Port-city Exhaust Emission Model: an approach to Cruise and Ferry operations in Las Palmas Port

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Abstract

Ports and cities relate as drivers of urban economic growth. Still, local and external regions benefit from well-functioning ports while some negative impacts remain in Port-city areas. Environmental impacts, as solid waste and air emissions, colligate to port-land activity and vessel traffic. In a port-related emission context and in despite of its small share in the world fleet, cruise and ferry navigation play a particular role. Hotelling, manoeuvring, loading, unloading and stationary operations at berth generate a large share of emissions resulting in externalities and human health consequences. The need to reduce environmental pressure and to define effective regulation in terms of vessel compliance requires a detailed assessment on emissions. This paper addresses this need by estimating the exhaust pollutants related to ferry and cruise operations by sea in Las Palmas Port and by connecting results with existent regulation. Emission assessment is based on the Ship Traffic Emission Assessment Model (STEAM) and messages transmitted by the Automatic Identification System (AIS) during 2011. Results are described as a breakdown of NOx, SOx, PM, CO and CO2 classified in hotelling, manoeuvring, cruising operations and weight classes, followed by discussion, conclusions, policy implications and future research recommendations.

Keywords: Emission modelling, Automatic Identification System (AIS), Ferry, Cruise, Regulation.

1. Introduction

Passenger transport by sea has a long history throughout which it has been transformed noticeably. It began as a core business for shipping companies operating luxury vessels but its activity diminished into such extent that by mid century 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 transoceanic services oriented to a recreational segment (cruise) and short-sea transportation services offered to carry passengers, 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 motivates 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 assumed 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 (Tzannatos, 2014) 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.

Passenger transport services ferry and cruise, share positive effects and economic benefits in ports and cities. Still, negative impacts, including air pollution, also relate to engine load variations while operating at port (Castells et al., 2014). Shipping activity and propagation of exhaust gases resulting from combustion of fuels have a significant impact on air and health quality of port-city areas. Harmful materials in the atmosphere have been addressed as a risk factor for cardiovascular, respiratory conditions or even human death (Corbett et al., 2007). Health problems and monetary costs related to air pollution have raised a global concern aiming to control and reduce combustion emissions. As a result of this, compliance and enhancement of emission regulation in shipping has been pursued.

Methodological aspects need to be considered when designing upcoming measures. Policy makers need to know how much, where, how and who releases emissions in order to assess adequacy and improvement of stringent policies. Scarcity of data has led into uncertainty and a widespread use of calculation methodologies concerning air emissions in shipping. Still, new technologies and traffic data put into question usefulness of the methodologies proposed so far (Miola et al., 2010).

AIS-based inventories can be effectively used to assess shipping emissions and policy changes in port areas (Ng et al., 2010). The challenge of identifying operating profiles of ships at berth during hotelling, manoeuvring and normal cruising navigation or emission dependency on engine load can be addressed with position records and commercial databases containing technical and engine details. This guarantees location; speed and route are always acknowledged, providing the additional possibility to model high-resolution maps of geographical distribution of emissions in port-city areas. AIS-based methodologies have been addressed before for shipping emission estimations. Yet, its functionalities have never been presented as a policy instrument to achieve inference on corrective measures for a specific sector as passenger shipping. Thus, the main contribution of this paper is to present empirical evidence on the application of AIS-based methodologies to assess gases and particles released by cruise and ferry services disaggregating results by weight classes, hotelling, manoeuvring and cruising operations. AIS-based methodologies have been previously addressed to disaggregate emissions according to their operational status (Ng et al., 2012); yet, this is the first time a similar case-study is presented to address a specific shipping sector, and the first time this is done in an island Port. Results of this study will not only support adequacy or improvement of existing policy in port-city areas but this can be also transferable to islands under similar conditions. Structure of this document is presented below.

Section 2 presents background information of exhaust emissions in shipping and existing regulation. Section 3 describes methodological evolution of shipping emission estimation to then present the Ship Traffic Assessment Model (STEAM). Section 4 describes results as a breakdown by hotelling, manoeuvring, cruising operations and weight classes. In addition to this, a selection of geographical outputs highlights distribution of results through high-resolution maps. Discussion, conclusions and future research are presented in Section 5.

2. Background

Exhaust emissions in shipping are released into the atmosphere as a result of diesel fuel combustion. Volatile carbon matter reacts with oxygen to form noxious gases and particle compounds. Little research has been done providing a satisfactory comprehension in the relationship between primary pollutant emissions, secondary aerosols formation and resulting air quality in port-city areas (Pandolfi et al., 2011). Still, epidemiological studies consistently link atmospheric concentrations of exhaust gasses and Particulate Matter (PM[1]) to negative health effects caused by short-term (headaches, dizziness, nausea, coughing, laboured breathing) and long-term exposure (cronical diseases, lung cancer and mortality) resulting in many cases, in hospital admissions and premature mortality (Corbett et al., 2007). In comparison with others pollutants (NOx, SOx, CO_2 and CO), exposure to PM is related to serious health effects. Thus, and in despite the extent level of effects continues to be discovered, harbour (Yau et al., 2013) and shipping-related PM emissions are held responsible for an average of 60,000 cardiopulmonary and lung cancer annual deceases in Europe, East Asia and South Asia´s coastlines (Corbett et al., 2007; Chen et al., 2012).

