelagos through regular services. Ferries form a part of the public transport systems of many waterside cities and islands. These are generally ships engaged in national cabotage services or short-distance connections and, sometimes it is considered that there is a socially desirable advantage in this transport being available. For instance, the case of inter-island passenger transport services in the Canary Islands, where they have the consideration of a public service obligation. This distinction is important and should be taken into account when regulating. Especially in those cases where the positive economic impact of the cruise activity on the destination is questioned.

The above figures highlight that, it is not always the same sub-sector that gives rise to the greatest costs. Therefore, if one of the core principles of sustainable development: The Polluter Pays Principle is applied, more precise measurements and calculations should be required. These measures could help ports to apply environmentally differentiated port fees by subsector as a way to distribute the costs of the services that the port provides its customers, making it cheaper for ships with better environmental status. This way, and through its publication (corrective effect or public pressure by informed citizens) polluters can be incentivised to ensure an optimal environmental practice. What is more, eco-efficiency indicators, also allow a comparison among companies operating in different subsectors (i.e. ferries vs cruise) on an equal footing, and the efforts of those acting proactively (acting in advance to deal with the emission problem through different tools such as the use of quality fuel, just in time ship operations technology, low-carbon berthing infrastructure and so on and so forth) gain presence in the port city-community, through these results (Tichavska and Tovar, 2015b). Last but not least, if emissions measures are used to define eco-taxes, it may act as incentive of change to greener fuels.

REFERENCES

Berechman, J., Tseng, P.H. 2012. Estimating the environmental costs of port related emissions: the case of Kaohsiung. Transp. Res. Part D 17 (1), 35–38.

McArthur, D.P., Osland, L. 2013. Ships in a city harbour: an economic valuation of atmospheric emissions. Transp. Res. Part D 21, 47–52.

Castells, S.M., Usabiaga, S.J.J., Martínez, D.O.F.X. 2014. Manoeuvring and hotelling external costs: enough for alternative energy sources? Maritime Policy Management. 41 (1), 42–60.

Castillo-Manzano, J. I., Fageda, X., Gonzalez-Laxe, F. 2014. An analysis of the determinants of cruise traffic: An empirical application to the Spanish port system. Transportation Research Part E, 66, 115-125.

CE/INFRAS/ISI. 2008. Internalisation Measures and Policies for the External Cost of Transport Produced Within the Study Internalisation Measures and Policies for all External Cost of Transport (IMPACT) – Deliverable 3Delft: CE Delft, 2008.

Contini D., Gambaro, A.; Belosi, F.: De Pieri, S.; Cairns, W.; Donateo, A.; Zanotto, E.; Citron, M. 2011. Direct influence of ship traffic on atmospheric $PM_{2.5}$, PM_{10} and PAHs in Venice. Journal of Environmental Management, 92, 2119-2129. DOI: 10.1016/j.jenvman.2011.01.016

Contini D., Gambaro, A.; Donateo, A.; Cescon, P.; Cesari, D.; Merico, E.; Belosi, F.; Citron, M. 2015. Inter-annual trend of the direct contribution of ship emissions to PM2.5 concentrations in Venice (Italy): efficiency of emissions mitigation strategies. Atmospheric Environment, 102, 183-190. DOI: 10.1016/j.atmosenv.2014.11.065

Delft, C.E., Infras, F.I. 2011. External Costs of Transport in Europe. Update Study for 2008. Commissioned by: International Union of Railways UIC. Delft, CE Delft, September, 2011.

Denisis, A. 2009. An Economic Feasibility Study of Short Sea Shipping Including the Estimation of Externalities with Fuzzy Logic. Ph.D. Thesis, The University of Michigan, USA.

Directive 2005/33/EC of The European Parliament and of The Council of 6 July 2005 amending Directive 1999/32/EC. Official Journal of the European Union. L 191/59. (Accessed on 07/02/2018) http://eur-lex.europa.eu/LexUriServ/LexUriServ.do?uri=OJ:L:2005:191:0059:0069:EN:PDF

Donateo A., Gregoris, E.; Gambaro, A.; Merico, E.; Giua, R.; Nocioni, A.; Contini, D. 2014. Contribution of harbour activities and ships traffic to PM2.5, particle number concentrations and PAHs in a port-city of the Mediterranean Sea (Italy). Environmental Science and Pollution Research, 21(15), 9415-9429. DOI: 10.1007/s11356-014-2849-0

Dragovic, B., Tzannatos, E. Tselentis, V. Meštrovic, R., Škuric, M. 2018. Ship emissions and their externalities in cruise ports. Transportation Research Part D, 61, 289-300.

EMSA. 2015. Monitoring, Reporting and Verification. Air emissions from shipping: the case for continuous monitoring. Presented by EMSA, Environmental Protection in Brussels, Belgium. Available online: http://www.transportenvironment.org/sites/te/files/P2_Overview_verification_schemes_EMSA.pdf

ESPO 2016. European Port Industry Sustainable Report. http://www.espo.be/media/news/EuropeanPortIndustrySustRep2016-dimished.pdf

Heinbach, C. 2012. Dirty Containers: A Measurement and Cost Estimation Approach of Atmospheric Pollution in Hong Kong. Diplomica Verlag, Hamburg, Germany.

Jalkanen, J-P.; Johansson, L.; Kukkonen, J. 2013. A Comprehensive Inventory of the Ship Traffic Exhaust Emissions in the Baltic Sea from 2006 to 2009. A Journal of the Human Environment 43(3), 311-324.

