This version is the accepted manuscript. The final version is available at:
https://doi.org/10.1016/j.jenvman.2020.111807.

Citation: Spengler, T., Tovar, B. (2021): Potential of cold-ironing for the reduction of externalities from in-port shipping emissions: The State-owned Spanish Port System case. Journal of Environmental Management. 279, 111807.
https://doi.org/10.1016/j.jenvman.2020.111807.

Potential of cold-ironing for the reduction of externalities from in-port shipping emissions: The State-owned Spanish Port System case

Thomas Spengler
University of Las Palmas de Gran Canaria. Campus Universitario de Tafira, Módulo D, Las Palmas de Gran Canaria, Spain,
thomas.spengler101@alu.ulpgc.es

Beatriz Tovar
University Institute for Tourism and Sustainable Economic Development (TIDES), Universidad de Las Palmas de Gran Canaria. Campus Universitario de Tafira, Módulo D, 35017, Spain Tel: (0034) 928 45 17 94
beatriz.tovar@.ulpgc.es

Acknowledgements

Financial assistance for this work was provided by PROJECT 2015-EU-TM-0417 OPS MASTER PLAN FOR SPANISH PORTS Grant NEA/CEF/TRAN/M2015/1128

ABSTRACT
This paper provides insights into the potential of cold-ironing for the reduction of externalities. External cost derived from the emissions of CO_2, NO_x, SO_x, and PM from berthed ships in the Spanish port system during 2016 are estimated providing a Spain-wide empirical evidence into where the highest externalities exist and where, on a port by port level, the introduction of cold ironing could yield the highest potential on reducing said externalities. The combined overall external costs from both local and global effects of shipping emissions from berthed vessels were between 326 and 440 million Euro. Eco-efficiency parameters are also obtained. It is found that the population in the port city as well as the composition of traffic are key factors when the external costs are determined, and they should be considered when the investment decision about where cold ironing should be placed is taken.

Keywords: Cold-ironing, externalities, in-port emissions, air quality, Spanish ports, external cost

1. Introduction

Vessels account for 90% of international transport and for 2.2% of worldwide emissions (Smith et al., 2015). Apart from the often referred to CO_2 emissions, vessels also contribute in a significant way to emissions of NO_x, SO_x and particulate matter. It is therefore not surprising that considerable mitigation efforts are undertaken by stakeholders from, both, the private as well as public sector to mitigate and abate these emissions. In particular, emissions of short-lived climate pollutants (SLCPs) are of interest when considering vessels calling at ports that are in or near to densely populated areas. SLCPs, such as for example particulate matter, stay in the atmosphere for a relatively short time period when compared to CO_2. The negative health impacts might however be much greater for the people in the direct vicinity of where the emission occurs.

During the past decades, different approaches can be observed to avoid or mitigate emissions and the associated external costs that are caused by shipping. In particular, in ports that are in the direct vicinity of densely populated areas. One of the approaches to reduce said emissions from vessels in ports, cold ironing, is often perceived (Cullinane and Cullinane, 2019; Pettit et al., 2018) as one way to a cleaner and more environmentally friendly sea transport.

The issue of allocating the limited resources amongst the various options to attain sustainability and emission reduction goals is a common challenge for many ports. Analysis of subsidy programs for cold ironing as a potential strategy have been carried out (Wu and Wang, 2020) and even though cold ironing has a relatively high marginal cost when considered as a mere CO_2 abatement technology (Wan et al., 2018), it is shown in this paper, that the benefits of cold ironing are substantial when considered as a way of reducing the external cost to the society in general and to the port cities in particular.

However, to be able to assess the benefits that would come from cold ironing, it is necessary to have a deeper look into how the introduction of the measure would impact the different ports. The results obtained in this paper provide a wide insight into the potential that cold ironing could have for the Spanish ports and they allow to take a more granular decision about the question of investment in cold ironing.

In addition, policy makers face the challenging task of implementing rules and regulations that encourage the port sector to reduce their environmental impact. One possible way to contribute to a more sustainable port sector is to internalize external costs. A challenge for internalizing external costs is the fact that external costs are very often not known. In the event of some metrics were known, they would be hardly comparable (Tichavska and Tovar, 2015b). The findings in this report make it possible to measure the cost of not having cold ironing in various ports and can help the policy makers conceive rules and regulations that are likely to yield the highest benefit for the society. Also, by comparing eco-efficiency indicators, policy makers could be aware of potential risks that certain regulations could have in terms of wrong incentives when considering only overall external costs. By way of example, if a policy-maker introduces a regulation only addressing overall external costs, it would entirely disregard the question of how many vessels are calling a port and how long the vessels are staying in the port. However, by comparing eco-efficiency indicators, policy makers would be made aware of potential risks that certain regulations could have in terms of wrong incentives if there are great discrepancies between ship calls and port stay durations.

Furthermore, market-based approaches such as emissions trading are often mentioned (cf. Kachi et al., 2019) as a way to promote more sustainable alternatives to the use of fossil fuels such as cold ironing. The advantage of mark-based approaches is, that they could offset the high initial cost of the installation of cold ironing facilities on the shore side (Dai et al., 2019). Yet, in order to implement a market-based approach, such as emission trading between ports, it is necessary to have a well-established and understood basis. The findings in this report could serve as a base for the policy makers and the stakeholders from the port sector that could have an insight into how the installation of shore-power supply facilities could financially benefit the respective port (e.g. through the emission trading).

Apart from these contributions to the practical side of policy implications and further benefits for other stakeholders, this work also contributes in a significant way to the existing body of literature. It offers, to the best of the knowledge of the authors, for the first time a nation-wide overview of the external costs that can be allocated to berthed vessels in all major ports of a country highlighting where investments can be undertaken to get the maximum reduction on these external costs in its port-cities.

Moreover, this paper, offers for the first time insights into the potential of cold-ironing for the State-owned Spanish Port System case by providing an estimation that allows for comparisons and also highlights the Spanish ports[1] that can be of interest for further research due to their higher potential. On the other hand, these measurements (external costs) are also useful to estimate ports' environmental efficiency providing important information for policymakers (Tovar and Wall, 2019; 2020a).

This work is structured as follows: First, a review of relevant literature with regard to emissions from vessels in the vicinity of ports in general and cold ironing in particular is given. This is followed by a brief overview of the area under study, Spain, and its port

[1] A deeper analysis of each one of those ports has been left as a task for future research. This tailored analysis is needed because differences in the contribution to total external costs from different ship categories exist between ports and they should be considered when it comes to deciding how to prioritize the investment (e.g. which berths, and therefore ship categories, the OPS will be offered first to).

system. The methodology is described in Section 4. The results are provided in Section 5. Section 6 concludes.

2. Literature

The movement towards cleaner shipping is reflected by the amount of literature that has been published in this field of research since 2006 (Davarzani et al., 2016). The matter of emissions from ships in the vicinity of a port has already received a noticeable amount of attention. One frequently cited paper in this respect is the one of Merk (2014) who reported, based on a literature review, that the share of shipping emissions in total emissions in port cities with regard to some pollutants such as SO_2 can be as high as 54%. Following the Benefits Table database (BETA), he estimated the external costs of the 50 largest ports to be 12 billion Euro per year. Cold ironing as an abatement measure is also mentioned in particular. It is sometimes understood as a measure that can best unveil its true potential when the initial costs are offset and hence, the economic performance is improved through measures such as emission trading (Dai et al., 2019).

For the case of the port of Piraeus in Greece, Chatzinikolaou et al. (2015) estimated the total external health cost, to be approximately 25.3 million Euro,of which more than half (61%) was attributed to particulate matter. Maragkogianni and Papaefthimiou (2015) considered 4 ports, including Piraeus and only focused on cruise ship activity. For the port of Piraeus, they reported that the external costs are 11.8 million Euro or 7.88 million Euro according to the New Energy Externalities Development for Sustainability (NEEDS) and Clean Air for Europe (CAFE) methodologies, respectively.

In relation to cold ironing, it is also recognized (Zis et al., 2014) that the type of vessel plays an important role as this can be determining for the time spend at berth which in turn can be a deciding factor for whether to use cold ironing or not.