2.1 Regulatory framework for air emissions in shipping

Current regulation seeks to reduce emissions form ships by forcing the introduction of new abatement technologies and establishing minimum fuel quality standards. The International Maritime Organization (IMO) has addressed ship pollution under the MARPOL convention. The regulation of air pollution by ships was defined in MARPOL Annex VI, first adopted in 1997 and enforced in 2010 including a progressive reduction of global SOx, NOx and Particulate Matter (PM) in Emission Control Areas (ECA). MARPOL Annex VI is the only global regime that directly addresses air emissions from ships. For this reason, numerous countries have either ratified the Annex or adopted national standards.

The European Union (EU) has also expressed its concerns about transport-related impact through the Strategy for Sustainable Development published on its White Paper on Transport Policy (Gemeinschaften, 2001) establishing a stringent sulphur regulation through sulphur directives: 2012/33/EU, 2005/33 and 1999/32. This sets the 0.1% limit on sulphur content in ECA starting 2015, defined by the IMO. Also, all passenger ships operating on scheduled services to or from any Community port should not exceed 1.5% sulphur limit and all vessels calling an EU port should use low sulphur fuel (less than 0.1%) during port stays longer than two hours. Unfortunately, regardless of its abatement potential, policy design face difficulties in relation to

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[1] Particulate Matter (PM) is associated with tiny pieces of solid or liquid particles suspended as atmospheric aerosol. Its composition is defined in international standards (ISO 8178) according to diameter measures (10 micrometres or less, and 2.5 micrometres or less).

allowance distribution according to ship types, uses and dimensions. Also, compliance constraints exist in relation to the International Law of the Sea, and in particular with the United Nations Convention on the Law of the Sea 1982 (UNCLOS) to which the EU is signatory. There is currently no legal basis for the EU to exercise extra-territorial jurisdiction and this is likely to give non-EU states and industrial bodies grounds for challenging emissions reduction measures adopted by the EU for maritime transport (Miola et al., 2010).

Flag states shall exercise full jurisdiction and control in administrative, technical and social matters over vessels flying their flag. Which means, regardless of the environmental requirements enforced by member states, flags of convenience may refuse to comply, and demand a right of passage according to UNCLOS Art. 24 and enforced by UNCLOS Articles 18, 19 and 26 and 227 which determine that states shall not discriminate in form or fact against vessels of any other state.

Maritime state is responsible for compliance of ships operating in its territorial waters and calling at their ports. UNCLOS gives the coastal state to legislate in certain areas such as environmental protection and the prevention and control of pollution. It also grants the right to enforce international regulations in their territorial waters. Paris Memorandum of Understanding (PMoU) was constituted with the aim of guaranteeing vessel compliance. By 2010, it was signed by 27 countries and followed by the establishment of similar agreements through the Mediterranean Sea, Tokyo, the Caribbean, Latin America, the Indian Ocean and others. The United States controls its own program.

Actions carried out by Port Authorities are consistent with their commercial and infrastructure development. Alliances or participation in port associations whose purpose is to increase efficiency, planning, safety and environmental improvement is regularly seen. Although the environment impact of passenger operations will be discussed later, it should be noted that ports have not remained outside the scope of policy and strategy implementation that aim to reduce air emissions. In fact, in April 2008, the International Association of Ports and Harbours (IAPH) requested its Environmental Committee in consultation with the Regional Organization of Ports for a mechanism to assist ports to abate climate change. In July 2009, fifty-five ports around the globe gathered at the World Climate Conference in Rotterdam to jointly commit to reduce global climate change. In addition to this, the main ports of the world signed the Declaration of World Ports for a better climate, which aims, among others, to achieve methodology appliance for carbon footprint calculation and thus for carbon reduction in port areas.

Since 2011, Port of Rotterdam offers a 10% incentive discount based on International Environmental Ship Index (ESI) registration. Green Award certificate was introduced in Norway in 2007. Also, European Ports incentivize innovative projects that lead to environmental improvement (eg. ESPO award 2014) and actions for the benefit of the wider port and local communities (eg.EcoPorts Network). In Spain and in the Canary islands, according to Law 33/2010, incentive discounts are offered by ports, address operators that either comply with environmental certifications as the ISO14001:2004[2] and the European Eco-Management and Audit Scheme (EMAS), or with a best practice agreement signed with the Port Authority according to environmental guidelines authorized and provided by Puertos del Estado. In addition to incentive schemes, and since 2010, Spanish ports have also started to seek for sustainable schemes for development. Main Canarian Ports (Las Palmas and Santa Cruz de Tenerife) were certified by ISO14001:2004 in 2014.

2.2 Abatement methods for exhaust emissions in shipping

Emission reduction has been achieved by the implementation of MARPOL Annex VI (Buhaug, 2009; Johansson et al., 2013). Nevertheless, on-board and on-shore abatement is also feasible from a technological perspective. Ship design (hulls, power, speed, propulsion systems) and operational improvements (route and energy optimization or fleet management) can minimize exhaust pollution. Wind, solar and wave energy can be used for on-board or on-shore operations. Wet or dry scrubbing systems may remove or neutralize harmful substances from gas streams. Unfortunately, its success is bounded to implementation speed and cost limitations (Buhaug, 2009).

