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Shipping Emissions in Ports

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Shipping emissions in ports are substantial, accounting for 18 million tonnes of CO_2 emissions, 0.4 million tonnes of NO_x, 0.2 million of SO_x and 0.03 million tonnes of PM_{10} in 2011. Around 85% of emissions come from containerships and tankers. Containerships have short port stays, but high emissions during these stays.

Most of CO_2 emissions in ports from shipping are in Asia and Europe (58%), but this share is low compared to their share of port calls (70%). European ports have much less emissions of SO_x (5%) and PM (7%) than their share of port calls (22%), which can be explained by the EU regulation to use low sulphur fuels at berth.

The ports with the largest absolute emission levels due to shipping are Singapore, Hong Kong (China), Tianjin (China) and Port Klang (Malaysia). The distribution of shipping emissions in ports is skewed: the ten ports with largest emissions represent 19% of total CO_2 emissions in ports and 22% of SO_x emissions.

The port with the lowest relative CO_2 emissions (emissions per ship call) is Kitakyushu (Japan); the port of Kyllini (Greece) has the lowest SO_x emissions. Other ports with low relative emissions come from Japan, Greece, UK, US and Sweden.

Shipping emissions have considerable external costs in ports: almost EUR 12 billion per year in the 50 largest ports in the OECD for NO_x, SO_x and PM emissions, the emissions most directly relevant to local populations. Approximately 230 million people are directly exposed to the emissions in the top 100 world ports in terms of shipping emissions.

Most shipping emissions in ports (CH_4, CO, CO_2 and NO_x) are estimated to grow fourfold up to 2050. This would bring CO_2-emissions from ships in ports to approximately 70 million tonnes in 2050 and NO_x-emissions up to 1.3 million tonnes. Asia and Africa will see the sharpest increases in emissions, due to strong port traffic growth and limited mitigation measures.

In order to reduce these projected emissions, strong policy responses will be needed. This could take the form of global regulation such as more stringent rules on sulphur content of ship fuel (such as the 0.5% sulphur cap already agreed by the IMO), or more emission control areas than the four that are currently in place (which would extend the 0.1% sulphur requirements to more areas). In addition, shipping could be included in market-based mechanisms for climate change mitigation.

A lot could also be gained by policy initiatives of ports themselves. Various ports have developed infrastructure, regulation and incentives that mitigate shipping emissions in ports. These instruments would need wider application in order for ship emissions in ports to be significantly reduced.

1. INTRODUCTION

Shipping could – in one way - be considered a relatively clean transport mode. This is particularly the case if one takes the angle of emissions per tonne-kilometre. Typical ranges of CO_2 efficiencies of ships are between 0 and 60 grams per tonne-kilometre, this range is 20-120 for rail transport and 80-180 for road transport (IMO 2009). There is considerable variety between vessel types and CO2 efficiency generally increases with vessel size; e.g. CO_2 emissions per tonne-km (in grams per year) for a container feeder ship (with capacity up to 500 TEU) were 31.6, three times higher than the emissions for Post Panamax container ships, with a capacity larger than 4,400 TEU (Psaraftis and Kontovas, 2008). This difference is even larger for dry bulk ships, with a difference of more than a factor 10 between the smallest vessels (up to 5000 dwt) and capesize vessels (> 120,000 dwt).

At the same time, the air emissions from shipping are considerable. Depending on the methodology, different studies have estimated CO_2 emissions from shipping to be around 2-3% of total global emissions and shares that are much higher for some of the non-GHG emissions: in the range of 5-10% for SO_x emissions and 17-31% for NO_x emissions (Table 1). A solid body of research exist on shipping emissions in particular parts of the world (e.g. Europe) that confirm the reliability of these shares of shipping emissions (e.g. Cofala et al. 2007).

In comparison with other transport modes, shipping emissions are also substantial. Whereas CO_2 emissions of shipping might be approximately a fifth of those of road transport, NO_x and PM emissions are almost on a par, and SO_x emissions of shipping are substantially higher than those of road transport by a factor of 1.6 to 2.7 (ICCT, 2007). According to Eyring et al. (2003) international shipping produces about 9.2 more NOx emissions than aviation, approximately 80 times more SO_x emissions and around 1200 times more particulate matter than aviation, due to the high sulphur content in ship fuel.

These emissions have increased at a large pace over the last decades and are expected to increase in the future. Eyring et al. (2003) show that main shipping emissions (CO_2, SO_x, NO_x and PM) grew with a factor of approximately 4 over the period 1950-2001, faster than the increase of the number of ships over that period, which tripled. Shipping emissions are projected to increase over the coming decades. E.g. the IMO assumed in 2014 that shipping-related carbon dioxide emissions would increase with a factor two to three up till 2050 (IMO, 2014).