Innes and Monios (2018) mention 28 ports with cold ironing facilities and Zis (2019) mentions 43 ports with either cold ironing already installed or planned. In this context, it is worth noting that said cold ironing facilities are not universally made available to all vessels. In most cases, the option of receiving a shore power connection is only available for a certain type of vessel (e.g. Ro-Ro or cruise ships) and also only at certain berths.

This is related to the technical challenges of installing cold ironing facilities in ports as described by Sciberras et al. (2015). A first and often mentioned challenge is that the alternating current on vessels very often has a frequency of 60 Hz while national power grids in Europe generally operate at 50 Hz. This makes it right from the beginning more challenging for European ports to implement the said technology as compared to ports in the United States where the frequency of alternating current in the national power grid is in fact 60 Hz.

Ballini and Bozzo (2015) undertook a case study for a new cruise pier in the port of Copenhagen which is "prepared for the introduction of cold-ironing". The study worked on the assumption that about 60% of the cruise ships operating in the Baltic Sea could be retrofitted with cold ironing equipment, and an approximation that the overall cost of final installation would amount to a capital cost of 37 million Euro. In a cost benefit analysis based on these assumptions, the result was that the capital cost could be recovered, merely by health cost savings and disregarding CO_2 emissions, after 12 to 13 years. Innes and Monios (2018) found in a similar case study with regard to the port of Aberdeen, in Scotland, that in the most optimistic scenario, the capital as well as operating cost could be recovered in only 7 years. Reason for this considerably lower estimate are due to a generally rather clean and increasingly clean energy mix in Scotland, the assumption that all vessels would be using cold ironing and an assumed much lower initial investment cost for installation. In a worst-case scenario, Innes and Monios (2018) estimated the payback period to be almost 14 years. The estimates should however be taken with a grain of salt as no sensitivity analysis was carried out with regard to the discount rate.

The matter of how the electric energy is produced is not only a key factor in cost benefit analysis but also in general when considering cold ironing. While local effects would certainly be shifted to the location where the energy is produced, the matter of global effects still persist. Zis (2019) reports that an auxiliary engine, powered by marine gas oil, would emit between 678 and 709 gram of CO_2 per KWh whereas 940 gram of CO_2 per kWh would be emitted by a coal power plant. While the population density tends to be comparably low in regions of coal power plants and a smaller proportion of the population would be affected by the negative local effects of energy production with a coal power plant, the negative global effect caused by CO_2 would be less if the electricity needed by a given vessel would be produced by means of auxiliary generator. Still, Zis (2019) also reports on the emission factors for grid electricity for ports around the world and all of them are way below the above-mentioned 678 to 709 g/kWh for the marine gas oil engine.

This matter can be particularly relevant in the case of Spain, which has considerable number of ports on small islands and concrete plans for the cold ironing in the near future ("Main Spanish Shipping Liners", 2018). The electric power grid of islands is often not connected to the mainland and all electricity production has to take place right on the island in question. Accordingly, the emissions per kilowatt hour can differ significantly from the overall emissions per kilo watt hour of the respective country. For the case of Gran Canaria, Tichavska and Tovar (2015a) argued that, even though the island is currently heavily dependent on the use of oil for electricity production, the regional government of the Canary Islands has already taken steps to support the use of renewable energy. In this context, it should be noted that there are also efficiencies of scale when it comes to electricity production from oil. This implies that even electricity production from oil can be assumed to emit less CO_2 per KWh than electricity production from oil onboard a given vessel.

Another relevant factor taken up by Zis (2019) is the one of economic viability of cold ironing for ship operators. This question is heavily intertwined with the volatility of energy prices and with the question of where a given vessel is bunkering as bunker prices tend to differ substantially between different locations. Zis (2019) reports the costs for producing electricity by means of auxiliary engines and the costs of buying electricity from the national power grid for the years from 2010 to 2017 for several countries. Due to the plummeting oil prices between 2014 and 2016, the production of electricity by means of auxiliary engines would have been cheaper when compared to most countries. However, already between the years of 2016 and 2017 an increase in oil prices could be observed while prices for electricity from the national power grids maintained relatively stable. It should also be noted that electricity taken from shore is taxed in some regions whereas electricity produced by means of auxiliary engines usually is not subject to said taxes (Kumar et al., 2019). This is currently a matter of debate within the European Union in general and in Spain in particular. The European Parliament (2018) has recognized the importance of the taxation scheme for shore-side power supply and called therefore on their Member States to review the disparities in energy taxation in a resolution. The Spanish Institute for the Diversification and Saving of Energy has announced that new electricity regulations will come into force with regard to ships at berth ("IDAE announces", 2018). Germany and Sweden were already allowed by the European Union to provide electricity by means of cold ironing at a reduced tax rate in 2011 (Ballini and Bozzo, 2015).

Notwithstanding the above-mentioned challenges for the implementation of cold ironing, there are good reasons to believe that a higher penetration of this technology will be observable in the upcoming years. One of the reasons is that ports could be considering making the use of cold ironing compulsory. The latter has to be understood against the background that some argue that "*the main barrier for the further implementation of [cold ironing] solutions […] is the associated high installation cost*" (Zis, 2019).

In addition, given the current regulations within sulphur emission control areas (SECAs), the operators of vessels are met with a range of different sulphur limits of marine fuel. Inside EU SECAs (European Maritime Safety Agency, 2016; European Parliament and Council, 2016.) the sulphur limit is currently 0.1%. While outside of SECAs the maximum sulphur limit has been 3.5% until 2020 when the Sulphur limit became 0.5% instead of 3.5%. However, the sulphur limit is 0.1% at berth/anchor even outside EU SECAs if the vessel in question is more than two hours at berth or at anchor.

For a passenger vessel that half of the year is sailing in the Mediterranean and Baltic Sea and the other half of the year is sailing in the area of Latin America, this might mean that fuel with two different types of sulphur content might need to be stored on board of the vessel to always be able to use the cheapest permissible fuel. This, of course, is impractical for several reasons.

One possible way to address said challenge is the installation of scrubber systems or a cold ironing system on board. The cost of retrofitting a scrubber system is reported to be up to 6 million USD (Zis et al., 2016) whereas the cost of installing cold ironing equipment is comparably cheaper, with a cost of between 300.000 and 2 million USD.

This would also have the additional benefit of not being forced to use the most expensive fuel with 0.1% sulphur content at berth.

The key benefit of cold ironing technology, however, lies in the reduction of local and global emissions and noise reduction. Depending on the region, the effects naturally seem to differ. For six container terminals in different regions of the world Zis et al. (2014) report that by means of cold ironing a reduction potential for "*CO_2, SO_2, NOx and BC emissions by 48-70 per cent, 3-60 per cent, 40-60 per cent and 57-70 per cent, respectively*" exists. In Gothenburg, Sweden, an actual reduction of 10% of CO_2 emissions from RoRo and ferry ships was reported (Styhre et al., 2017). Also, Styhre et al. (2017) report that the main part of the emissions occurs during the "at berth" mode of operation and are consistent with Zis et al. (2014), arguing that a greater saving potential exists for larger vessels. In absolute numbers Styhre et al. (2017), has calculated the emissions to be 150.000, 240.000, 97.000 and 95.000 tonnes of CO_2 emissions for the ports of Gothenburg, Long Beach, Osaka and Sydney respectively. A hypothetical estimation if all ships were to use cold ironing is provided by Chang and Wang (2012) for the Kaohsiung harbour in Taiwan, estimating a potential reduction of CO_2 emissions by 57.2%, NO_x emissions by 49.2%, SO_x by 63.2% and PM emissions by 39.4%. Adamo et al. (2014) found that by cold ironing in the port of Taranto, Italy, emissions of NO_x and CO_2 could be reduced by 1.097 tons per year and 25.686 tons per year respectively.

Even though a significant amount of research has been carried out, a certain gap in literature still can be identified: Spain was never subject to a case study where virtually all ports could be compared. The benefit of doing so lies in the fact that the so values obtained allow for a more in depth understanding of externalities in the context of ports and the potential of cold ironing on a country wide basis.