The switch from residual to distillate fuels is implied in MARPOL Annex VI from IMO regulation. Still, the use of Biofuels and Liquefied Natural Gas (LNG) is being explored. Organic composition of biofuels implies technical complications as stability during storage, biological growth while contained in addition to the complex processes to adapt current fuel systems to its use. LNG contains no sulphur and it can meet SOx requirements without additional exhaust treatments, limited by storage challenges on-board and fuel provision on-shore. Also, conversion from diesel to LNG demands significant changes on engines. LNG has so far maintained competitive in terms of price when compared with distillate alternatives and this has increased existing interest on its use in ECA and short-distance navigation (Livanos et al., 2014). Pioneer vessels, as the Viking Grace with a dual-fuel engine[3], and the Stavengerfjord pure gas operations, have been designed to cruise under short distances and start operations cruising under particular conditions as shallow waters in archipelagos. Also, supplying facilities appear as a

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[2] Requirements of the ISO 14001:2004 intend to be incorporated into any environmental management system (eg. air emissions, spills, soil pollution, natural resource management, energy use, energy emission –heat, radiation, vibration-,and others). The extent of the application will depend on factors such as environmental policies, products, services and location of the organization.

[3] In addition to pure gas operations, dual-fuel technology configuration allows HFO, diesel or LNG navigation.

new generation of services moving towards a heavy use of LNG (Einang, 2007; Acciaro, 2014). According to Merk, (2013), Bremenports constructed an LNG depot (2011) to be used by its service fleet in Bremen and Bremerhaven and also to be set as a precedent for port visitors. Rotterdam opened its first LNG gate in 2011, signing contracts with up to five costumers by 2013. Gothenburg aims to have its own LNG terminal operational by 2015. LNG fuelled ships and supplying facilities may imply higher costs, yet, investment on such technologies will provide competitive advantage over counterparts as regulation becomes increasingly stringent and EU regulation proposes port members to feature LNG facilities by 2020 (COM[2013] 480).

In Spain, LNG shipping has not been deployed yet as a short-distance service (either for ferries or for service vessels as tugs). Indeed, abatement actions adopted by ports have been so far, mostly focused on land-based and not sea-based activities at Port[4]. If existent, diverse approaches of initiatives can be seen. For instance, Port Authority of A Coruña classifies emissions from shipping as indirect effects related to the port community and not to the Port Authority as such, measuring emission and propagation land-based emission concentration facing piers where solid bulk movements take place, or by the parking and transit area of trucks. Port of Cartagena, for instance, does aim to develop technologies and models to reduce emissions cause by ships in three scenarios: port approach, manoeuvring, and port stay.

On the other hand, Shore electric power enables energy supply for lighting, air conditioning, communication equipment and further on-board requirements from vessel operations (Merk, 2013). Its functionality requires for infrastructure configuration to supply electrical networks of different ratings and on-land power supplying grids. Since 2002, this measure has been successfully implemented in Europe (27 ports), North America (12 ports) and Asia (7 ports). Reader is referred to Merk, (2013) for further references. In Spain, shore-side electricity systems for ships to improve surrounding in terms of noise, vibration and air emissions have also been proposed. Port Authority of Bealearic Islands, announced the leadership of a national project aiming to reduce annual emissions and local effects equivalent to 6.000 vehicles, with cold ironing. Ports of Barcelona and Melilla collaborate in similar projects to reduce emissions in port areas. Actions proposed in these cases, also imply So far, Canarian Ports have not addressed shore electric power or any particular action to reduce air emissions.

A positive evolution of shipping-related exhaust emissions has led to regulatory stringency and technological development of abatement techniques. Regardless of the existence of the abatement alternatives, adoption feasibility is often limited by costs and a lack of incentive regulation (Buhaug et al., 2009). Also, experience on technological alternatives is limited; this makes modelling and effectiveness verification a challenging task.

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[4] http://www.puertos.es/sites/default/files/memoria_sostenibilidad_2011.pdf

3. Methodology

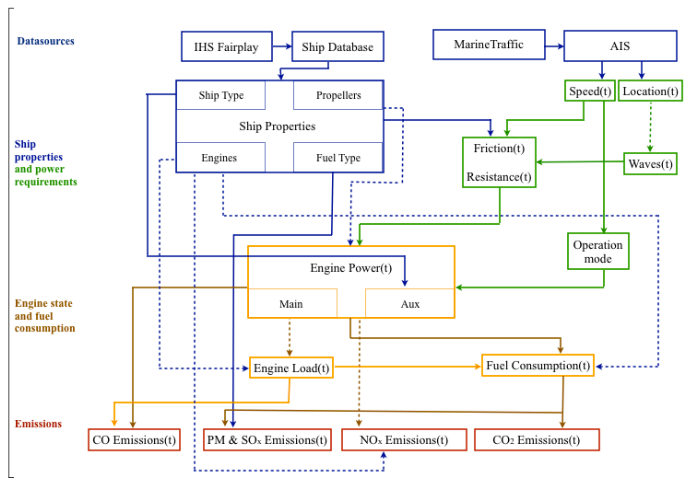
Over the years, two dimensions have been considered for emission evaluation in maritime transport: quantity and location variables that determine where pollutants are released. Bottom-up (Tzannatos, 2010; Paxian et al., 2010), top-down (Endersen et al., 2007), or a mixture of both approaches (Wang et al., 2010; Wang and Corbett, 2007) has been used to assess these dimensions. Still, data scarcity, and assumptions in literature result in an open debate on adequacy of approaches and contexts analysed so far (Miola et al., 2010). Buhaug et al. (2009) has made an attempt to homogenize results from different studies. Uncertainties when comparing results, confirm the need for the so-called, full bottom-up approaches, integrating a great extent of traffic data (vessel movements, port calls -origin-destination- and vessel´s individual characteristics). Technical information, ship activities and geographical distribution of maritime traffic were, until a few years ago, retrieved from average information. Today, if not in a total extent, improvements in accuracy can be achieved as a result of the introduction of innovative technologies for vessel monitoring at sea.

