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Environmental valuation of in-port shipping emissions per shipping sector on four Spanish ports

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Abstract

This work provides an insight into the external costs associated with ships which had been berthed in four Spanish ports before COVID-19 was on the agenda. Firstly, on a port-by-port level and by individual vessel types, as this can also provide valuable insights. The economic valuation is based on the combination of the significant bottom-up European studies which follow the impact pathway approach (IPA) to calculating costs from transport air emissions. Our results showed higher total external costs for Las Palmas de Gran Canaria (€74.4 m), followed by Tenerife (€20 m), Palma de Mallorca (€19.5 m) and Pasaia (€1.5 m). The external costs by shipping subsectors give more insights into the relationships between ship types and external costs. This has been done to correctly assign the responsibilities among the different shipping sectors inside a port and to better understand the potential benefits of implementing abatement technologies, such as cold ironing. Potential benefits from cold ironing were found to differ hugely among the different ports analysed.

Keywords: Environmental costs, Emissions from berthed ships; Air quality, Port city, Cold ironing

1. Introduction

Understanding and potentially mitigating the negative impact of transport on the well-being of people living close to major infrastructure hubs is a critical challenge in the upcoming decades. This paper aims to contribute to a potential solution by providing insights into the external costs associated with berthed vessels in four ports in Spain: Las Palmas de Gran Canaria, Palma de Mallorca, Pasaia and Tenerife. Local as well as global external costs will be presented.

The key distinction that must be made in the case of local and global effects lies in the scope, not only spatial but also temporal. Global effects are mostly associated with carbon dioxide (CO_2), which remains in the atmosphere for a considerable time and leads to global warming and climate change (IPCC, 2018). Local effects, which are often associated with particulate matter (PM), nitrogen oxides (NO_x) and sulphur oxides (SO_x), stay in the vicinity of the source of the emission and are harmful to humans' health (Vianna et al., 2020). Estimating the external costs associated with those local effects has been the subject of wide ranging research during the last few years (Tzannatos, 2010a, 2010b; Tovar and Tichavska, 2019; Nunes et al., 2019). While the level of uncertainty in the estimations is still significant, the results can provide valuable insights.

For cities or regions in the direct vicinity of sea ports, the external costs of those ports are a major concern. Therefore, it is not surprising that several stakeholders from the public and private sector are interested in knowing the external costs related to ship operations; this is both in general and regarding the effect that potential abatement technologies such as cold ironing[1] could have on external costs (Chatzinikolau et al., 2015).

Cold ironing provides electric energy from the shore to the vessels. Electricity generation on board vessels almost exclusively works through diesel generators with the associated emissions; thus, the associated negative impact of exhaust gases occurs directly in the port. The greater or lesser benefit of cold ironing technology lies in how and where energy is produced. Firstly, power supplied from shore can come from renewable sources, which will automatically reduce external costs. Secondly, even if renewables are not employed, the much larger power plants ashore benefit from efficiencies of scale when compared to relatively small diesel generators on board the vessels. In addition to that, large coal and diesel power plants are usually located further away from the city. This will ultimately lead to fewer people being exposed to the emissions, therewith leading to lower external costs.

[1] A detailed analysis of cold ironing is beyond the scope of this article, but a recent review regarding this issue could be found in Spengler and Tovar (2021). The interested reader could also see Sciberras, et al., (2015); Zis et al., (2015) and Zis (2019).

Such issues go hand in hand with regulatory efforts aiming at reducing pollution from vessels. One of the better known examples is the Convention for the Prevention of Pollution for Ships (MARPOL 73/78), which was introduced by the International Maritime Organization (IMO) in 1973. This regulation was further developed to account for new knowledge about the effects of different pollutants, as well as technological advancements. In particular Annex VI of MARPOL must be mentioned as it not only introduced progressive reductions in NO_x emissions from marine diesel engines installed on ships[2], but it also incrementally lowers limits for sulphur content of fuel in all areas of the world and even lowers the upper limits in designated Emission Control Areas (ECA). Moreover, in 2018, the IMO adopted its initial strategy for the reduction of GHG emissions from ships, and among the identified potential short-term measures it included promoting the provision of shore-side electricity.

The European Union and the United States have introduced further limits and regulations for the sulphur content of fuel, in particular for berthed vessels. Diesel fuel with the required low sulphur limits is considerably more expensive, which might to a certain extent offset the additional costs for fitting vessels with cold ironing facilities. Moreover, shore power has been identified as one of the alternative fuel technologies in EU Directive 2014/94/EU, which requires European ports to install shore power facilities as a priority by December 31, 2025. This has been reinforced by the "Fit for 55" package launched by the European Commission in July 2021.

As a result of the aforementioned interest, several initiatives can be found. One of them is the On-Shore Power Supply (OPS) Master Plan for Spanish ports, which aims to draft a Master Plan for the supply of electric power to ships at berth in Spanish ports. This paper will focus on the four ports, which were the first to become involved in the OPS project, and it provides an insight into the external costs associated with ship calls in four Spanish ports before COVID-19 was on the agenda. First, we analyse on a port-by-port basis. Second, we consider the individual vessel types, as this can also provide valuable insights. Furthermore, relative indicators will be introduced to give more insights into the relationships between levels of activity, ship types and external costs.

Apart from the value that lies in providing figures for these four ports, this work also contributes in a broader sense to the existing body of literature. The findings presented here can be further used to estimate the impact shipping ports have on the cities in the vicinity. The research conducted here differentiates external costs by vessel type, which also allows for more finely grained adjustments to policies and port management strategies. Furthermore, existing measurements of external costs are improved and expanded upon by the results hereby presented. Finally, and independent of how the

[2] Although different levels (tiers) of control apply, based on the ship's construction date.

situation will evolve, it can be expected that the impact of COVID-19 on the shipping industry in general, and the external costs at seaports in particular (due to congestion and delays at ports and terminals), will be subject to future research. Even an impact on port management and governance might be expected (Notteboom and Haralambides, 2020). Profound analysis of the situation in a pre-COVID setting, such as the one offered here, is a prerequisite for conducting comparative research.

The work is structured as follows. First an overview of the relevant literature is given, and subsequent to this is a section elaborating on the methodological approach and the material used in the preparation of this document. In continuation, the results will be presented, first from an overall perspective and then from the perspective of relative indicators. After that, we provide our conclusions, the limitations and an overview of areas for possible further research.

2. Brief Literature Review and Problem Statement

A recent review of the studies analysing the impact of harbour activities on the air quality in port cities (Sorte et al., 2020) has shown the relevant contribution of those activities in terms of concentrations of the main critical pollutants, namely PM_{10}, $PM_{2.5}$, NO_2 and SO_2. These pollutants are affecting human health and causing other environmental damage, such as a decrease in biodiversity and crop yield, damage to materials and building surfaces, to name but a few.

Estimating a monetary value to assess the impact of pollution on humans, the environment and the property is not an easy task. It is intertwined with many factors ranging from personal preferences to considerable difficulties in obtaining accurate data. However, they have several applications for policy use in port-cities, such as their utility as indicators in demonstrating that a port deserves more attention (Nunes et al., 2019), and/or to apply taxes or special fees as an incentive to ensure that best environmental practices are observed (Tichavska and Tovar, 2015; Tovar and Tichavska, 2019). What is more, they also can be used to investigate whether ports could reduce external costs derived from the exhaust emissions while maintaining their level of service (Tovar & Wall, 2019, 2021). Therefore, despite the difficulties it is worth calculating them.

As a comprehensive review of the extant literature has shown (Tichavska and Tovar, 2017[3]), during the past few years, the impact pathway approach (IPA) has developed into a de facto standard for

[3] This brief literature review is made only to put our paper into the proper context. For a recent review of the state of the art methodological and empirical external costs estimation due to port emissions released by vessels, see Tichavska and Tovar (2017).

estimating the external costs associated with air emissions. Major European bottom-up studies such as (1) BeTa, (2) CAFE, (3) HEATCO and (4) NEEDS followed IPA[4] in their estimations of external costs.

(1) The Benefits Table (BeTa) methodology provides external costs figures for several pollutants. Namely NO_x, $PM_{2,5}$, SO_2 and Volatile organic compounds (VOCs). A general differentiation that is made by BeTa is with regard to the location where the emission occurs, and this differentiation is made between rural, urban and shipping. In the case of shipping, a differentiation is also made between four different bodies of water (The eastern Atlantic, Baltic Sea, English Channel, northern Mediterranean and North Sea).

As for the emissions on shore, the specific external costs factors are provided for rural areas by country, and cover 15 European countries. As for the emissions in urban areas, there is no disaggregation at a country level. The differentiation for urban areas takes place depending on the number of inhabitants for $PM_{2.5}$ and SO_2. It is assumed that the external costs increase linearly for up to 500,000 inhabitants and after does so at a lower proportion (non-linear). For "several million people" and over, a maximum for external costs and non-marginal increase is assumed. First, this is based on processes in atmospheric layers close to the ground which, in the case of large cities, means an appreciable loss of pollution. Second, large cities are not compact and may contain large areas where the resident population is effectively zero (major industrial and shopping zones, large rivers, etc.), which lead to no further increase in population density.