The matter of credibility in relation to external cost estimates is commonly raised and also underlined by the conducted review of relevant literature. Until now, no entirely comparable set of external cost estimates is made available. This matter is to some extent addressed by the here presented research as a large number of ports is analysed by means of the same methodology.

3. Case context – The Spanish port system

The network of Spanish ports moves goods worth 200.000 million Euro or 20% of the country's GDP each year. That underlines the strategic importance of ports that handle 57% of consumer goods exports and 78% of imports from and to Spain.

By the end of 2016, Spanish ports reached a new historical high in throughput. Total goods traffic in 2016 was 495.58 million tons. The largest type of traffic was containerized general cargo (33.97%), followed closely by liquid bulk (33.81%), solid bulk (18.56%) and break bulk (13.65%). Moreover, more than 31 million passengers, 27.95% of which were cruise passengers and 76.53% were non-cruise passengers, utilized Spanish ports. The ports with the highest throughput are the ones of Algeciras, Valencia and Barcelona. On national level, the five ports with the highest gross traffic growth in 2015 were the ports of Algeciras, Huelva, Valencia, Baleares and Barcelona.

Spain plays a major role in the European port sector. Rodríguez-Álvarez and Tovar (2012) and more recently Tovar and Wall (2020b) have analysed the Spanish regulatory framework of the port sector and found that it has undergone substantial changes during the last three decades. The port authorities follow the landlord model. Currently, they have great autonomy with regard to legal, managerial as well as budget aspects of their work. The said port authorities are governed by the state-owned Enterprise of National

Ports (Ente Público Puertos del Estado, EPPE). Figure 1 depicts the forty-six General Interest ports[2].

General Interest ports are managed by port authorities that are governed by the EPPE. In this context, it should be noted that a variety of different ports fall under said regime. Spanish ports are relatively heterogeneous in terms specialization and size. Some ports handle cargo and passenger traffic whereas the main activity of others is cargo (passenger traffic is virtually non-existent). In addition, within one port, several different terminals can operate that handle different cargos or even passengers.

Figure 1: Spanish General Interest Ports

Source: EPPE, 2019

[2] Following Tovar and Wall (2020) "*Ports in Spain can be classified into two legal categories. General interest ports are the property of the State (dependent on the Ministry of Public Works) and must comply with certain characteristics. These may include, among others, international maritime activity, provision of services of strategic national economic importance or port activity that affects several Autonomous Communities (regions).*"

Table 1 shows the top ten Spanish ports by type of cargo and passengers. A first observation with regard to the cargo as well as passenger throughput is that there are some ports in the system that are amongst the most important ports in more than one category. One of the ports is Algeciras, which happens to be the most important port for containerized cargo, liquid bulk cargo as well as for non-cruise passengers in Spain. Moreover, Algeciras is the third most important Spanish general cargo port. Other ports seem to make use of the apparent economies of scope as well. Castellón, located north of Valencia at the east coast of Spain, is Spain-wide the port with the sixth highest container as well as solid bulk throughput. In terms of liquid bulk, it ranks seventh. Bilbao comes in fifth with regard to its general cargo, liquid bulk and container throughput. In terms of solid bulk, it comes in eighth. This pattern continues and it can be argued that many ports that have specialized in one cargo also have specialized in another cargo[3].

In Spain, passenger traffic by sea has been of high importance in certain geographic regions, such as the Strait of Gibraltar, the Canary Islands and the Balearic Islands. A distinction is made between cruise passengers and non-cruise passengers based on the vessel and its destinations. Passengers that are embarking on a short-distance voyage with a passenger or vehicle ferry are considered non-cruise passengers.

Moreover, cruise shipping and the associated cruise passengers are of significant importance in Spain as it has not stopped growing since its appearance more than two decades ago. However, it should be noted that there are seasonal differences between the regions due to their different climatic conditions. While the most important Spanish cruise destinations in the Mediterranean Area, such as Barcelona and Palma, are chiefly frequented between May and October, the destinations on the Canary Islands receive a

[3] For a deeper analysis of this issue, see Tovar and Wall (2017, 2019).

substantial amount of their cruise passengers during the winter of the northern hemisphere due to the warm climate even during those months.

Table 1 Top Ten Spanish ports by type of cargo and passengers

Liquid bulk		Solid bulk		Container	
Port	Ton	Port	Ton	Port	TEUs
Algeciras	27,309,859	Gijón	16,023,647	Algeciras	4,761,444
Cartagena	25,025,669	Tarragona	9,065,474	Valencia	4,670,810
Huelva	24,136,062	Huelva	5,759,383	Barcelona	2,236,961
Tarragona	20,268,771	Cartagena	5,304,817	Las Palmas	851,473
Bilbao	18,087,202	San Cibrao	5,230,449	Bilbao	596,689
Barcelona	11,415,816	Castellón	5,198,982	Castellón	226,903
Castellón	8,354,528	Barcelona	4,430,798	S/C Tenerife	350,337
A Coruña	8,169,622	Bilbao	4,362,064	Vigo	218,044
S/C Tenerife	6,012,950	A Coruña	4,345,101	Alicante	159,664
Las Palmas	4,411,677	Ferrol	4,175,590	Sevilla	145,672

Non containerized general cargo		Cruise Passenger		Non cruise passenger	
Port	Ton	Port	Number	Port	Number
Barcelona	10,737,040	Barcelona	2,683,594	Algeciras	4,220,710
Valencia	8,114,037	Palma	1,631,206	Ibiza	2,461,249
Algeciras	7,591,875	Las Palmas	615,485	La Sabina	2,074,374
Palma	7,039,505	S/C Tenerife	559,100	Ceuta	1,923,483
Bilbao	3,126,518	Málaga	444,176	Los Cristianos	1,535,538
Las Palmas	3,053,536	Valencia	403,264	Tarifa	1,397,338
S/C Tenerife	2,345,678	Cadiz	385,067	S/C Tenerife	1,319,165
Sagunto	2,329,058	Arrecife	377,803	Barcelona	1,275,366
Ibiza	2,310,508	Ibiza	251,249	SS de la Gomera	1,228,332
Pasajes	2,216,792	S/C de la Palma	224,448	Las Palmas	1,108,666

Source: Own elaboration based in EPPE Annual Report

In absolute numbers, Barcelona with more than 2.5 million passengers stands out as the most important cruise port in Europe and ranking fifth on a worldwide level. The Palma port (Balearic Islands) with almost 2 million passengers rank fourth in Europe and thirteenth in the world. On the north-western Atlantic coast of Spain, more than 465.000 passengers were counted, representing 5.4% of the national total. Of that, 200.000 passengers could be allocated to the port of Vigo. Two million cruise passengers were counted in the Canary Islands in 2015, making it the third most active market in Europe and arguable the most active market in Europe during the European winter. On the Canary Islands, Tenerife and Las Palmas are the most important ports with 559.100 and 615.485 cruise passengers, respectively. It is worth noting that the electricity consumption of passenger vessels in hoteling is considerably higher than the one of cargo vessels. Therewith comes the greatest potential for the reduction of externalities by means of cold ironing for those vessels.

4. Methodology

With the introduction of a variety of plans and programs to mitigate or, at least, reduce emissions from vessels, ports have started to move to a more environmentally friendly way of handling cargo and passengers. In the case of Spain, a major initiative is the OPS Master Plan. this plan is, in turn, part of the National Action Framework for the development of infrastructure for the use of alternative fuels in the transport sector. This, again, is in compliance with Article 13 of Directive 2014/94 EU.

Estimating the potential benefits to society that the supply of vessels with on shore electricity could have is a crucial step for the OPS Master Plan project as well as the Spanish National Ports Agency, which in turn is responsible for the coordination of said plan. A prerequisite for doing so is to first estimate the emissions of CO_2 and other pollutants such as NO_x, SO_x, and PM from berthed ships in the Spanish port system.

The emission released by vessels while hoteling operation inside one of the Spanish ports during 2016[4] has been calculated as part of the EU-funded research project Master

[4] This calculation for all ports was only carried out once for the 2016 data and it was never repeated thereafter as following estimations were only focused on some ports.