AIS-based inventories can be effectively used to assess shipping emissions in port areas. The challenge of identifying operating profiles of ships at berth during manoeuvring and normal cruising navigation and emission dependency on engine load can be addressed with position records and commercial databases containing technical and engine details. This guarantees location; speed, route, individual dimensions, engine and fuel consumption are always acknowledged, also providing the possibility to model a high-resolution map of geographical distribution of emissions in port-city areas, in addition to emission disaggregation per flag, weight classes and hotelling-manoeuvring navigation mode to define adequacy or improvement of existing policy instruments in port-city areas, such as low sulphur fuel reduction, taxes and tax refund schemes, investment subsidies for technological improvements and differentiated port fees granting discounts and green awards to ship owners with the best environmental performance.

3.1 The STEAM model and its main components

An overview of this model is presented in this section, for extensive details; the reader is referred to Jalkanen et al., (2009), Jalkanen et al., (2012) and Jalkanen et al., (2013). Emission estimations in this paper are evaluated by using the Ship Traffic Emission Assessment Model (STEAM). STEAM is based on the properties of ships and its power requirements. It was presented as a first attempt to assess NOx, SOx, PM, CO and CO_2, emissions related to shipping activity according to traffic data provided by the Automatic Identification System (AIS) (Jalkanen et al., 2009; Jalkanen et al., 2012). The AIS was conceived as a navigational aid for ship monitoring and collision avoidance at sea. According to the International Maritime Organization (IMO) regulation 19.2 of Safety Of Life at Seas (SOLAS), an AIS transceiver shall be equipped in every sea-going ship larger than 300 gross tons and every passenger vessel irrespective of size. Its system transmits static and voyage-related information every 6 minutes in addition to dynamic information with a frequency related to the vessel´s speed underway (2-10 seconds) and navigational status (3 min. when anchored). For this case study historical dynamic information was provided through a historical request to terrestrial and satellite services from MarineTraffic (see section 3.2.2). Model components are presented in Figure 1. Input data and output results are presented in the uppermost and lowest row of rectangles. Arrows describe the model´s information flow, dependency between factors in addition to dotted and solid arrows used for visual clarity. Colours denote variable categories included in the model.

Figure 1 – Main components of the STEAM and their inter-relations.



Source: adapted from Jalkanen et al. (2012).

3.2 Input values

A ship database of over 50,000 vessel particulars (over a third part of the global fleet) and AIS position records provided by MarineTraffic define input values for the STEAM.

3.2.1. Ship database

Ship database considers: physical dimensions, engine particulars and variables presented on Table 1. Database holds information among others, on experimentally determined emission factors, installed abatement techniques, shaft generators, specific fuel oil consumption, fuel type and sulphur content of fuel for main and auxiliary engines. Information was provided mainly, by the Lloyds ship register, engine manufacturers, local authorities and ship owners.

Table 1- STEAM model regarding the properties of ships

Identification	Physical properties	Main engine properties	Auxiliary engine properties
Ship name	Length	ME, Fuel sulphur content	AE, installed kW
IMO registry number	Breadth	ME, abatement technique	Number of AE
MMSI code	Draught	ME, SFOC	AE, Fuel type
Ship type	Build year	ME, design	AE, Fuel sulphur content
Gross tonnage	Design speed	ME, model	AE, SFOC
Deadweight tonnage	Number of cabins	ME, stroke type	AE, abatement technique
	Hull type	ME, rpm	
		Number of ME	
		ME, installed kW	
		ME, Fuel type1	
		ME, Fuel type2	
		Measured EFs	

Note: MMSI = Mobile Maritime Service Identity, ME=Main engine, AE=Auxiliary engine, rpm=crankshaft revolutions per minute, SFOC=Specific Fuel Oil Consumption, Measured EF = Experimental value for emission factors of NOx, SOx, CO and PM. Source: adapted from Jalkanen et al. (2009). Additional data fields, like the existence of bulbous bow, propeller details and cargo capacity are also used (see Jalkanen et al. (2012).