As for the effects that are considered, again a relatively finely grained set of features from a variety of sources is considered to estimate the external costs. By way of example, the effect that SO_2 has on buildings and other structures is considered.

It should be noted that BeTa is the bottom-up study that makes specific reference to damage from shipping-related air pollution at seaports. Therefore, it is the main approach following in this paper.

(2) The Clean Air for Europe (CAFE) methodology provides external costs figures for NH_3, NO_x, $PM_{2,5}$, SO_2 and VOCs disaggregated by land (EU25 excluding Cyprus) and the corresponding sea areas.

A general challenge in designing a model for capturing externalities is the difficulty in setting boundaries and deciding what to account for and what not to. In the justification of the design of CAFE, it was argued that they chiefly considered those factors that are likely to have a substantial effect on

[4] A bottom-up approach in which environmental costs are estimated by following the pathway from source emissions via quality changes of air to physical impacts before being expressed in terms of monetary benefits and costs.

the outcome of the computations, while the ones that were not believed to have a significant effect were omitted.

Nonetheless, it was admitted in the design of CAFE that there are factors where it just could not be stated whether they have a substantial impact or not. A prime example of this is the chronic health impact ozone has on humans. Due to lack of reliable data, the said impact was omitted.

In addition, it was recognized that in a given application of the CAFE methodology one might be inclined to consider a set of inputs to be more suitable than another given set. To account for that, external costs figures were provided for a number of combinations. Namely, the value of a life year (VOLY) could be either taken from the median or the mean. Also, instead of the VOLY, one could consider the value of a statistical life (VSL), which naturally is considerably higher. Then again, the median or the mean for the VSL numbers could also be taken.

To add to the already relatively complex picture, the effect of ozone on health below a threshold of 35 ppm has apparently not been fully investigated. Also, non-ozone related health impact is divided into two subsets in the CAFE methodology: a core set of functions that are considered robust and a "sensitivity" set of functions that are considered to be less robust.

Overall, the number of combinations that could arise from the given considerations would be overwhelming if one still wanted to introduce a methodology where the results of the applications could still be compared with each other. To account for those external costs, numbers were only provided for four possible combinations, or scenarios. Namely: (1) VOLY median for PM and ozone mortality, only using the set of health functions and a threshold for ozone at 35 ppm. (2) VSL median for PM mortality, VOLY median for ozone mortality, core health functions and a threshold for ozone at 35 ppm. (3) VOLY mean for PM and ozone mortality, sensitivity health functions and no threshold for ozone. (4) The same as (3) but with the VSL mean for PM mortality.

When it comes to estimating the external costs derived from in-port shipping emissions (Tovar and Wall, 2021), an alternative approach to BeTa is to complement the BeTa urban conversions factors with rural factors derived from CAFE, under these four scenarios. Therefore, and in order to make a comparison with the estimation obtained through BeTa, as several authors do (see below), we also follow this method.

(3) The Harmonised European Approaches for Transport Costing and Project Assessment (HEATCO) is, as the name suggests, aimed specifically at transport and infrastructure projects. The objective of HEATCO is to offer a "set of harmonised guidelines for project assessment and transport costing".

HEATCO was intentionally, and from the beginning, set up to cover a wide range of different concerns, ranging from the valuation of congestion and accident risk reduction to infrastructure cost, as well as the external costs.

It lies in the very nature of such approaches that certain trade-offs are made with regard to detail and while specific external costs factors are provided for air, bus, car and train, no such factor is provided for shipping. However, the recommendation is to use the country specific cost factors, which are available for different areas.

As for the external costs factors, it must be noted that only data for $PM_{2.5}$, PM_{10}, SO_2 and volatile organic compounds is considered. It can be argued that limiting oneself to only those pollutants might lead to a more accurate estimate for the said contaminants. Still, when comparing aggregated estimates from HEATCO with the results from other methodologies it should be taken into account that the HEATCO estimates are only based on those four pollutants.

HEATCO has never been used in the context of shipping. This is likely related to the fact that no external costs factors are provided for shipping. Tichavska and Tovar (2015) argue that the cost factors for street traffic are not appropriate for use in the context of shipping as the exhaust gases from the funnel of a ship are released at a higher altitude than the exhaust gases from a car or bus. Tzannatos (2010a,b) argues that the cost factors from BeTa are more appropriate as they are specific to the activity of shipping. Castells et al. (2014) and Maragkogianni and Papaefthimiou (2015) put forward the argument that there are more recent and updated cost factors that should be used rather than those of HEATCO. In the presented study, the arguments of the aforementioned authors are followed and the external costs factors of HEATCO will not be applied.

(4) The New Energy Externalities Development for Sustainability (NEEDS) methodology was initially intended to calculate the "the full (i.e., internal + external) costs of energy technologies" (Korzhenevych et al., 2014). In fact, the use of NEEDS for other emission sources such as shipping was not on the agenda when NEEDS was designed.

However, due to the fact that it covers all major pollutants in all EU member states and their related externalities, it is far from surprising that the provided figures are widely used in other contexts, including maritime transport in general and ports in particular. It is often referred to as "the most updated methodology for calculating external costs of maritime transport" (Nunes et al., 2019), and was, for example, applied by Maragkogianni and Papaefthimiou (2015) and Tichavska and Tovar (2015).

While NEEDS does provide marginal air pollution cost factors for a variety of sea regions, the categories of vessels that are covered is limited. Korzhenevych et al. (2014) explained this, but with a lack of comprehensive data. More specifically, no cost factors are available for Ro-Ro vessels, container vessels, refrigerated vessels, cruise vessels and passenger ferries. To provide completeness, we also calculate the external costs following the NEEDs study; although due to the structure of vessels that call at the ports under study, NEEDS bottom-up is deemed to be the least suitable for the study conducted here.

BeTa, CAFE and NEEDs have been applied in numerous studies to estimate the external costs from vessel emissions at port. Some of which are briefly presented below and summarized in Table 1.

Miola et al., (2009) was the first to estimate the external costs of air emissions. They applied CAFE to estimate the external costs associated with cargo and passenger vessels in the Port of Venice, and in 2006 it reached €23 million.

Table 1: Overview of the Academic Literature on External Costs Estimation from Vessel Emissions at Port. Source: Own elaborations based on Tichavska and Tovar (2017)

Paper	**Area**	**Scale**	**Timeframe**	**Shipping sector**	**Vessel operative**	**Cost Factor from**
Miola et al., (2009)	Italy	Port	2006	passenger and cargo	cruising	CAFE
Tzannatos (2010a)	Greece	Port	2008-2009 (12 months)	passenger and cruise	hotelling and manoeuvring	BeTa
Tzannatos (2010b)	Greek Sea	Regional	1984-2008	domestic and international shipping	cruising	BeTa
McArthur and Osland (2013)	Bergen (Norway)	Port	2010	entire fleet	hotelling	BeTa, CAFE and several studies
Castells et al., (2014)	Selected Spanish ports	Regional	2009	Ro-Ro, passenger, and container ships	hotelling and manoeuvring	BeTa, CAFE
Dragović et al., (2015)	Dubrovnik and Kotor (Croatia)	Port	2012-2014	cruise	hotelling and anchor	NEEDS
Maragkogianni and Papaefthimiou (2015)	Piraeus, Santorini, Mykonos, Corfu and Katakolo	Port	2013	cruise	hotelling and manoeuvring	CAFE and NEEDS
Tichavska and Tovar (2015)	Las Palmas de Gran Canaria (Spain)	Port	2011	entire fleet	hotelling, manoeuvring and cruising	BeTa, CAFE and NEEDS
Nunes et al., (2019)	Leixões, Setúbal, Sines and Viana do Castelo (Portugal)	Port	2013	entire fleet	hotelling and manoeuvring	BeTa, CAFE and NEEDS
Tovar and Tichavska (2019)	Las Palmas de Gran Canaria (Spain), St. Petersburg (Russia) and Hong Kong	Port	2011-2012	entire fleet	hotelling	BeTa
PRESENT STUDY	Las Palmas de Gran Canaria, Palma de Mallorca, Pasaia, and Tenerife (Spain)	Port	2017-2018 (12 months)	entire fleet	hotelling	BeTa, CAFE and NEEDS

Tzannatos (2010a) analysed the emissions and associated externalities derived from passenger vessels in the port of Piraeus, and later (Tzannatos, 2010b) analysed the shipping emissions and externalities derived from domestic and international shipping for all Greece. The BeTa based approaches lead to findings indicating that the external costs associated with shipping reach €51 million per year in Piraeus alone, and €3.1 billion per year for the whole of Greece.