Plan for OPS in Spanish Ports (Agreement No. INEA/CEF/TRAN/M2015/1128893). To do that, data regarding the time a vessel is berthed, the size of the vessel and the type of the vessel are needed. The type of the vessel is needed to make estimations with regard to the auxiliary engine power. Based on this data, it is then possible to compute the emissions with Equation 1:

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

Where E are the emissions in tons for pollutant i, AE is the auxiliary engine power in kilowatt. The power is estimated using the bin responding to vessel in question, following the 3rd International Maritime Organization (IMO) Study on Greenhouse gases (GHG) (Smith et al., 2015) The time, t, is calculated in hours and FE is the emission factor for pollutant i in tons per kilowatt-hour.

The proposed methodology of the European Environment Agency (EEA) and the US Environmental Protection Agency (EPA) in the years 2013 and 2010 respectively was followed based on the following three assumptions: (1) Tier II is achieved by the auxiliary engines with respect to NO_x, (2) the auxiliary engines are of "medium speed diesel" type and (3) the auxiliary engines are burning Marine Diesel Oil (MDO)/Marine Gasoil (MGO) fuel. For the other data it was referred to operational and vessel traffic information such as Automatic Identification System (AIS) data, port call data and the information regarding berthing location.

Estimating external costs related to site-specific emissions from both, local and global effects, is a non-trivial undertaking[5]. When doing so it is often referred to Impact Pathway Analysis (IPA) as the most comprehensive methodology by policy makers and the

[5] For a review of the methodological and empirical state of the art, see Tichavska & Tovar (2017).

scientific community alike. IPA is also followed by several European bottom-up studies for the calculation of external costs related to air emissions from transport in European countries and even sometimes for approximating external costs for shipping or ports. However, it has to be noted that there are methodological differences between those studies with regard to the emission cost calculation pathway. In this paper, BeTa (Netcen, 2004) is followed as it proved to be appropriate for the context at hand in previous studies (Nunes et al., 2019; Tichavska and Tovar, 2015)[6].

BeTa allows among other things to estimate long- and short-term effects of a variety of emissions on mortality and morbidity as well as the effects of SO_2 on buildings and other structures. It should however be noted that some effects are excluded for example non-ozone effects on agriculture and impacts on ecosystems. In addition, Netcen (2004) recognize that there are unknown effects that cannot be included.

It is also recognized that the assumed effects are still subject to a wide variety of research, reaching from detailed analysis of indoor air pollution (Mulenga and Siziya, 2019) to using sensitive plants to evaluate pollution (Benaissa et al., 2019). Also, different indices for air quality have been compared (Motesaddi et al., 2017).

A key assumption in BeTa is that the externalities do not scale linear for larger cities above 500.000 inhabitants (see figures in Table 2). The rationale behind this assumption is (a) that in larger cities other chemical processes take place in the atmospheric layer close to the ground and that (b) larger cities are not as compact as smaller ones and do

[6] Although Tichavska and Tovar (2015b) and Nunes et al. (2019) followed the same methodology than the one followed in this paper the operational modes considered to calculate the external costs were different: both articles calculated the external costs including the three phases (hotelling, manoeuvring and cruising operations at port) whereas the present study only measures the external costs derived from berthed vessels (hoteling phase). Moreover, not only location (this has been analysed by Tovar and Tichavska, 2019) but also the time when the analysis was done plays a role due to differences and/or changes of regulations (e.g. the limits on sulphur oxides have been progressively tightened). Therefore, the results comparisons among those studies would not yield much insight.

have a considerable number of parks, lakes, industrial zones and the like. Thus, the cost factor proposed by BeTa depend on the port city population as depicted in Table 2. That is, urban externalities for $PM_{2.5}$ and SO_2 for cities of different sizes are calculated by multiplying results for a city of 100,000 people by the factors shown below

Table 2. Urban External cost factors for $PM_{2.5}$ and SO_2 from BETA

City population	**Prices**	**$PM_{2.5}$**	**SO_2**
City of 100,000 people (€/tonne)	2000	33000	6000
Scale factor	**Prices**	**$PM_{2.5}$**	**SO_2**
City of 500,000 people (€/tonne)	2000	5	5
City of 1,000,000 people (€/tonne)	2000	7.5	7.5
Several million people (€/tonne)	2000	15	15

Source: Own elaboration based on Netcen (2004)

Still, the number of inhabitants is of course a deciding factor for the external cost. Nunes et al. (2019) derivate from BeTa at this point and assume the same external costs for emitted pollutant for cities of 100.000 inhabitants or less which can be thought to be difficult to justify.

With regard to emissions in rural areas, BeTa provides external costs per ton of pollutant for all of the EU-15 countries. The values for Spain are shown in Table 2 for NO_x, SO_x and $PM_{2.5}$.

While the effect of NO_x, SO_x and $PM_{2.5}$ are timewise as well as geographically limited, the effects of CO_2 is in both of those two aspects much broader and therewith more difficult to assess. Moreover, climate costs are generally believed to increase over time, depending on the accumulation in the atmosphere that has already taken place. Therefore, and following the approach of previous research (Tichavska and Tovar, 2015b, 2019), a lower and an upper value for the costs of CO_2 will be presented, corresponding to two different avoidance target scenarios. The lower estimate is produced under the assumption that the EU GHG reduction target for 2020 is met, with a resulting 25 Euro per ton of CO_2. The upper estimate is produced under the assumption that the long-term goal of keeping the concentration of CO_2 in the atmosphere below 450 ppm is met as well as the target to not exceed a temperature rise of more than 2 degrees Celsius. In this case, the assumed cost per ton of CO_2 is 146 Euro. A conclusive overview of the external cost factors used in this paper is presented in Table 3.

Table 3. External cost factors for NO_x, SO_2, $PM_{2.5}$ and CO_2

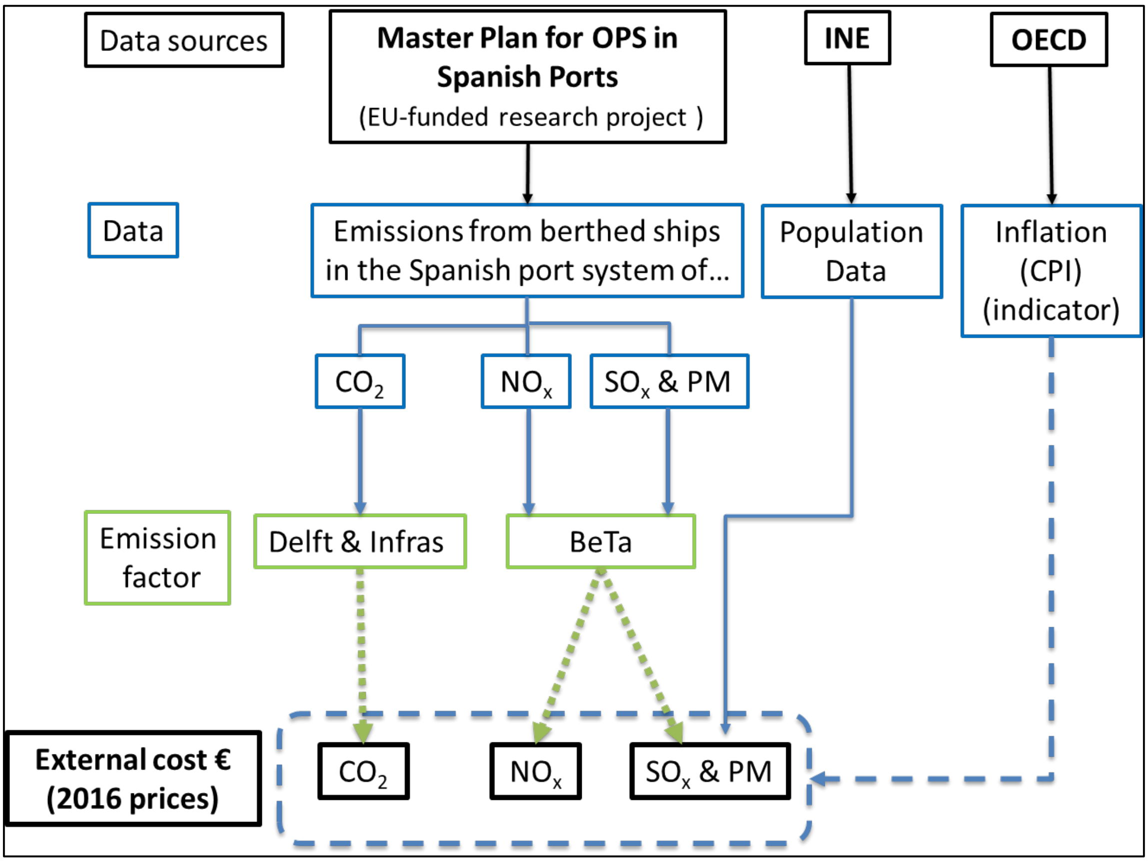
Cost factor come from the following sources:	**Prices**	**NO_x (€/tonne)**	**SO_2 (€/tonne)**	**$PM_{2.5}$ (€/tonne)**	**CO_2 (€/ton)**
BeTa urban (Spain)	2000	4700	Depend on port city's population (see Table 2)		
BeTa rural (Spain)	2000	4700	3700	7900	
Denisis 2009	2003				
Delft and Infras 2011 low	2008				25
Delft and Infras 2011 high	2008				146