IMO MARPOL, Regulation 14 on Sulphur Oxides and Particulate Matter. http://www.imo.org/en/MediaCentre/HotTopics/GHG/Documents/FAQ_2020_English.pdf.

Kalli, J.; Repka, S.; Alhosalo, M. 2015. Partnerships and ports: Negotiating climate adaptive governance for sustainable transport regimes. International Journal of Sustainable Transportation, 9 (2), 468-477.

Maragkogianni, A.; Papaefthimiou, S., 2015. Evaluating the social cost of cruise ships air emissions in major ports of Greece. Transport. Res. Part D: Transp. Environ. 36, 10–17.

Merico, E.; Gambaro, A.; Argiriou, A.; Alebic-Juretic, A.; Barbaro, E; Cesari, D.; Chasapidis, L.; Dimopoulos, S.; Dinoi, A.; Donateo, A.; Giannaros, C.; Gregoris, E.; Karagiannidis, A.; Konstandopoulos, A.G.; Ivoševic´, T.; Liora, N.; Melas, D.; Mifka, B. Orlic´, I.; Poupkou, A.; Sarovic, K.; Tsakis, A.; Giua, R.; Pastore, T.; Nocioni, A.; Contini, D. 2017. *Atmospheric impact of ship traffic in four Adriatic-Ionian port-cities: comparison and harmonization of different approaches*. Transportation Research Part D: Transport and Environment 50, 431- 445. DOI: 10.1016/j.trd.2016.11.016.

Merico E., Donateo, A.; Gambaro, A.; Cesari, D.; Gregoris, E.; Barbaro, E.; Dinoi, A.; Giovanelli, G.; Masieri, S.; Contini, D. 2016. Influence of in-port ships emissions to gaseous atmospheric pollutants and to particulate matter of different sizes in a Mediterranean harbour in Italy. Atmospheric Environment 139, 1-10. DOI:10.1016/j.atmosenv.2016.05.024

Miola, A., Paccagnan, V., Mannino, I., Massarutto, A., Perujo, A., Turvani, M. 2009. External costs of transportation. Case study: Maritime transport. Ispra: JRC European Commission.

NETCEN. 2004. Benefits Table database: Estimates of the marginal external costs of air pollution in Europe. BeTa Version E1.02a. Created for European Commission DG Environment by Netcen.

Nursey-Bray, M 2016. Partnerships and ports: Negotiating climate adaptive governance for sustainable transport regimes. International Journal of Sustainable Transportation, 10 (2), 76-85.

Ports of Auckland 2017. Cruise Vessel Emission Reduction Technologies Feasibility Study. (available in: http://www.poal.co.nz/media/ports-of-auckland-releases-study-into-%E2%80%98plugging-in%E2%80%99-cruise-ships. Accessed on 23/01/208)

Rodriguez-Álvarez, A.; Tovar, B. 2012. Have Spanish Port sector reforms during the last two decades been successful? A cost frontier approach. Transp. Policy 24, 723–782.

Song, S. 2014. Ship emissions inventory, social cost and eco-efficiency in Shanghai Yangshan port. Atmos. Environ. 82, 288–297.

Song, S. 2017. Assessment of transport emissions impact and the associated social cost for Chengdu, China. International Journal of Sustainable Transportation, 0 (0), 1-12.

Tichavska, M. ;Tovar, B. 2015a. Port-City exhaust emission model: an application to cruise and ferry operations in Las Palmas Port. Transport. Res. Part A: Policy Practice. 78, 347–360.

Tichavska, M.; Tovar, B. 2015b. Environmental cost and eco-efficiency from vessel emissions in Las Palmas Port. Transportation Research Part E: Logistics and Transportation Review, 83, 126-140.

Tichavska, M.; Tovar, B. 2017. External Costs of Vessel Emissions at port: A Review of the Methodological and Empirical State of the Art. Transport Review. 37 (3), 383-402

Tichavska, M., Tovar, B., Gritsenko, D., Johansson, L.; Jalkanen, J-P. 2017. Air emissions from ships in port: Does regulation make a difference? Transport Policy https://doi.org/10.1016/j.tranpol.2017.03.003.

Tovar, B., Wall, A., 2012. Economies of scale and scope in service firms with demand uncertainty: an application to a Spanish port. Marit. Econ. Logist. 14 (3), 362–385.

Tovar, B.; Wall, A. 2014. The impact of demand uncertainty on port infrastructure costs: useful information for regulators? Transp. Policy 33, 176–183.

Tzannatos, E. 2010a. Costs and benefits of reducing SO2 emissions from shipping in the Greek seas. Maritime Economics & Logistics 12 (3), 280-294.)

Tzannatos, E. 2010b. Ship emissions and their externalities for the port of Piraeus - Greece. Atmos. Environ. 44 (3), 400–407.

Tzannatos, E., 2010c. Cost assessment of ship emission reduction methods at berth: the case of the Port of Piraeus, Greece. Marit. Policy Manag. 37, 427–445.

Tzannatos, E., Papadimitriou, S., Koliousis, I. 2015. A Techno-Economic Analysis of Oil vs. Natural Gas Operation for Greek Island Ferries. International Journal of Sustainable Transportation, 9(4), 272-281.

Viana, M. Hammingh, P. Colette, A. Querol, X. Degraeuwe, B. de Vlieger, I. van Aardenne, J. 2014. Impact of maritime transport emissions on coastal air quality in Europe. Atmospheric Environment, 90, 96-105