3.2.2. AIS data

AIS data is broadcasted in open air, and its signals can be received through terrestrial or satellite stations. For this case study, AIS dynamic records were obtained from terrestrial services provided by MarineTraffic. This results in a data flow of thousands of positions per ship, per year. Longitude, Latitude, a unique nine digit Maritime Mobile Service Identity (MMSI) of vessels, Navigation Status (at anchor, under way using engine, not under command among others), Speed over ground, Course (relative to true north to 0.1°), Heading (0 to 359 degrees) and Timestamp in Coordinated Universal Time (UTC) integrate dynamic fields from AIS data transmitted by passenger vessels during 2011 in Las Palmas Port (area defined by bounding coordinates: LAT from 28° to 28,45 °, LON from -15,60° to 15°).

3.3. Model performance and uncertainty considerations

Model performance and uncertainty considerations have been extensively described in Jalkanen et al. (2009), Jalkanen et al., (2012) and Jalkanen et al., (2013). As described in Johansson et al., (2013), the model has been able to predict aggregate annual fuel consumption of a collection of large marine ships with a mean prediction error between 9 and 15%. Still, uncertainties regarding properties of ships and AIS information should be considered as well as limitations for auxiliary power predictions and its relevance for ship emissions occurring in port areas.

3.3.1. Uncertainty regarding properties of ships

Uncertainties of power prediction should be considered due to the neglect of environmental effects in estimations (wind, currents, sea ice covers and others). Also, insufficient experimental data on the chemical composition of particulate matter emissions should be taken into consideration. The model uses emission factors from the most recent literature. Still, experimental setups are diverse (Johansson et al., 2013).

3.3.2 Uncertainty regarding AIS and harbour activity

Ship routes and a high-resolution activity map can be expected from the AIS messages and their location signal transmitted. Still, the temporal and spatial coverage of the AIS will depend on performance of terrestrial receiving stations and equipment installed in vessels (AIS transponder, GPS, and navigation tools). An accurate modelling of hotelling and manoeuvring operations in harbour areas requires a frequent update of data (several times per minute) as the speed of vessels may change constantly. Temporal gaps and a low frequency of messages may be the cause of significant inaccuracies. Also, uncertainties related to the auxiliary engine power usage onboard vessels can be significant. Commercial databases may offer an incomplete representation of installed auxiliary engine power, which must be augmented with data from classification societies, fleet owners or engine manufacturers. This information is often unavailable and must be estimated based on existing knowledge. In contrast to the main engine power predictions, there is no accurate, generally available model for auxiliary engine usage of ships as it may vary in accordance to their cargo handling gear, need for heating, cooling, pumping and additional uses of energy.

4. Case study, Las Palmas Port.

The Canary Islands are one of Spain's seventeen Autonomous Communities and an outermost region of the European Union. Located in the Atlantic Ocean, consist of seven islands; the islands are located at 115 kilometers far from the northwest African coast and at an average distance of 1750 kilometers from Madrid; the nearest mainland port is Cadiz, at an average distance of 1200 kilometers. The Autonomous Community of the Canary Islands integrates two provinces, Las Palmas and Santa Cruz de Tenerife. Gran Canaria and Tenerife, both capital islands, are the main nodes connecting the archipelago, mainland Spain and other countries. The Canary Islands main ports, Las Palmas port (located in Gran Canaria) and S.C. Tenerife port (located in Tenerife) are managed by different Port Authorities. In 2011, freight transported in these ports, summed up to more than 88% of the total freight transported from and to other geographical areas. Las Palmas Port is a major logistic platform between Europe, Africa and America and it offers many advantages to ocean-going vessels such as a recognized technical and commercial maritime community and competitiveness in supplies and repair services. Its location between main commercial trade routes makes it a main container (1.207.939 TEU in 2012), cargo (over 23 million tons from loading, unloading and transhipments) and passenger hub with over 908.000 passengers in 2011. Passenger traffic is growing steadily over time.

To meet the maritime transportation demand in the Canarian archipelago (passengers or passengers and goods), ferry routes are offered in a daily basis through direct or scaled services. Hub operations are set in both main canaries ports. Direct connections are regularly offered from Gran Canaria, and Tenerife in direction to: Fuerteventura, Lanzarote, La Gomera and Spanish mainland (Huelva). In addition to the regular ferry services, passenger numbers accounted in cruise operations in the Canary Islands have increased steadily up to 1.600.000 with a major participation of Carnival (49%) and Royal Caribbean cruise lines (23%), (EDEI, 2011). According to Puertos del Estado, passenger share of Las Palmas Port increased in over 20% with a total of 1.605.531 passengers in 2013. Sustained market growth increases the need to identify and measure environmental impacts generated by vessel traffic, particularly in locations where actions to mitigate these are not being practiced as it is in many other harbours in the world.

Cruise passengers and new vessels are deploying services in Canarian ports In comparison to the others, cruise traffic in Las Palmas Port holds one of the largest shares of cruise traffic with 197 port visits, 418.184 cruise passengers and up to 56 cruise ships (22% of the archipelago´s cruising share). A remarked increase in the number of passengers is attributed to the concentration of ships with hub operations during winter season. Indeed, cruise operations are expected to expand even more over time. In addition to what we refer in previous lines, socio-political stability, currency, infrastructure improvement and recognized quality on land services play a particular role in terms of recruitment of new vessels and hosting hub services over the year.

Emissions estimated for passenger traffic are presented in the following section as a breakdown of hotelling, manoeuvring cruising operations and weight classes. To follow, geographical distribution outputs will be addressed through a sample of high-resolution maps. To our knowledge, this is the first study analysing relation between passenger services (cruise and ferry) and air emissions in an island. Results of this study can be of use to further islands or archipelagos under similar conditions.