McArthur and Osland (2013) applied BeTa to the port of Bergen in Norway. According to their application of BeTa, the external costs of ships at berth in the port of Bergen reach approximately €6.07 million per year. They also applied the CAFE approach to the port in Bergen, and they reported that the external costs per year in Bergen for ships at berth reached €4.75 million. That is a substantially lower figure than the BeTa figure.

Castells et al., (2014) estimated the external costs in the Spanish port system by applying BeTa and CAFE, similar to McArthur and Osland (2013). They calculated emissions for three types of vessels: passenger, Ro-Ro and container, and reported the share of emissions to be 41%, 33% and 25% respectively. Given the complexity CAFE brings, it is deemed appropriate to compare the results of BeTa with the alternative approach to complement the BeTa urban conversions factors with rural factors derived from CAFE. With these four scenarios, it is possible to see if substantial changes can be observed. Tovar and Tichavska (2015 and 2019) and Nunes et al., (2019) also followed this approach when they analysed the external costs for Las Palmas port, then for three ports under different regulatory regimes and finally for four ports in Portugal, in their respective papers.

Maragkogianni and Papaefthimiou (2015) focused only on cruise ships, during hotelling and manoeuvring operatives, in the ports of Piraeus, Santorini, Mykonos, Corfu and Katakolo in Greece. They applied CAFE and NEEDS and estimated that the health impact from cruise shipping may be as high as €5.30 per passenger. Dragović et al. (2015) also focused exclusively on cruise ship in the ports of Dubrovnik and Kotor. They only applied NEEDS and also considered vessels at anchor.

Tichavska and Tovar (2015) estimated external costs through BeTa for the port of Las Palmas de Gran Canaria. They calculated emissions for all vessels and considered cruising, manoeuvring and hotelling operatives. They also introduced the following eco-efficiency indicators: external costs per passenger, per ton of cargo, per ship call and per port revenue. They estimated the overall external costs for Spain to be €174 million for 2011. They also applied CAFE and reported, depending on the sensitivity scenario, a variation of between -8% to +18% when compared to the results that were exclusively obtained from BeTa. Following the same approach, Nunes et al., (2019) analysed the ports of Leixões, Setúbal, Sines and Viana do Castelo in Portugal. They found that Sines and Setúbal were the ports with the highest estimated external costs with €200 million, and Viano do Castelo was the port with the lowest estimated external costs with only €6.3 million.

Finally, Tovar and Tichavska (2019) analysed three ports that are under different regulatory regimes. The methodological challenge of applying cost factors from BeTa to non-European countries was solved by utilizing the EU15 average. They estimated the external costs to be €2,311 million, €779 million and €7,423 million in Las Palmas de Gran Canaria, St. Petersburg and Hong Kong respectively.

The here presented literature review has shown that there is several conducted research which apply a wide variety of cost factors that come from the major European bottom-up studies. To the best of the authors' knowledge, this is the first paper to compare the total external costs savings of providing cold-ironing in four Spanish ports and to also offer the granular external costs savings about ship types and seasonality. Furthermore, eco-efficiency indicators that might allow for the introduction of market-based measures that are based on the said eco-efficiency indicators and vessel types have been calculated.

3. Material and Methodology

The here presented work extends the work of Spengler and Tovar (2021). While Spengler and Tovar (2021) focused on providing a Spain wide overview of all ports, they offered limited insights into the temporal dimension as well as the external costs depending on the type of vessel which will both be presented in Section 4 of this document. External costs will be computed for vessels at berth.

The data used to estimate the emissions were obtained through the On-Shore Power Supply (OPS) Master Plan. It should be noted that all member states of the European Union are required to develop policy frameworks to support alternative fuels for sustainable mobility as specified in the Directive 2014/94/EU. The Spanish government introduced the National Action Framework for the development of infrastructure for the use of alternative fuels; the OPS Master Plan[5] is part of that action framework. The following section focuses on the four ports which were the first to become involved in the OPS project, which is why they were studied more in depth than the others (Las Palmas de Gran Canaria, Palma de Mallorca, Pasaia and Tenerife), and it provides the necessary insight into the most important aspects of those ports.

[5] For further information about the OPS Master plan, please refer to http://poweratberth.eu/?lang=en

3.1 Port Under Study

The port of Las Palmas de Gran Canaria lies within the direct vicinity of Las Palmas de Gran Canaria, which has roughly 380,000 inhabitants[6]. The port is of significant importance due to its geographic location in the Atlantic between Europe and Latin America. The port is connected to more than 180 other ports in the world (Las Palmas Port, 2018).

The port is of particular importance as a bunkering port. In 2017 alone, it supplied vessels with 2,330,190 tonnes of fuel; also, the port is working on being able to supply vessels with Liquified Natural Gas (LNG). In 2017. Furthermore, more than one million containers were handled by the port of Las Palmas de Gran Canaria and more than 674,000 cruise passengers were recorded. With regard to the overall cargo quantities, it can be said that more than 23 million tons were moved through the port of Las Palmas de Gran Canaria in 2017 (Las Palmas Port, 2018).

The port of Las Palmas de Gran Canaria publishes annual sustainability reports that includes various eco-efficiency and environmental indicators including those related to, for example, air quality (Autoridad Portuaria de Las Palmas, 2018). In addition to that, the port of Las Palmas de Gran Canaria participates in a number of projects related to ecological innovations, eco-efficiency as well as ballast water treatment. This can be seen as an indication that the port of Las Palmas de Gran Canaria is putting a substantial effort into reducing external costs. Furthermore, Laxe et al., (2017) conducted a study based on the concept of synthetic indexes and found that the port of Las Palmas de Gran Canaria ranks first in the environmental dimension, which is related to the aforementioned activities as well as positive results in the area of environmental management.

Also, the port of Las Palmas de Gran Canaria has allocated a tender budget of €2.1 million towards the installation of cold ironing facilities in the port. Shore power is to be supplied to ferry vessels with a power demand of up to 1,600 kW (Loyarte, 2019). In the case of Las Palmas de Gran Canaria, Martínez-López et. al., (2021a) estimated a reduction of external costs because of cold ironing for the feeder vessel as well as for the ro-pax vessel by 28% and 11% respectively.

Tenerife is the largest of the Canary Islands with about 200,000 people living in Santa Cruz de Tenerife. However, it should be noted that the city of Las Palmas de Gran Canaria has more inhabitants than Santa Cruz de Tenerife, which is relevant in the context of external costs as they are related to the number of inhabitants in the direct vicinity of the port. The port is located in the north-east of the island.

[6] Population data for the port cities under study were obtained from the Spanish National Statistics Institute (INE).

In terms of traffic, the port of Tenerife facilitates a wide variety of different cargo ranging from liquid and dry bulk cargo and fish to general cargo. Quantity wise, general cargo, both containerized and non-containerized, accounted for the highest share of throughput with roughly 7.3 million tons in 2017. This is followed by liquid bulk with 5.1 million tons. It should be noted that almost all of the liquid bulk cargo consists of oil products (Tenerife Port, 2018).

Martínez-López et al., (2021a) analysed potential savings of external costs by means of cold ironing and LNG in short sea shipping. On the basis of one feeder vessel with a considerable amount of reefer containers and one ro-pax vessel, a variety of estimations were made. They found that, because of connection and disconnection lag times and the way electricity is produced in Tenerife, the use of cold ironing could potentially lead to higher external costs on a per trip basis than using conventional power generation on board of the vessel by means of auxiliary engines.

The port of Tenerife has an environmental code of conduct (Puertos de Tenerife, 2014); however, it should be noted that the document is somewhat dated as it goes back to 2014. While the code of conduct mostly references applicable law and no direct mention is made in the code of conduct regarding external costs or cold ironing, the port of Tenerife participates in the OPS Master Plan and has installed cold ironing facilities that could contribute greatly to reducing external costs.

Mallorca is the largest of the Balearic Islands with roughly 400,000 inhabitants. Numerous ferry connections are offered from and to Palma de Mallorca; for example, to and from Valencia and Barcelona. Hence, it is not surprising that a total of 925,809 ferry passengers passed through the port in 2017. Also 1,673,210 cruise passengers were counted in 2017. It is considered an important destination for cruise vessels within the entire Mediterranean Sea area (Rosa-Jiménez, 2018). In terms of quantities of cargo, it can be said that roughly one million tons of oil products and almost 8.1 million tons of general cargo were moved through the port. With regard to container traffic, a total of 560,542 Twenty Equivalent Unit (TEU) were handled in the port in 2017 (Palma Port, 2018).

With reference to the sustainable development goals, the port authority of the Baleares stresses its commitment to those goals by also being a member of United Nations Global Compact. This approach is clearly somewhat different from the approach of Las Palmas de Gran Canaria as the global development goals can be regarded as rather rough guidance instead of providing actionable indicators.