Source: Authors based on sources as indicated

The applied unit cost values of NO_x, SO_2 as well as $PM_{2,5}$ are on the lower end of the scale when compared to values that have been used in other research (see for example Zis et al., 2019).

Another important factor that must be taken into account is that the external costs are reported in prices ranging from 2000 to 2008 (see Table 3). For this reason, the external costs factors for emissions are adjusted for the year under study (2016). This was done, using the Consumer Price Index (CPI) for Spain to adjust country specific cost factor values. The CPI for EU28 (OECD, 2019) was used to adjust non-country specific cost factors. Figure 2 shows the applied methodology in a flow chart.

Figure 2: Flow Chart of Methodology



Note: INE = Instituto Nacional de Estadistica
Source: Own elaboration

5. Results

The following estimates will depict what the maximum saving potential would be, assuming that all vessels would receive shore power. This of course is a theoretical exercise as it would be hardly feasible and would also come with side effects such as the potential need for new power plants in the vicinity of ports. However, it does provide insights into where the greatest saving potential exist and where it would make most sense to promote the provisioning of shore power supply (for another example of a hypothetical estimation if all ships were to use cold ironing see Chang and Wang, 2012).

Table 4 depicts the external costs from shipping emissions from berthed vessels in Spain on both, local and global level. An initial finding is that the combined external cost from both local and global effects lie between 326.8 million Euro and 439.7 million Euro depending on whether the CO_2 high or low estimation, respectively, is used. In further elaborations, it will be referred to the CO_2 high estimation. Of the total external costs, roughly 31% can be allocated to global effects but the majority of externalities occurs in the direct vicinity of the port in question.

Table 4. Estimated external cost (2016 prices)

	From emission affecting						
	Local environments (€)					Global (€)	
Port	**NO_X**	**SO_X**	**PM_{10}**	**$PM_{2.5}$**	**TOTAL**	**CO_2 (high)**	**TOTAL (€)**
Barcelona	1.39E+07	6.45E+06	2.64E+07	2.48E+07	7.15E+07	1.29E+07	8.44E+07
Valencia	1.50E+07	3.57E+06	1.43E+07	1.34E+07	4.63E+07	1.40E+07	6.02E+07
Bilbao	8.68E+06	1.56E+06	5.97E+06	5.60E+06	2.18E+07	1.18E+07	3.36E+07
Algeciras	1.64E+07	9.85E+05	3.74E+06	3.51E+06	2.46E+07	8.07E+06	3.27E+07
Las Palmas	1.27E+07	8.33E+05	2.77E+06	2.59E+06	1.89E+07	1.52E+07	3.41E+07
All ports	**1.46E+08**	**1.86E+07**	**7.15E+07**	**6.70E+07**	**3.04E+08**	**1.36E+08**	**4.40E+08**

Source: Own elaboration based on Tovar (2019)

Of those local effects, almost half (48.2%) of the external cost is caused by NO_X. Most of the remaining costs are caused by particulate matter (45.5%) and only 6.1% can be attributed to emissions of SO_X. The relatively low share can be due to the regulations with regard to SO_X emissions (Tichavska et al., 2019; Tovar and Tichavska, 2019).

Evidently, not all external costs can be mitigated by means of cold ironing. It very much depends on how the power on shore is produced. Still, even when considering electricity production on shore by means of oil-fired power plants, those power plants will exhibit greater efficiencies of scale than auxiliary engines on board of vessels. Also, even if power plants emit the same quantity of pollutants than vessels, there would be a reduction of external costs due to the fact that power plants are usually located far away from cities.

The potential reduction of external costs by means of introducing cold ironing facilities is highest in Barcelona, followed by Valencia as depicted in Figure 3. Both are important ports for many cargoes as well as passengers. In addition, both cities have a great number of people that could benefit from the improvements introduced by cold ironing. Also, the external costs of vessels at berth could be substantially reduced by introducing cold ironing in Bilbao, Algeciras and Las Palmas de Gran Canaria.

Figure 3. Total external costs per port corresponding to the reduction in annual gas emissions if electricity was supplied to vessels at berth in 2016.

Note: Total external cost figures are calculated based on the CO_2 high estimation
Source: Own elaboration

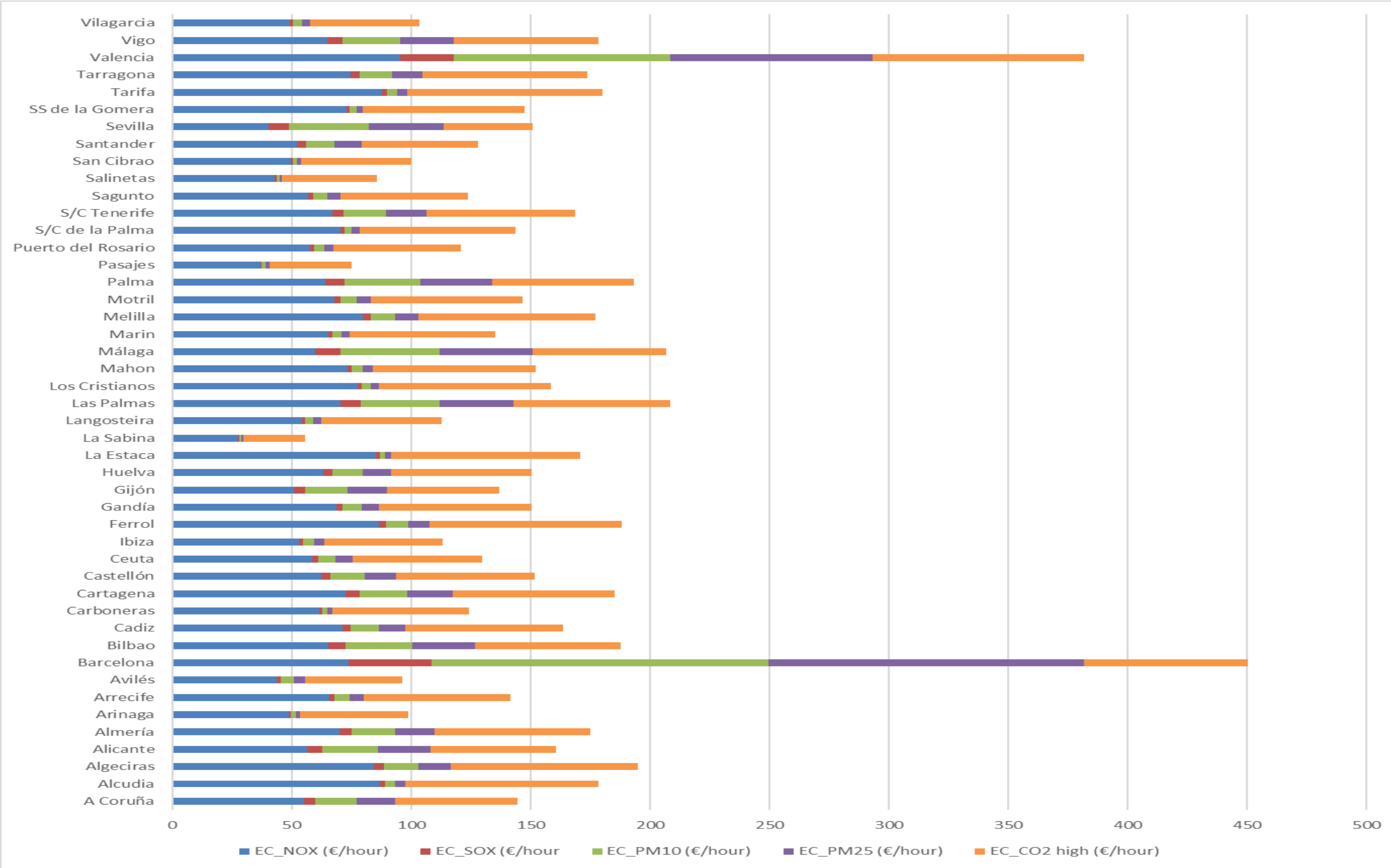
It should be noted that there are substantial differences between the external cost levels even among the top five (see Table 4). Between the first and the second, Barcelona and Valencia respectively, the difference is 24.14 million Euro. Between the second and the third, Valencia and Las Palmas the difference is with 26.14 million Euro even greater. However, the difference between Las Palmas and Bilbao or Las Palmas and Algeciras is only 0.49 and 0.93 million Euro respectively.