4.1 Results

According to terrestrial AIS data received during 2011, seventy-four passenger ships navigated Las Palmas Port in 2011. From these, 57 vessels (75%) are classified as cruise ships and 12 of them (19,7%) as RoPax operating ferry services. Engine requirements and operational needs among shipping sectors are diverse, particularly in a port-city context. In the case of passenger ships, for instance; the energy demand of a large cruise ship with more than a thousand air-conditioned cabins is considerably different from that of a bulk cargo carrier or, in ferry services (Jalkanen et al., 2009). Also hotelling-manoeuvring and acceleration-deceleration operations result in engine load changes and increased emissions in most marine diesel engines.

For this reason, emission results and time spent at hotelling; manoeuvring and cruising operations at port are disaggregated in 10 different ship types and presented in Table 2. Ship types, including others and unknown, are an automated classification according to information received from the AIS[5]. Indeed, categories of others and unknown are the ones that in relative terms, contribute with a minimum amount of emissions and a considerable number of hours spent at port. Emission results of these categories are most probably attributed to technical configuration of small-sized vessels and their operating time. On the other hand, a high share of emissions can be noticed from passenger and cargo classes. Results are line with further studies (Stipa et al., 2007; De Meyer et al., 2008; Ng et al., 2012; Kalli et al., 2013; Jalkanen et al., 2013; Johansson et al., 2013).

Results for all categories except others and unknown[6] are represented in Figure 2 as percentage terms in as a fraction of total port emissions and total port time of operation accordingly. It can be observed that the container and the passenger categories are the ones that, in relative terms, pollute more by operating less time at port. Passenger, container and tanker contributions are the highest, both in local (NOx, SOx) and global contribution of emissions (CO, CO2). In addition to this, when compared with the rest of categories, the role of these vessels is also relevant in terms of PM2.5.

Table 2- Emissions related to traffic share as predicted by STEAM

2011	Las Palmas Port	NOx [Kg]	SOx [Kg]	PM2.5 [Kg]	CO [Kg]	CO_2 [Kg]	H	M	C
Traffic share	Passenger	1,072,171	538,281	113,449	99,889	50,896,353	23,059	1,072,171	4,360
	Service	282,882	72,042	18,705	36,772	14,500,000	26,583	338	316
	Cargo	372,906	112,158	27,460	46,891	17,700,000	59,444	2,121	3,861
	Container	1,019,379	287,831	73,453	119,174	48,000,000	63,889	1,648	2,712
	Tankers	666,583	185,561	47,261	91,107	33,300,000	65,833	2,889	3,028
	Other	240,744	52,376	14,636	36,675	13,300,000	78,889	4,500	2,361
	Fishing	296,009	59,027	17,095	32,705	15,100,000	43,611	229	349
	Vehicle Carriers	152,567	56,219	13,081	16,889	7,478,647	8,583	245	699
	Unknown ships	142,657	58,230	13,258	17,633	8,892,110	90,833	3,667	5,972
	Total	4,245,897	1,421,726	338,399	497,734	209,167,110	460,726	4,245,897	23,657

Note: Hotelling-manoeuvring operational time was estimated by excluding vessel operations over 5 knots. Time spent in Hotelling (H) (0 knots), Manoeuvring (M) (1-5 knots) and Cruising operations (C) are expressed in hours. Fuel consumption and emissions released while at berth are included. Compliance of IMO and EU regulatory frameworks for marine fuels is assumed and also included in these estimations.

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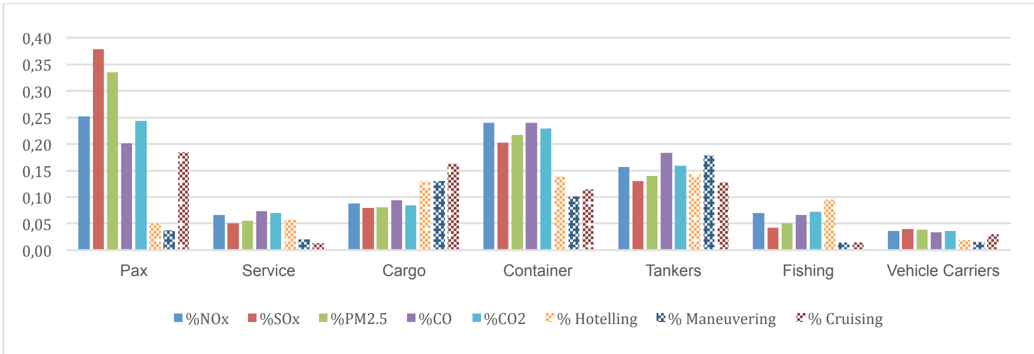
[5] Types of ships are configured in the AIS transponder according to codes referred in the ITU-R, (2010). Unknown category refers to failure cases of identification (no static message received, no connection to national MMSI databases available, small vessels not transmitting a valid IMO registry number).