In terms of specific actions, it can be noted that the port of Palma de Mallorca has the same tender budget for the installation of cold ironing facilities as the port of Las Palmas de Gran Canaria.

The port of Pasaia is, in contrast to the other ports under study, not located on an island but on the North of the Spanish mainland. Consequently, the structure of operations is somewhat different. The number of passengers in 2017 was only 815. Also, the population is the smallest of the four ports under study with only around 16,000.

In terms of cargo, a strong specialization directed towards the steel industry can be observed. A total of 48%, or 1.5 million tons, of the cargo handled in 2017 in Pasaia was steel cargo. Also, the automotive industry, with 400,000 tons, plays an important role in Pasaia. While Pasaia is an important fishing port in Spain, the 25,987 tons of fish landed do not play an important role in the overall cargo structure.

The port of Pasaia follows a hands-on approach to air quality, such as using a monitoring device for PM_{10} that was obtained from the Basque Regional Government and the hosted air quality surveillance network. While this very practical approach to air quality is noteworthy, it should also be taken into account that there is no mention of sustainability related matters, let alone external costs, in the annual report of the port (Pasaia Port, 2018).

3.2 External Costs Estimation

Figure 1 depicts data sources, processing as well as the obtained results.

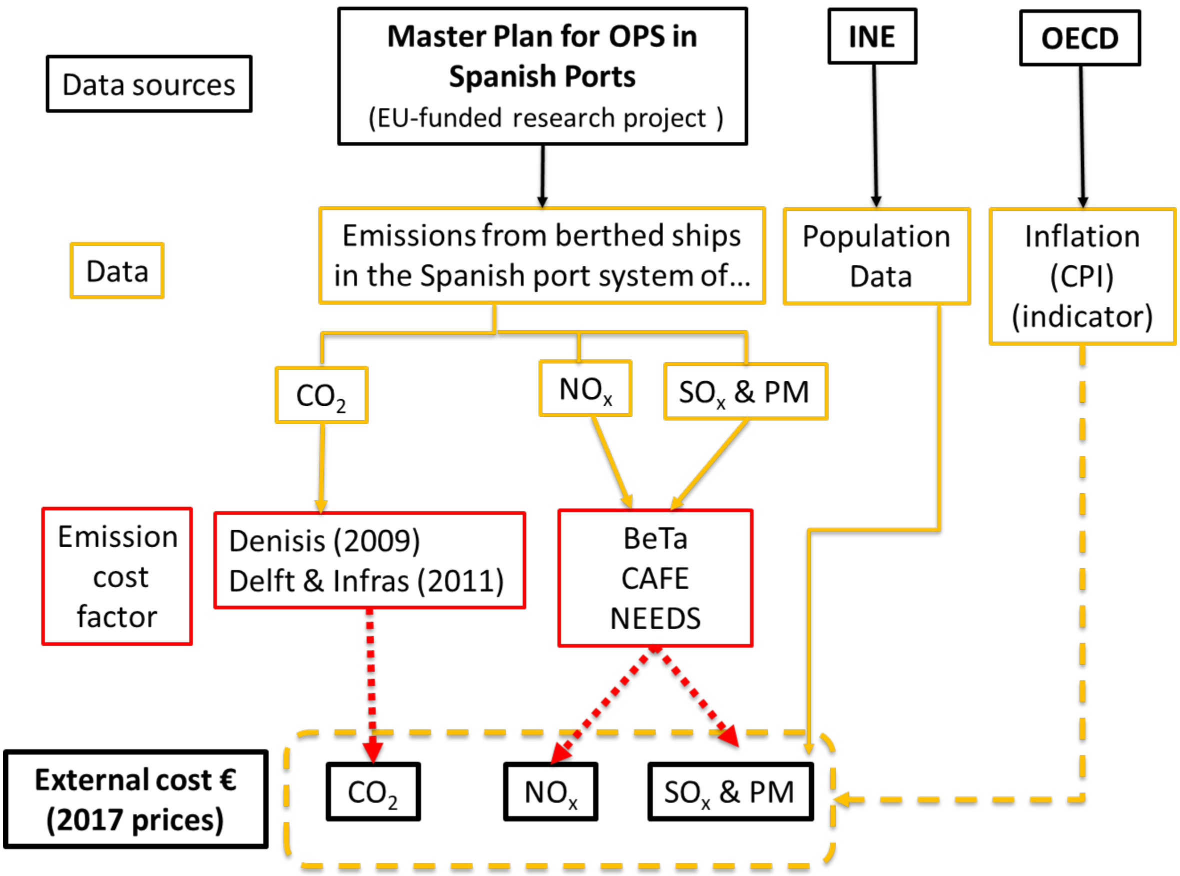

Figure 1: Flow Chart of Methodology, Source: Own elaboration.

Emissions of a given pollutant are calculated as a product of the auxiliary engine power in kilowatts, the time in hours and the emission factor for the respective pollutant in tons per kilowatt hour. To estimate the auxiliary engine power, the 3rd International Maritime Organization (IMO) Study on Greenhouse Gases (GHG) (Smith et al., 2015) is followed. To obtain the time, data from the Automatic Identification System (AIS), data on port calls as well as data on the location of berths was used. The emission factor was computed following the methodology of the European Environment Agency (EEA) in the year 2016. This was done under the assumption that the auxiliary engines are of the type "medium speed diesel", they achieve Tier II in terms of NOx and they run on Marine Diesel Oil (MDO)/Marine Gasoil (MGO).

The emissions occurring during hotelling, which serve as a basis for the calculations for external costs, are estimated based on Equation 1. The emissions E for the pollutant i are obtained in tons. AE is the auxiliary engine power in kilowatts obtained as described above. The time t is obtained from the AIS data and calculated in hours and FE is the respective emission factor for the pollutant i in tons per kilowatt-hour.

$$E_i = AE \cdot t \cdot FE_i \qquad (1)$$

Table 2 depicts the mooring hours as well as the estimated emissions of NOx, SOx, and PM (PM_{10}, $PM_{2.5}$) from ships berthed at the four ports.

Table 2: Emissions and Operative Time from Vessels at Berth (July 2017-June 2018)

Port	**Mooring (hours)**	**NOx (Tons)**	**SOx (Tons)**	**PM_{10} (Tons)**	**$PM_{2.5}$ (Tons)**	**CO (Tons)**	**CO_2 (Tons)**
Las Palmas de Gran Canaria	200000	2060	303	55.80	51.70	158	99900
Palma de Mallorca	30000	60.20	8.37	1.21	1.31	4.04	3000
Pasaia	40000	64.50	9.78	1.89	1.73	5.04	3220
Tenerife	70000	693	102	18.50	16.90	54.20	34000

Table 3 shows the external costs factors in euros per ton according to major European bottom-up studies adjusted for 2017. Following the same approach as other authors (Castells et al., 2014; Tichavska and Tovar (2015); Tovar and Tichavska, 2019; and Nunes et al., 2019) external costs are estimated using different combinations of the cost factors presented in Table 3; to adjust the prices for the year 2017, the Consumer Price Index (CPI) for EU28 (OECD, 2019) was utilized.

Table 3: External Costs Factor (€/Ton). (2017 Prices)

Bottom-up study	**Local**				**Global**	
	NOx	**SOx**	**$PM_{2.5}$**	**CO**	**CO_2**	
					Low	**High**
BeTa urban (Spain)	6590	Depend on port city's population (see Table 4)		-	-	-
BeTa rural (Spain)	6590	5188	11076	-	-	-
CAFE rural (Sensitivity case 1, Spain)	2818	4660	20591	-	-	-
CAFE rural (Sensitivity case 2, Spain)	4118	7153	31429	-	-	-
CAFE rural (Sensitivity case 3, Spain)	5635	9103	40098	-	-	-
CAFE rural (Sensitivity case 4, Spain)	7803	13005	58522	-	-	-
NEEDS (Korzhenevych et al., 2014)	5380	7643	52033[a]; 211603[b]	-	-	-
Denisis (2009)	-	-	-	3.9	-	-
Delft and Infras (2011)	-	-	-	-	27.5	160.6

Note: a = value for Pasaia. b = value for the other three ports

While only BeTa is used in further elaborations (when we disaggregate by subsector and by month), it is worth comparing the external costs factors that are used in deeper analysis to the ones that are not. The rural external costs factor for NO_x applied here according to BeTa is 6,590 euros which is higher than the external costs factors of NEEDS and CAFÉ in the one to three sensitivity cases. In terms of external costs factors for SO_x and $PM_{2.5}$, the external cost factors for BeTa are shown in Table 4 as they depend rightfully on the number of inhabitants that are exposed to the pollutant.