Answering why these differences exist is not a trivial undertaking. The amount of external costs is not solely dependent of the population. This factor has not influence on the rural part of the calculation and it is by itself only relevant for the local effect related to SO_x and PM but not NO_x. Furthermore, the shipping activities that can be observed in the various regions are rather heterogeneous and this not only concerns the type of ship (read: type of cargo or type of passenger's vessel) but even within those different types, the ages and sizes of the ships in question are key contributing factors. To address this matter and account for the apparent heterogeneity, it is necessary to introduce eco-efficiency indicators, which are presented in Figures 3 and 4.

Figure 4 depicts the external costs at berth of each pollutant and port on a Euro per hour basis. Introducing these eco-efficiency indicators helps in untangling the relation of port stay duration and a potential linkage to ports themselves (factors related to the port can influence how long a vessel stays in a port).

While Valencia and Barcelona are also experiencing the highest amount of external costs per hour, new insights can be derived from the eco-efficiency indicators presented in figure 4. For instance, Barcelona and Valencia are both important ports. With reference to Table 1, it can be said that Valencia has a considerable higher amount of containerized cargo whereas Barcelona has a higher amount of general cargo. This pattern continues for example with cruise passengers where Barcelona is more important than Valencia and is even more apparent with solid bulk and non-cruise passengers where Valencia does not even appear in the top 10. However, the external costs per hour that can be allocated to NO_x and CO_2 are higher in Valencia than in Barcelona.

Figure 4 Eco-efficiency: External cost at berth of each pollutant and port 2016 (€/hour)



Source: Own elaboration

In this respect, it has to be noted again that the external cost of NO_x and CO_2 are independent of the population. With respect to the other pollutants Barcelona always exhibits higher external cost, which might be due to the fact that Barcelona has almost twice the number of inhabitants than Valencia. The same can be said about the external cost per ship.

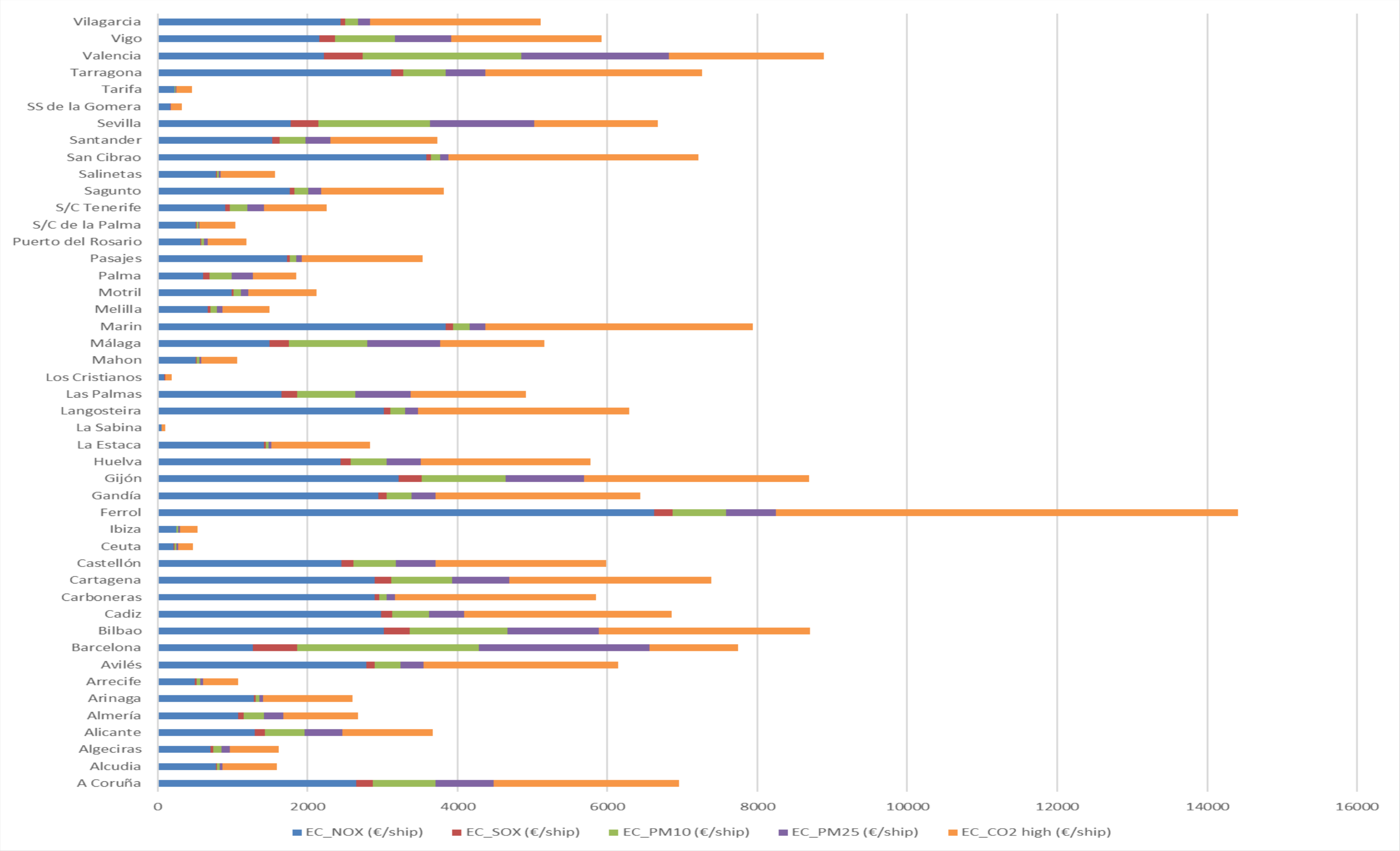
The effect population has become even clearer when Algeciras and Barcelona are compared. Again, the external costs per hour that can be allocated to NO_x and CO_2 are higher in Algeciras but with regard to all other pollutants the external costs are higher in Barcelona.

A comparison of ports with a relatively similar population can be thought to be useful. Malaga and Seville have a population of 569,009 and 690,566 respectively. The external costs for Malaga and Seville are 9.6 and 13.7 million Euro respectively. In general, Seville has more traffic in all categories than Malaga except for non-cruise passengers where Seville has none and cruise passengers where Malaga also has significantly more traffic. Still, Malaga experiences higher external costs per hour.

Generally speaking, it can be said that the eco-efficiency external costs per hour has considerably less spread than the eco-efficiency external costs per ship as depicted in figure 5. The most apparent reason for that is that the amount of external costs generated per hour is in and by itself within much tighter boundaries than the time that vessels may stay in a given port.