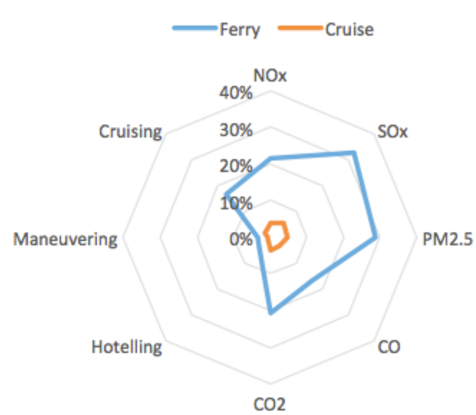
[6] Removed from the figure to save space and facilitate its view.

Figure 2 – Emission and time operation shares by shipping sector, Las Palmas Port.



As expected, passenger sector is among the highest contributors of emissions. Thus, it is of interest to analyse, if this segment´s contribution is similar when categorized as sub-groups (cruise and ferry). Figure 3 presents results for cruise and ferries a fraction of pollutants released at port. It can be seen that contribution of ferries is significantly large in both, local and global-effect emissions (particularly PM) while time spent at hotelling, maneuvering and cruising operations is not significant. Results may be due to operational and technical differences with cruise, as ferry operations relate to regular services with large engines working on a tight schedule, pushing engines to their limits and increasing fuel consumption and exhaust emissions, rapidly (Jalkanen et al., 2009).

Figure 3 – Emission and time operation shares by Cruise and Ferry, Las Palmas Port.



Weight is also crucial to fuel consumption and emission estimation. Table 3 presents results for cruise and ferry as a total of passenger categories. According to results and in terms of emissions the role of the heaviest weight classes (from 45 to 80kt) is representative for cruise operations, while ferry services are mainly allocated between 10 and 30kt. The largest share of local impacts from air pollutants is attributed to ferry vessels between 10kt-30kt, small crafts below 4kt and 10kt, and GT over 80kt. Global impacts are also allocated, mostly, under weight classes between 10 and 30kt. Also, when compared with cruise, ferry vessels have the highest share of emissions while their total time of operations at port is significantly lower. In fact, it is interesting to highlight how most of the operational time from ferries is allocated at cruising. This differs with cruise vessels, as their time is mostly spent in hotelling or manoeuvring operations.

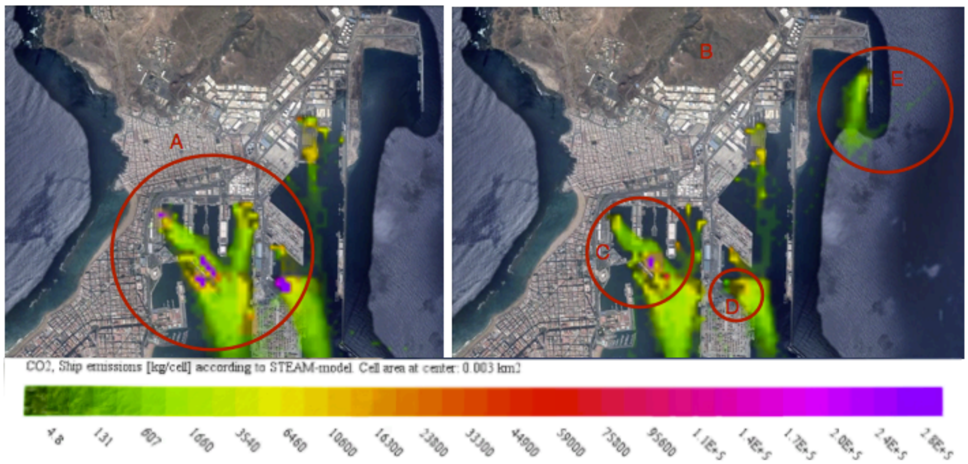
Table 3- Emissions and time of operation related to weight classes as predicted by STEAM

2011	Las Palmas Port	NOx [Kg]	SOx [Kg]	PM2.5 [Kg]	CO [Kg]	CO_2 [Kg]	H	M	C
Cruise	GT Below 4kt	1,785	569	138	237	96,433	368,231	2,1860	5
	GT Between 4kt-10kt	8,204	1,592	447	986	45,8050	5,630,058	11,550	9
	GT Between 10kt-20kt	2,753	784	189	249	133,136	196,812	7,273	4
	GT Between 20kt-30kt	7,541	1,887	486	672	360,221	853,531	30,820	14
	GT Between 30kt-45kt	26,463	9,694	2,123	2,322	1,277,065	1,376,373	47,228	14
	GT Between 45kt-60kt	7,982	3,265	715	814	364,687	366,198	18,615	7
	GT Between 60kt-80kt	86,902	43,788	9,246	9,477	4,140,508	3,906,833	122,232	32
	GT over 80kt	16,749	13,687	2,735	2,877	857,836	1,119,320	55,443	21
	Total Cruise	158,379	75,266	16,079	17,634	7,687,936	13,817,356	315,021	106
Ferry	GT Below 4kt	381	79	22	46	2,175	199	1	1
	GT Between 4kt-10kt	65,604	14,623	35,951	6,502	3,007,778	3,822	51	655
	GT Between 10kt-20kt	588,183	315,770	65,059	46,641	27,446,454	10,854	329	2,433
	GT Between 20kt-30kt	259,434	132,490	28,324	29,050	12,686,242	4,352	143	843
	Total Ferry	913,602	462,962	129,356	82,239	43,142,649	19,227	524	3,932
	Total Pax	**1,071,981**	**538,228**	**145,435**	**99,873**	**50,830,585**	**13,836,583**	**315,545**	**4,038**