Table 4: Urban External Costs Factor (€/Ton) Following BETA for Each Port. (2017 Prices)

Port	**Inhabitants (2018)**	**SOx**	**$PM_{2.5}$**
Las Palmas de Gran Canaria	378,517	31,842	175,129
Palma de Mallorca	409,661	34,461	189,538
Pasaia	16,128	1,357	7,462
Santa Cruz de Tenerife	204,856	17,233	94,781

Table 4 shows the local external costs factors (adjusted for 2017 prices) at berth for each port as well as the number of inhabitants. It is apparent that the four ports under study are vastly different in terms of population. As the external costs factors of SO_x and $PM_{2.5}$ are a function of the number of inhabitants, the aforementioned external costs factors are also vastly different. Those differences underline the necessity as well as benefit of this presented study. Without concluding prematurely, it can be stated that the potential benefits of implementing abatement technologies such as cold ironing, will differ hugely among different ports.

External costs factors associated with global effects, mostly attributable to the emission of CO and CO_2 are not considered by BeTa, CAFE or NEEDS. The decision was made to use the external costs factors provided by Denisis (2009) and Delft and Infras (2011) for global external costs, as shown in Table 3. This is in line with Tichavska and Tovar (2015).

4. Results and Discussion

Table 5 depicts the estimated local external costs (in 2017 prices) for each of the ports under study. It only includes local external costs, as the costs associated with CO_2 do not vary among the different methodological approaches.

Table 5: Estimated Local External Costs of Berth for Each Port (€). (2017 Prices)

Bottom-up studies	LAS PALMAS DE GRAN CANARIA		PALMA DE MALLORCA		PASAIA		TENERIFE	
	TOTAL	% Var/ BeTa(1)	TOTAL	% Var/ BeTa(1)	TOTAL	% Var/ BeTa(1)	TOTAL	% Var/ BeTa(1)
BeTA(1)	5.84E+07	100	1.53E+07	100	9.81E+05	100	1.52E+07	100
BeTA(2) + CAFE SC1	5.15E+07	88	1.35E+07	89	7.67E+05	78	1.28E+07	85
BeTA(2) + CAFE SC2	5.61E+07	96	1.47E+07	96	9.15E+05	93	1.44E+07	95
BeTA(2) + CAFE SC3	6.07E+07	104	1.58E+07	104	1.06E+06	108	1.59E+07	105
BeTA(2) + CAFE SC4	6.84E+07	117	1.78E+07	116	1.31E+06	133	1.85E+07	122
BeTA(2) + CAFE SC_Avg	5.92E+07	101	1.55E+07	101	1.01E+06	103	1.54E+07	102
NEEDS	3.62E+07	62	9.01E+06	59	6.10E+05	62	1.20E+07	79

Note: BeTA(1)=Urban + Rural cost factor from BeTA; BeTA(2) + CAFE SC=Urban cost factor from BeTA + Rural cost factor from CAFE under different scenarios and on average.

Table 5 also shows the external costs variations among the different estimations[7] as a percentage, with BeTa as baseline. The combination of BeTa and CAFE yields results that are between 22% below and 33% above the estimations obtained just from BeTa. When considering the average of CAFE scenarios, the differences are only between 1% and 3%.

NEEDS will not be considered in further elaborations as it is not specific to ports, and hence offers only a limited insight (Tichavska and Tovar, 2015; Spengler and Tovar, 2021). In addition to that, the findings as presented in Table 5 indicate that NEEDS tends to underestimate in-port shipping emissions, which is also in line with the findings of Nunes et al., (2019).

As our literature review showed, in previous studies BeTa and CAFE with the average of the scenarios was chosen for further analysis. It was decided to not follow those previous approaches here, but to only consider BeTa for further analysis. The reasons for that are as follow: (1) the differences between the approaches are negligible as discussed above, and (2) it is aligned with the approach of Spengler and Tovar (2021) which can be considered complementary to the present work. Table 6 shows the

[7] Following other authors (see Section 3) the following combinations were estimated: BeTA(1) = urban and rural cost factors from BeTA; BeTA(2) + CAFE SCi = urban cost factors from BeTA + rural cost factor (i sensitivity scenario) from CAFE; BeTA(2) + CAFE SC_Avg = urban cost factors from BeTA + (four sensitivity scenarios) average rural cost factor from CAFE.

combined local costs following BETA and global external costs, including both the low and high estimates of CO_2 for the ports under study.

Table 6: Estimated Total External Costs of Berth for Each Port (€). (2017 Prices)

External costs	**LAS PALMAS DE GRAN CANARIA**		**PALMA DE MALLORCA**		**PASAIA**		**TENERIFE**	
Local BeTa	58,398,369	58,398,369	15,267,280	15,267,280	981,218	981,218	15,168,202	15,168,202
Global (CO_2 Low)	2,747,079	-	716,587	-	88,620	-	935,997	-
Global (CO_2 high)	-	16,042,942	-	4,184,865	-	517,539	-	5,466,222
Total (with CO_2 Low)	61,145,448	-	15,983,867	-	1,069,838	-	16,104,199	-
Total (with CO2 high)	-	74,441,311	-	19,452,145	-	1,498,757	-	20,634,424

In terms of total external costs, including the high estimation for CO_2, the port of Las Palmas de Gran Canaria has the highest external costs with €74.4 million, followed by Tenerife with €20 million and Palma de Mallorca with €19.5 million. The port of Pasaia has the lowest total external costs with €1.5 million.

While there are many factors that play a role when one wants to explain those differences, unsurprisingly a key role is the number of inhabitants in the direct vicinity of the port, as is the amount of ship traffic a port receives. Palma de Mallorca has roughly 8% more inhabitants than Las Palmas de Gran Canaria. However, the number of moored hours in Las Palmas de Gran Canaria is, with 200,000 hours, roughly 6.5 times higher than the number of moored hours in Palma de Mallorca.

With 30,000 moored hours Palma de Mallorca has the lowest number. The external costs that occur in this port are roughly the same as in the port of Tenerife, even though Tenerife has more than twice the number of moored hours. Then again, Palma de Mallorca has roughly twice the number of inhabitants of Tenerife.

While number of moored hours and number of inhabitants certainly cannot explain everything, they clearly are two determining factors when considering the external costs from shipping.

Figures 2, 3, 4 and 5 show the development of external costs by vessel type over time for the Ports of Las Palmas de Gran Canaria, Palma de Mallorca, Pasaia and Tenerife, respectively.