.

Figure 5 Eco-efficiency: External cost at berth of each pollutant and port 2016 (€/ship)



Source: own elaboration

The port stay time of a given vessel also depends on a variety of factors. A general rule of thumb for cargo vessels is that a smaller vessel can be discharged quicker than a larger vessel. However, this is not always the case. This can be attributed to the fact that more cargo handling equipment can be working simultaneously on larger vessels. Also, it can be noted that bulk vessels of the same size as container vessels are considerably slower to be discharged. This is very well reflected by the fact that for example Gijón, the port with the highest throughput of solid bulk, is one of the ports with the highest external cost per ship call.

Apart from the port stay time that can be seen as a major contributing factor to the considerable variation in external costs per vessel calling a port, it is also the vessels themselves that have different properties, causing higher or lower external costs per port call. Such properties are related to age, size and mere type of vessel, most prominently the differentiation between cruise and non-cruise vessels. This effect, however, is not as noticeable in the data as many confounding factors play a role such as the population in the direct vicinity of the port and the fact that many ports that receive a high number of calls from cruise vessels also receive a high number of calls from non-cruise vessels

6. Conclusion

It has been calculated that cold-ironing reduces total shipping-related greenhouse gases by less than 0.5%; though of greater importance are the benefits related to SOx, NOx and PM reductions and improvement in local air quality (Cullinane and Cullinane, 2019). Therefore, not only the environment but also the local population living near the port could obtain a benefit which can be calculated as a monetary equivalent of avoided damage by the effects of ship emission.

The result of this work provides a Spain-wide insight into where, on a port by port level, the highest externalities exists and where the introduction of cold ironing could yield the highest potential on reducing said externalities. To the best of the knowledge of the authors, this is the first time a Spain-wide analysis of external costs and the associated saving potential of cold ironing was conducted.

Based on the analysis, three main observations can be made:

Firstly, population plays a key role in the estimation of external costs but does not explain all. In particular, when considering the indicator 'external cost by ship' one can observe that the obtained values are always higher for Seville than Malaga even though it clearly is the other way around for external costs per hour.

Secondly, the activity or rather the composition of the traffic plays an important role, which also shows in the difference of two of the commonly used metrics of port activity: berth hours and ship calls. In this respect, it must be noted that the indicator berth hour is a homogenous measure while ships are not. This is due to the fact that ships cannot only differ in age and size but also in type. Essentially, a container vessel has to be treated as an entirely different entity than a cruise ship or a ferry.

Thirdly and potentially most importantly, if one sets out to fully understand the different aspects of sustainability in a port, there is a clear need for an individually tailored analysis of the port with a much more refined analysis that includes the eco-efficiency indicators by hours and also by type of ship. This also can be seen as a clear area for future research as well as a contribution to the existing body of literature.

While the recommendation of specific policy measures is beyond the scope of this document, it should be noted that the presented findings can contribute in a significant way to the potential introduction of new rules and regulations in the Spanish port sector. As it was shown in the literature review, introducing cold ironing is one of the most expensive abatement technologies. If only the global impact of shipping emissions is considered, the relatively high cost of installing cold ironing facilities in ports, would not make it appear as a very attractive abatement technology. The here presented findings underline the importance of local effects, in particular when they are considered as external costs.

Internalization of those external costs has been a challenge for policy makers for a substantial amount of time. This is due to the fact that rules and regulations should have a sound basis that is backed up by evidence, in order to avoid unforeseen consequences brought from wrong incentives derived from poorly designed policies. The here presented results can serve as such basis as they are already providing a good insight into the relationship between population size, traffic mix and external costs. Furthermore, the introduced eco-efficiency indicators can help to support the introduction of new policy measures such as, for example, emission trading between ports.

A clear limitation of the here conducted research was that the feasibility of installing cold-ironing facilities in ports has not been addressed. Also, it is acknowledged that the obtained estimates are still surrounded by a good amount of uncertainty. A contributing factor to the mentioned uncertainty is related to the external cost factors that are based on previous studies (BeTa) and generally considered out of scope in studies like this.

Finally, it should be noted that the potential reduction of external costs by means of introducing cold ironing facilities is even greater than the one estimated in this study since other externalities (e.g. noise) were not included in the calculation.

While this document offers insights into many different aspects of external costs in the Spanish port system and their potential abatement through cold ironing, there are still things left for future research. As it was shown, there are clear differences when external costs are considered in terms of eco-efficiency indicators. Future research should address how those differences come to exist. One potential aspect that should be considered is the vessel type, read container, bulk, Roll-On Roll-Off, cruise vessel, as it is very likely to play a major role in terms of impact on the here introduced eco-efficiency indicators.

Notation

SLCP	Short-Lived Climate Pollutant	*MDO*	Marine Diesel Oil
BETA	Benefits Table database	*MGO*	Marine gasoil
NEEDS	New Energy Externalities Development for Sustainability	*CPI*	Consumer Price Index
CAFE	Clean Air for Europe	*E*	Emissions in tons for pollutant i
SECA	Sulphur Emission Control Area	*AE*	Auxiliary engine power in kilowatt
IPA	Impact Pathway Analysis	*t*	time
GHG	Greenhouse gases	*FE*	emission factor for pollutant i in tons per kilowatt-hour
IMO	International Maritime Organization	*AIS*	Automatic Identification System

References

Adamo, F., Andria, G., Cavone, G., De Capua, C., Lanzolla, A. M. L., Morello, R., Spadavecchia, M. 2014. Estimation of ship emissions in the port of Taranto. Measurement, 47, 982-988. https://doi.org/10.1016/j.measurement.2013.09.012

Ballini, F., Bozzo, R. 2015. Air pollution from ships in ports: The socio-economic benefit of cold-ironing technology. Res. Transp. Bus. Manag. 17, 92-98. https://doi.org/10.1016/j.rtbm.2015.10.007

Benaissa, F., Bendahmane, I., Bourfis, N., Aoulaiche, O., Alkama, R. 2019. Bioindication of urban air polycyclic aromatic hydrocarbons using petunia hybrida. Civ. Eng. J., 5(10.28991). https://doi.org/10.28991/cej-2019-03091333

Chang, C. C., Wang, C. M., 2012. Evaluating the effects of green port policy: Case study of Kaohsiung harbor in Taiwan. Transp. Res. Part D Transp. Environ. 17, 185-189. https://doi.org/10.1016/j.trd.2011.11.006

Chatzinikolaou, S. D., Oikonomou, S. D., Ventikos, N. P., 2015. Health externalities of ship air pollution at port–Piraeus port case study. Transp. Res. Part D Transp. Environ. 40, 155-165. https://doi.org/10.1016/j.trd.2015.08.010

Cullinane, K., Cullinane, S., 2019. Policy on Reducing Shipping Emissions: Implications for “Green Ports”, in: Bergquist, R., Monios, J. (Eds), Green Ports. Inland and Seaside Sustainable Transportation Strategies. Elsevier Inc., pp. 35-62. https://doi.org/10.1016/B978-0-12-814054-3.00003-7

Dai, L., Hu, H., Wang, Z., Shi, Y., Ding, W. 2019. An environmental and techno-economic analysis of shore side electricity. Transportation Research Part D: Transport and Environment, 75, 223-235. https://doi.org/10.1016/j.trd.2019.09.002

Davarzani, H., Fahimnia, B., Bell, M., Sarkis, J., 2016. Greening ports and maritime logistics: A review. Transp. Res. Part D Transp. Environ. 48, 473-487. https://doi.org/10.1016/j.trd.2015.07.007

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

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

European Maritime Safety Agency, 2016. Information for state authorities, ship owners, masters, fuel suppliers, agents or operators of ships on Directive 1999/32/EC.

European Parliament and Council 2016. Directive (EU) 2016/802 of the European Parliament and of the Council of 11 May 2016 relating to a reduction in the sulphur content of certain liquid fuels. Available at: https://eur-lex.europa.eu/legal-content/EN/TXT/?uri=CELEX%3A32016L0802

European Parliament, 2018. European Parliament resolution of 25 October 2018 on deployment of infrastructure for alternative fuels in the European Union: time to act! (2018/2023(INI)). European Union

IDAE announces on-shore power will be addressed by new electricity regulation to avoid air pollution from ships at berth. http://poweratberth.eu/?p=2033&lang=en (accessed 19 Nov 2018).