4.2 Geographical distribution of results

Location of berthing areas at port is relevant, not only in an operational context (arrival, departure, loading, unloading and berthing) but in the extent into which this determines areas with a highest/lowest concentration of exhaust pollutant released by hotelling, manoeuvring or cruising operations. As shown in Figure 4, in 2011, hotelling and manoeuvring operations of cruise and ferries observed in quays located near a densely populated coastline (left image, A), while in 2012 a ferry line was relocated (for logistical reasons) to an operational quay in La Esfinge (right image, E), surrounded by a lowest rate of inhabitants. In this case study, the view of the geographical distribution of emissions, enables us to observe the impacts that this sort of decisions may imply, in a context of air emissions when accompanied by dispersion modelling studies. Ship emission hot spots (left image, A) and their removal from densely populated areas, (right image, C and D) will decrease the human exposure to ship emissions.

Figure 4– Geographic distribution of CO_2 from hotelling-manoeuvring passenger traffic



5. Discussion, conclusions and future research

Following IMO Marpol annex VI the EU commission has adopted a legal framework of its own to address air emissions, starting with the EC Sulphur directive (1999/32/EU) and further amended by Directive 2012/33/EU in alignment with the revised MARPOL Annex VI. In this directive, all ships at berth in EU waters must use low sulphur fuel (0.1 %) since 2010. The Directive is applicable in all EU member states, also obliged to implement the regulations on territorial waters. A 0.50% limit will apply in EC waters outside SECAs from the 1st of January 2020. Vessels navigating territorial waters in the Canary Islands and operating at its Ports, must also comply with this directive. In addition to port state control, dissuasive penalties and incentives are required to ensure credible implementation of this Directive. Spanish ports should take enforcement action with respect to vessels flying their flag and to vessels of all flags while in their ports as there is a large price difference between distillate and residual fuels. To prevent non-compliance and to promote fair competition, Spanish ports should cooperate closely to take additional enforcement action with respect to other vessels in accordance with international maritime law.

Ports have decided to introduce new business opportunities and position themselves ahead of their competitors in society by pursuing emission reduction, savings in energy consumption and optimisation of energy management. In this sense, a thorough impact assessment study should be made. The monitoring of compliance to low sulphur fuel requirement of the EU sulphur directive should also take place in Las Palmas Port. We suggest starting with a fundamental step towards mitigation of negative impacts by reporting and monitoring air emissions, not only from land-based sources but also from vessel operations at sea. References of Ports pursuing the same objectives can be addressed with detail from Merk, (2013).

Emission estimates presented in this paper suggest passenger traffic as a major source of air pollution in Las Palmas Port. This is consistent with further studies (Ng et al., 2012; Castells et al., 2014). It can be observed that the container and the passenger sectors are responsible for a significant share of emissions considering time spent at port. Passenger, container and tanker contributions are the highest to local air quality (in regards NOx, SOx, PM and CO emissions) and also to CO2 emissions. When compared with the rest of categories, the role of these vessels is also relevant in terms of PM2.5.

Regarding passenger subsectors (ferry and cruise), the role of the heaviest weight classes (from 45 to 80kt) is representative for cruise operations, while ferry services are mainly carried out with smaller vessels, between 10 and 30kt capacity. The largest share of local impacts (NOx, SOx, PM2.5) from air pollutants is attributed to ferry vessels between 10kt-30kt, small crafts below 4kt and 10kt, and GT over 80kt. Global impacts are also allocated, mostly, under weight classes between 10 and 30kt. Emission maps confirm the location of emission hot spots. In particular, berthing quays assigned for cruise and ferry operations located near populated areas are distinguished from the rest.

AIS-based methodologies have been previously addressed to disaggregate exhaust emissions according to their operational status (Ng et al., 2012); yet, this is the first time a similar case study is presented to address a specific shipping sector in an island. It has been shown that AIS based methodologies, especially when accompanied with air quality modelling and impact studies, can be an effective tools to achieve inference on corrective measures for specific shares of traffic as cruise and ferry. Disaggregation of results and consideration of variables previously neglected (speed, engine loads and vessel particulars) provide high-resolution outputs and information of great interest for regulatory compliance and policy-making. This paper encourages the collection of emission information, which can be used to develop policies to mitigate harmful impacts. Compliance monitoring of low sulphur fuel usage, emission abatement measures, alternative fuels and relocation of emission hotspots outside densely populated areas can be used to reduce environmental burden. We also suggest feasibility studies for on-shore energy services, prioritizing berthing of shipping sectors (or sub-sectors) with the highest share of responsibility in exhaust emissions. Results of this study support adequacy or improvement of existing policy in port-city areas and are also transferable to islands under similar conditions.

Acknowledgements

The authors wish to extend their gratitude for the support provided by the Finnish Meteorological Institute (FMI) during the undertaking of the research presented in this paper. Also, they would like to gratefully acknowledge the assessment given by Dr. Jukka-Pekka Jalkanen and Mr. Lasse Johansson, which have been of infinite support for the completion of this work.

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