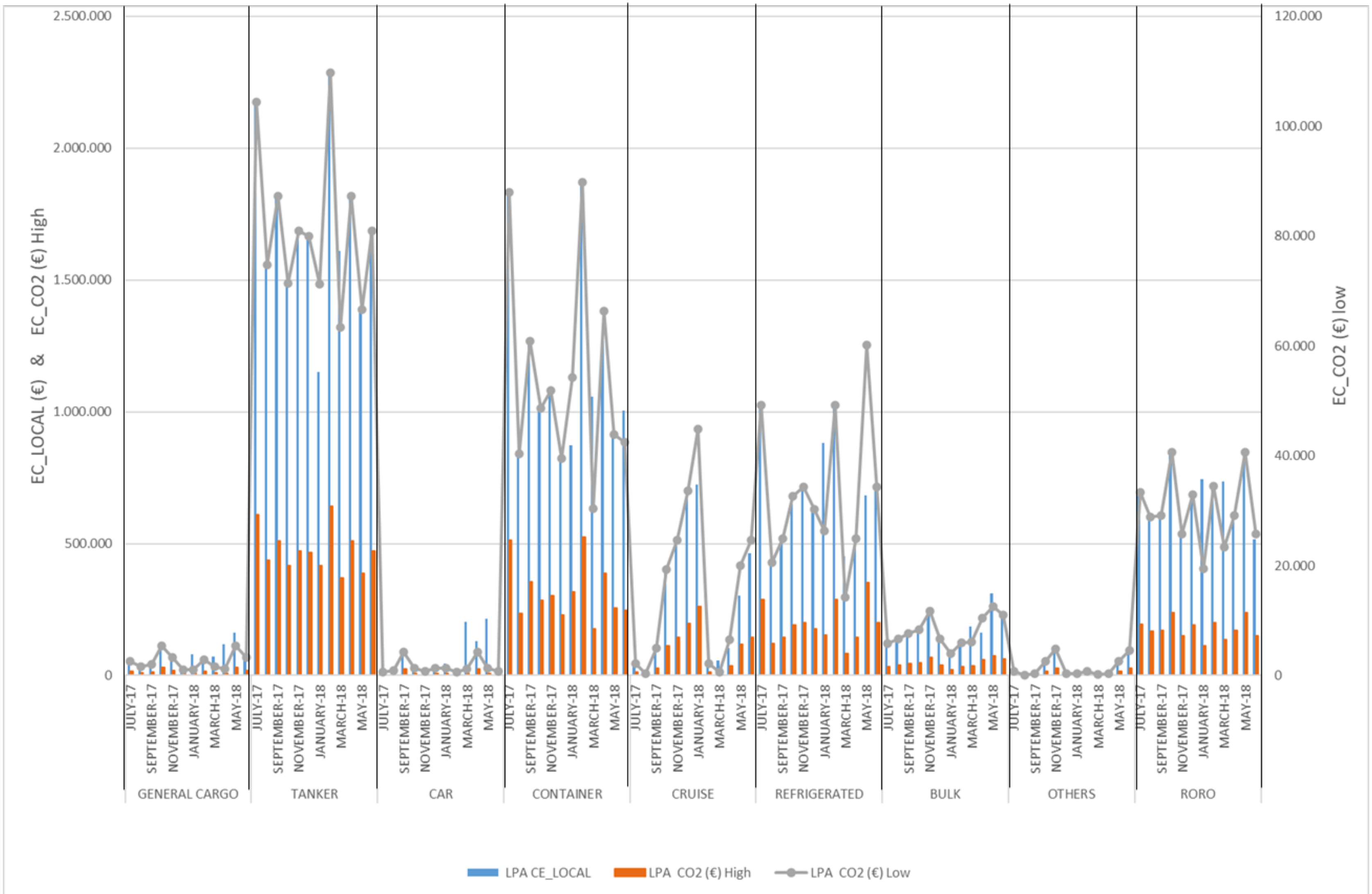

Figure 2: External Monthly Costs Per Vessel Type in Las Palmas de Gran Canaria Based on BETA (€ 2017). July-2017-June 2018

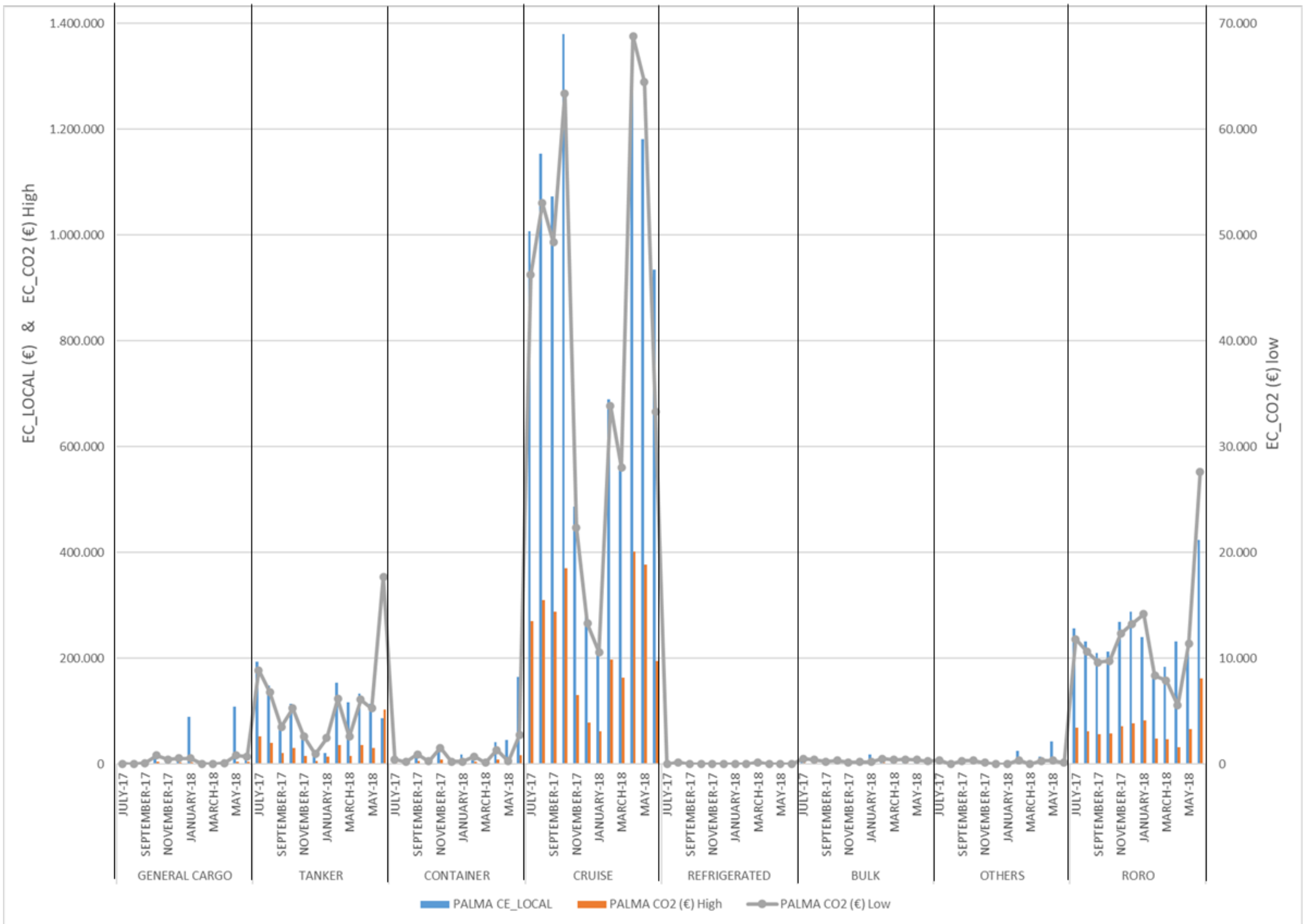

Figure 3: External Monthly Costs Per Vessel Type in Palma de Mallorca Based on BETA (€ 2017). July-2017-June 2018

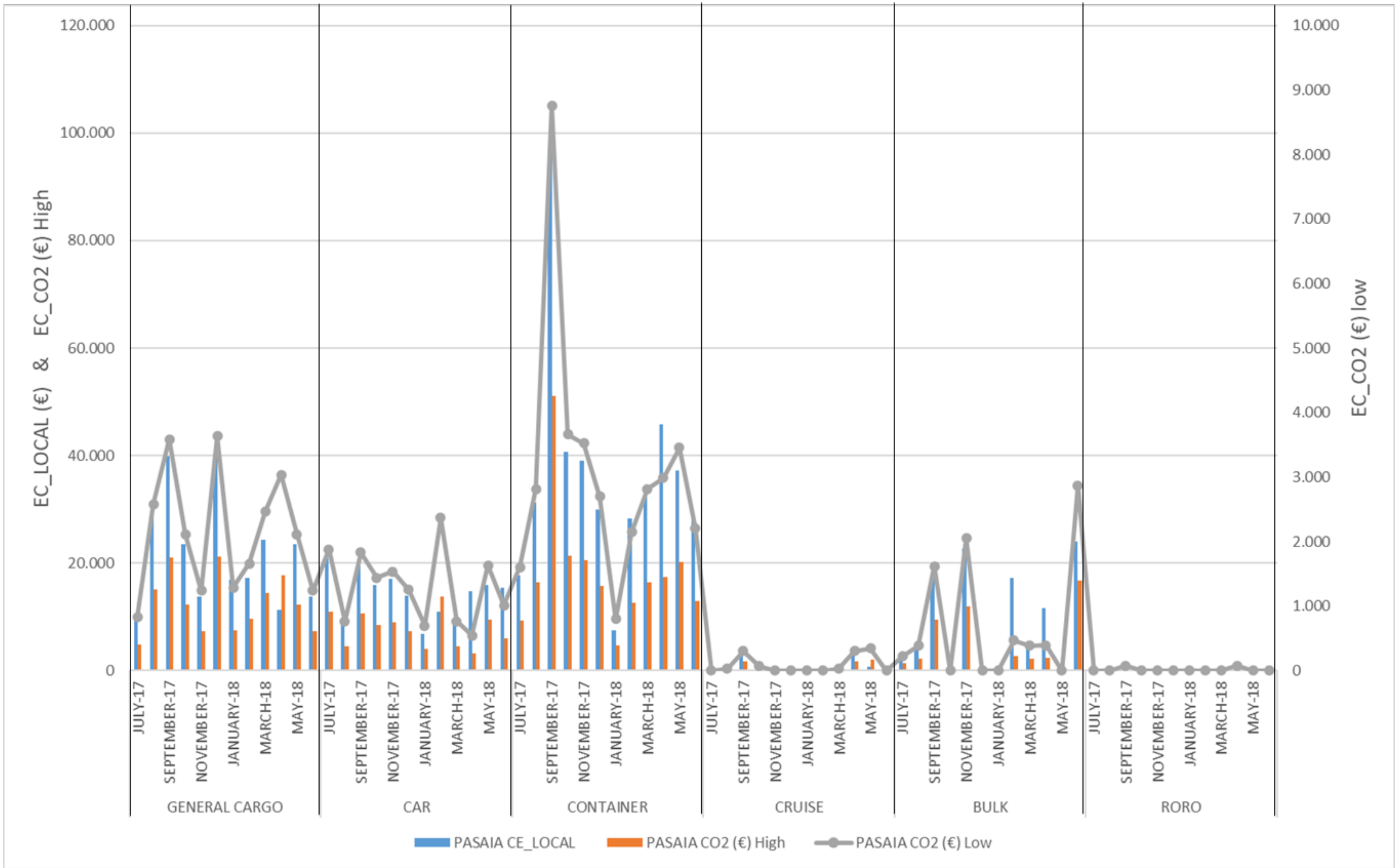

Figure 4: External Monthly Costs Per Vessel Type in Pasaia Based on BETA (€ 2017). July-2017-June 2018