Innes, A., Monios, J., 2018. Identifying the unique challenges of installing cold ironing at small and medium ports–The case of aberdeen. Transp. Res. Part D Transp. Environ. 62, 298-313. https://doi.org/10.1016/j.trd.2018.02.004

Kachi, A., Mooldijk, S., Warnecke, C. 2019. Carbon pricing options for international maritime emissions. Available at https://www.carbon-mechanisms.de/fileadmin/media/dokumente/Publikationen/Studie/Carbon-pricing-options-for-international-maritime-emissions.pdf

Kumar, J., Kumpulainen, L., Kauhaniemi, K., 2019. Technical design aspects of harbour area grid for shore to ship power: State of the art and future solutions. I. J. Electrical Power Energy Syst. 104, 840-852. https://doi.org/10.1016/j.ijepes.2018.07.051

Main Spanish shipping liners operating in Canary Archipelago will be provided with OPS in spring next year 2019. http://poweratberth.eu/?p=2003&lang=en (accessed 10 Oct 2018).

Maragkogianni, A., Papaefthimiou, S., 2015. Evaluating the social cost of cruise ships air emissions in major ports of Greece. Transp. Res. Part D Transp. Environ. 36, 10-17. https://doi.org/10.1016/j.trd.2015.02.014

Merk, O., 2014. Shipping Emissions in Ports. Int. Transp. Forum (No. 2014-20). Discussion Paper.

Motesaddi, S., Hashempour, Y., Nowrouz, P. 2017. Characterizing of air pollution in Tehran: comparison of two air quality indices. Civ. Eng. J., 3(9), 749-758. https://doi.org/10.21859/cej-030911

Mulenga, D., Siziya, S. 2019. Indoor air pollution related respiratory ill health, a sequel of biomass use. SciMed. J., 1(1), 30-37. https://doi.org/10.28991/SciMedJ-2019-0101-5

Netcen, 2004, Benefits Table Database: Estimates of the Marginal External Costs of Air Pollution in Europe. BeTa Version E1.02a. Created for European Commission DG Environment by Netcen

Nunes, R. A. O., Alvim-Ferraz, M. C. M., Martins, F. G., Sousa, S. I. V., 2019. Environmental and social valuation of shipping emissions on four ports of Portugal. J. Environ. Manag. 235, 62-69. https://doi.org/10.1016/j.jenvman.2019.01.039

OECD, 2019. Inflation (CPI) (indicator). doi: 10.1787/eee82e6e-en (Accessed date: 27 Feb 2019).

Pettit, S., Wells, P., Haider, J., Abouarghoub, W., 2018. Revisiting history: Can shipping achieve a second socio-technical transition for carbon emissions reduction? Transp. Res. Part D Transp. Environ. 58, 292-307. https://doi.org/10.1016/j.trd.2017.05.001

Rodriguez-Alvarez, A., Tovar, B., 2012. Have Spanish port sector reforms during the last two decades been successful? A cost frontier approach. Transp. Policy, 24, 73-82 https://doi.org/10.1016/j.tranpol.2012.06.004

Sciberras, E. A., Zahawi, B., Atkinson, D. J., 2015. Electrical characteristics of cold ironing energy supply for berthed ships. Transp. Res. Part D Transp. Environ. 39, 31-43. https://doi.org/10.1016/j.trd.2015.05.007

Smith, T. W. P., Jalkanen, J. P., Anderson, B. A., Corbett, J. J., Faber, J., Hanayama, S., 2015. Third IMO GHG Study 2014–executive summary and final report. Int. Maritime Organization (IMO).

Styhre, L., Winnes, H., Black, J., Lee, J., Le-Griffin, H., 2017. Greenhouse gas emissions from ships in ports–Case studies in four continents. Transp. Res. Part D Transp. Environ. 54, 212-224. https://doi.org/10.1016/j.trd.2017.04.033

Tichavska, M., Tovar, B., 2015a. Port-city exhaust emission model: An application to cruise and ferry operations in Las Palmas Port. Transp. Res. Part A Policy Pract. 78, 347-360. https://doi.org/10.1016/j.tra.2015.05.021

Tichavska, M., Tovar, B. 2015b. Environmental cost and eco-efficiency from vessel emissions in Las Palmas Port. Transp. Res. Part E: Logistics and Transp. Rev., 83, 126-140. https://doi.org/10.1016/j.tre.2015.09.002

Tichavska, M., Tovar, B., 2017. External costs of vessel emissions at port: A review of the methodological and empirical state of the art. Transp. Rev. 37, 383-402. https://doi.org/10.1080/01441647.2017.1279694

Tichavska, M., Tovar, B., Gritsenko, D., Johansson, L., Jalkanen, J.-P., 2019. Air emissions from ships in port: does regulation make a difference? Transp. Policy, 45, 128-140 https://doi.org/10.1016/j.tranpol.2017.03.003.

Tovar, B., 2019. External cost per Spanish port corresponding to the reduction in annual gas emissions if electricity was supplied to vessels at berth. OPS Master Plan for Spanish Ports project. Final Report. http://poweratberth.eu/?page_id=120&lang=en (Accessed date: 2 Feb 2019)

Tovar, B., Tichavska, M., 2019. Environmental cost and eco-efficiency from vessel emissions under diverse SOx regulatory frameworks: A special focus on passenger port hubs. Transp. Res. Part D Transp. Environ. 83, 126-140. https://doi.org/10.1016/j.trd.2019.01.019.

Tovar, B., Wall, A., 2017. Competition strategies in the Spanish port system in recent decades and their relation with port authority efficiency, in: Pettit, S..and Beresford A. (eds), Port Management: Cases in Port Geography, Operations and Policy. P Kogan Page Ltd. United Kingdon. pp: 376-406. http://hdl.handle.net/10553/55669

Tovar, B., Wall, A., 2019. Are larger and more complex port more productive? An analysis of Spanish port authorities. Transp. Res. Part A Policy Pract. 121, 265-276. https://doi.org/10.1016/j.tra.2019.01.008

Tovar, B., Wall, A., 2019. Environmental efficiency for a cross-section of Spanish port authorities. Transp. Res. Part D Transp. Environ. 75, 170-178. https://doi.org/10.1016/j.trd.2019.08.024

Tovar, B., Wall, A., 2020a. The external costs of port activity for port cities: An environmental efficiency analysis of Spanish ports. Working Paper. Las Palmas University. Spain.

Tovar, B., Wall, A., 2020b. Regulation and finance in the Spanish port sector, in: Haralambides, H., Tei, A., Ferrari, C., (Eds), Regulation and Finance in the Port Industry: lessons from worldwide experiences. Palgrave. Forthcoming.

Wan, Z., El Makhloufi, A., Chen, Y., Tang, J. 2018. Decarbonizing the international shipping industry: Solutions and policy recommendations. Marine pollution bulletin, 126, 428-435. https://doi.org/10.1016/j.marpolbul.2017.11.064

Wu, L., Wang, S. 2020. The shore power deployment problem for maritime transportation. Transportation Research Part E: Logistics and Transportation Review, 135, 101883. https://doi.org/10.1016/j.tre.2020.101883

Zis, T., North, R. J., Angeloudis, P., Ochieng, W. Y., Bell, M. G. H., 2014. Evaluation of cold ironing and speed reduction policies to reduce ship emissions near and at ports. Marit. Econ. Logist. 16, 371-398. https://doi.org/10.1057/mel.2014.6

Zis, T., Angeloudis, P., Bell, M. G., Psaraftis, H. N., 2016. Payback Period for Emissions Abatement Alternatives: Role of Regulation and Fuel Prices. Transp. Res. Rec. 2549, 37-44. https://doi.org/10.3141/2549-05

Zis, T. P., 2019. Prospects of cold ironing as an emissions reduction option. Transp. Res. Part A Policy Pract. 119, 82-95. https://doi.org/10.1016/j.tra.2018.11.003