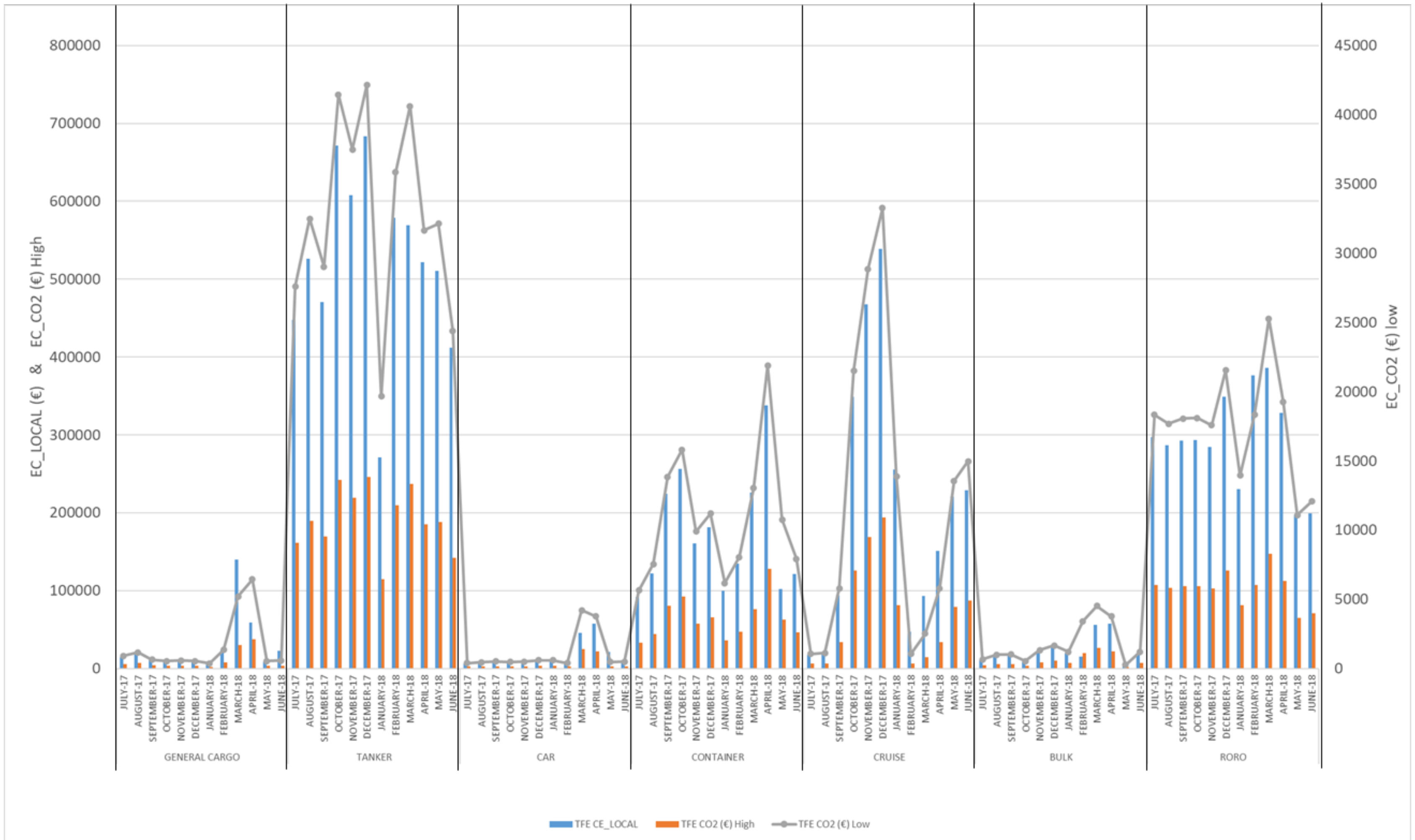

Figure 5: External Monthly Costs Per Vessel Type in Tenerife Based on BETA (€ 2017). July-2017-June 2018

In all ports, with the exception of Pasaia, a clear seasonality of external costs can be observed with respect to external costs associated with cruise traffic. Pasaia receives virtually no cruise traffic at all. In the remaining ports the seasonality in cruise traffic is different. While Tenerife and Las Palmas de Gran Canaria have clear peaks in the winter months of the northern hemisphere, the external costs in Palma are much higher in the summer months of the northern hemisphere. This clearly can be attributed to differences in the meteorological conditions on those islands.

In Las Palmas de Gran Canaria and Tenerife, the highest share of external costs can in most months be attributed to liquid bulk traffic. Las Palmas de Gran Canaria is, because of its geographical location, an important port for bunkering for vessels trading between Latin America, Africa and Europe. In Tenerife there is a refinery in the port.

A more or less high but consistent amount of external costs that can be attributed to Ro-Ro vessels can be observed in Las Palmas de Gran Canaria, Palma de Mallorca and Tenerife. Given the nature of ship traffic on islands, this is to be expected.

A variety of factors play a role if one is to determine the external costs of a vessel that is calling at a port. There clearly are differences between ship types that cannot be explained by the mere number of calls of a given ship type. Some are inarguably related to the average time a given vessel is berthed. Others can be thought to be related to the properties of a given vessel type and the age of the vessel in question. Liquid bulk carriers, for instance, usually are larger in average than container vessels or RoRo vessels. Vessel size, however, cannot explain the differences alone. Refrigerated vessels are generally small as they need to call at ports in remote places, and there would rarely be enough cargo to allow for a much bigger vessel. However, even when alongside, refrigerated vessels need to maintain a certain temperature in the cargo hold. This makes it necessary for them to produce a relatively high amount of electricity onboard the vessel.

The vastly different patterns of external costs from different types of vessels make it necessary to look at the matter from a perspective of relative indicators rather than absolute values. The indicators that were chosen are euros per hour and euros per vessel call; this is as they are believed to provide the best insight into the difficult patterns that need explaining.

Figure 6 depicts the local external costs per moored hour for different vessel types in different ports, and 7 depicts the external costs associated with port calls for different vessel types in the ports under study. It is obvious that the external costs differ substantially among those indicators and also among the ports and types of vessels.

Figure 6 and Figure 7 have to be viewed as being complementary. This becomes apparent when considering, for example, the external costs of reefer vessels. In Las Palmas de Gran Canaria the associated external costs per mooring hour of reefer vessels is relatively low when compared to Palma. However, when the external costs per port call is considered, the picture is the exact opposite: Reefer vessels have the highest external costs per port call in the port of Las Palmas de Gran Canaria, while the external costs of port calls of reefer vessels is relatively low in Palma de Mallorca. A similar observation can be made for cruise vessels.

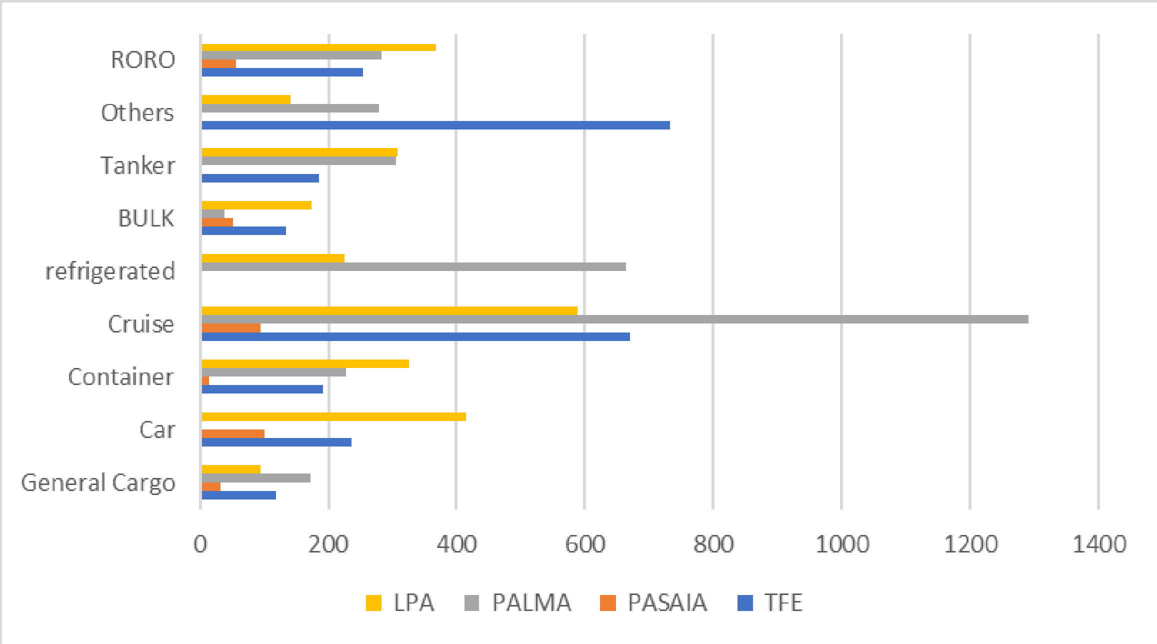

Figure 6: Local External Costs Per Moored Hour

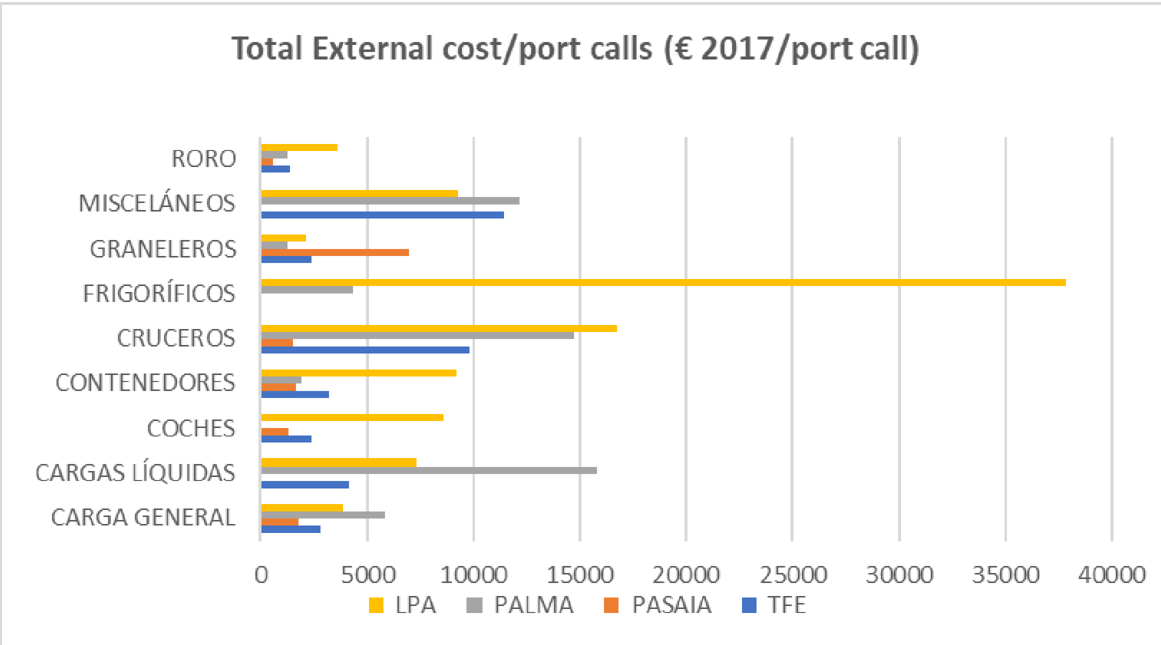

Figure 7: Total External Costs Per Port Call

The reason for those differences can lie in a number of factors ranging from specific vessel properties to the duration of a port stay. By way of an example, if a comparably small (and therewith relatively old) refrigerated vessel calls the port of Palma de Mallorca, it is likely that this vessel will have high external costs for the time it is moored. However, the cargo operations will not take the same time as with a comparably large vessel. The opposite also holds true: If a modern, efficient large vessel calls, for example, at the port of Las Palmas de Gran Canaria, the external costs per hour will be relatively low; however, the vessel is likely to stay longer and the external costs for this port call will be higher in total.

Interestingly, efficiencies of scale are not substantially observable in the external costs per hour. Container vessels are a good example of this. Intuition would suggest that external costs per hour are less at ports that are specialized in a certain vessel type. Las Palmas de Gran Canaria received 601 calls from container vessels, more than any other vessel type. In Palma de Mallorca, only 22 calls from container vessels could be observed. However, the external costs are 337 euros and 122 euros respectively. In fact, Las Palmas de Gran Canaria is the port with the highest number of vessels calls from container vessels, and also the port with the highest external costs.

Reasons for those counterintuitive figures are likely to lie within the differences in the same category of vessels. The size[8] of container vessels can range from below 100 metres to almost 400 metres. Therewith come great differences in generators that are in the end directly linked to the external costs for moored vessels.

5. Conclusion, limitations and further research

In recent years, air emissions and the negative effects derived from the growth of shipping have increasingly raised concern. Emission inventories and their economic valuation as external costs are necessary to properly assess mitigation strategies, voluntary programmes and an effective policy design within national and international contexts.

This paper contributes to the literature by estimating the external costs of the in-port shipping emissions (GHG and exhausts emissions commonly relate to local detriments in air quality: NOx. SOx, CO and PM) released by operative vessels at berth in four Spanish ports (Las Palmas de Gran Canaria, Palma de Mallorca, Pasaia, and Tenerife) during 2017-2018.

The four ports under study are quite heterogeneous in terms of cargo specialisation and size, have different traffic profiles and are located in cities with different populations. The external costs

[8] The gross register tonnage is important as well. In fact, there is a high correlation of gross register tonnage and length. This is almost perfect in the case of container vessels.

estimated might be correlated with these different characteristics, and thus offer a complete picture of different externality costs derived from ships. The differences also facilitate a comparison of the responsibility among the different shipping sectors; this serves to better know the potential benefits of implementing abatement technologies, such as cold ironing, which will differ greatly between different ports.

The presented results firstly point towards the important role the local effects of emissions, in terms of external costs, have on the cities and regions in the direct vicinity of a port. It has been shown that the external costs of a port are linked to the vessel type in question. However, we have also discussed that the findings leave room for interpretation because there can also be great differences within one vessel type.

Furthermore, the great potential for abatement technologies such as cold ironing is underlined by the findings in this work. It is now possible to assess to what extent such abatement technologies make sense and point towards the need of assessing the potential in each individual port per vessel type, as the differences are apparent.

A remaining challenge of cold ironing is how the retrofitting of vessels could take place. Martínez-López (2021b) offer a promising approach where environmental charges are based on a variety of factors that could incentivize the retrofitting of short sea shipping vessels with cold ironing facilities. However, it should be noted that the effect will depend to a wide extent on how the on-shore electricity is produced, as discussed in the introduction.

One limitation of the approach presented here is that it intrinsically limited to externalities that can be attributed to vessel traffic. A substantial share of emissions that might contribute to externalities depends on the equipment deployed within a given port, but this is beyond the scope of this document. The same can be said for externalities that arise when certain cargo such as solid bulk cargo is handled.

A further limitation of this document lies in the reliance on the deployed methodologies. If those methodologies are proven to be inaccurate, then these findings will consequently also have to be regarded as less valid. Furthermore, the external costs factors used in this document depend on the value of life estimations. These estimations are often subject to criticism from both a moral as well as methodological point of view. In the absence of a more favourable approach, the potential short comings are assumed to not outweigh the benefits of these findings.

Notwithstanding, the fact that estimating emissions as well as external costs are of key importance regardless of a pandemic, it should be recognised that the substantial changes such as those in cruise vessels provide a unique research opportunity. The current pandemic has had a significant impact on the cruise industry, which has been faced with unprecedented difficulties as cruise vessels were perceived to contribute to the spread of COVID-19 (Ito et al., 2020). There was considerably less traffic in 2021 and this is potentially so in 2022, depending on how the dynamic COVID-19 situation evolves. This opens a chance to investigate how external costs are evolving in a world with either less or no cruise shipping. While almost zero impact on cargo traffic can be observed, multiple scenarios are feasible where this might change in the future. It remains to be seen how the industry will develop in the upcoming years, and how future research possibilities might evolve.

A more technical challenge that needs to be overcome is that of different alternating current frequencies between the ship and the shore grid. Most vessels operate with an AC frequency of 60 Hz while the power grid in European countries operates at 50 Hz. The conversion from 50 to 60 Hz usually happens on the shore side, and it is associated with additional costs. Also, the matter of standardization of connectors must not be underestimated in complexity, as well as regulatory constraints imposed by for example Safety of Life at Sea (SOLAS). The biggest challenge however can be seen to lie within the (retro) fitting of vessels with cold ironing technology, which can be a significant cost factor. The here provided findings may help to determine for which vessels and ports, cold ironing might yield the highest benefits.

In addition to analysing the likely impact of COVID-19, it also remains to be analysed why the differences within the vessel types exist. This can also help to further assess the potential benefits cold ironing could have. Further developments from institutions like the IMO and the EU commission as well as a potential shift to renewable resources might also mandate further research in this area.

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