Although most of these emissions take place at sea, the most directly noticeable part of shipping emissions takes place in port areas and port-cities. It is here that shipping emissions have the most direct health impacts. NO_2 and CO-emissions in ports have been linked to bronchitic symptoms, whereas exposure to SO_2-emissions is associated with respiratory issues and premature births. Data from the Los Angeles County Health Survey reveal that Long Beach communities in close proximity to the Port of Los Angeles experience higher rates (2.9 percentage points on average) of asthma, coronary heart disease and depression, compared to other communities in Los Angeles (Human Impact Partners, 2010). Additionally, the California Air Resources Board attributed 3 700 premature deaths per year to ports and the shipment of goods (Sharma, 2006). On a global scale, calculations suggest that shipping-related PM emissions are responsible for approximately 60,000 cardiopulmonary and lung cancer deaths annually, with most deaths occurring near coastlines in Europe, East Asia and South Asia (Corbett, 2007).

Table 1. **Overview of studies on global shipping emissions**

	Estimation (mln tonnes)	Year	Share of total emissions	Source
CO_2	949	2012	2.7%	IMO 2014
	1050	2007	3.3%	IMO 2009
	944	2007	-	Psaraftis & Kontovas 2009
	695	2006	-	Paxian et al. 2010
	813	2001	3%	Eyring et al. 2005
	912	2001	3%	Corbett & Koehler 2003
	501	2000	2%	Endresen et al. 2003
	419	1996	1.5%	IMO 2000
SO_x	10	2012	-	IMO 2014
	15	2007	-	IMO 2009
	14	2005	10%	ICCT 2007
	12	2001	9%	Eyring et al. 2005
	13	2001	9%	Corbett & Koehler 2003
	6.8	2000	5%	Endresen et al. 2003
	16.5	2005	-	Cofala et al. 2007
NO_x	17	2012	-	IMO 2014
	25	2007	-	IMO 2009
	22	2005	27%	ICCT 2007
	24.3		-	Cofala et al. 2007
	21.4	2001	29%	Eyring et al. 2005
	22.6	2001	31%	Corbett & Koehler 2003
	12	2000	17%	Endresen et al. 2003
PM_{10}	1.3	2012	-	IMO 2014
	1.8	2007	-	IMO 2009
	1.9		-	Cofala et al. 2007
	1.7	2001	-	Eyring et al. 2005
	1.6	2001	-	Corbett & Koehler 2003
	0.9	2000	-	Endresen et al. 2003

Source: own data collection

However, relatively little is known about ship emissions in ports. The literature review below (section 2) identifies the main studies in this respect, which in most cases are case studies of one port. What is missing is a comprehensive overview of shipping emissions in ports, using a uniform definition and methodology, so that emissions in different ports can be compared with each other. This paper wants to fill this gap, by providing this comprehensive overview of shipping emissions in ports. It considers the following air emissions: CH_4, CO, CO_2, NO_x, PM_{10}, $PM_{2,5}$ and SO_x. The calculation of shipping emissions in ports makes use of a database of Lloyd's Marine Intelligence Unit on vessel movements in 2011, containing information on turnaround times of ships in ports across the world and ship characteristics, which allows for a bottom-up estimation of ship emissions during port calls. In these calculations, various policy measures implemented in ports to mitigate air emissions have been taken into account, such as the EU regulation to use low sulphur fuel at berth, shore power and various fuel switch programmes. The analysis has been made for different ship types, including containerships, bulk carriers, tankers and Roll on/Roll off- (Ro/Ro-) ships, carrying a variety of cargo categories. This calculation has been aggregated into emissions per port and per country in 2011. Projections have been made towards 2050, based on the ITF Freight projection model. These projections have been made per country.

2. LITERATURE REVIEW

There is a limited number of studies on global shipping emissions which contain estimations on the in-port emissions, that is ship emissions in ports. The two examples of these studies are Entec (2002) and Dalsoren et al (2008). The Entec-study (2002) estimates emissions from ships associated with movements between ports in European countries; as they assign ship emissions to 50 km by 50 km grid squares the ship-related emissions in port areas are made visible. The paper of Dalsøren et al. (2008) uses an approximation of port time to calculate the in-port shipping emissions, but does not give details on individual ports, except for Singapore. Although these studies certainly have their merits with regards to calculation of ship emissions in ports, they both suffer from relatively inexact data or assumptions on the time that ships spent in a port. The Entec study uses port time data based on a questionnaire survey of ports; and although the Dalsøren et al. paper is more accurate in that it takes actual time in ports, it cannot be very precise because the dataset measures port time in days and not in hours, let alone minutes.

Ports also increasingly measure emissions in port areas themselves via emission inventories (Table 2), but it is not always easy to separate the effects of shipping, port operations, hinterland transport and industrial development on the port site.

Table 2. **Emission inventories of ports**

Port	Main indicators	Since
Los Angeles	Port-related GHG emissions (electric wharf cranes, building electricity, building natural gas, port employee vehicles, expanded GHG inventory) Diesel particulate matter (DPM), nitrogen oxides (NO_x), SO_x, CO_{2e} emissions by source category: Ocean-going vessels (OGV), harbour craft (HC), cargo-handling equipment (CHE), heavy-duty vehicles (HDV), rail locomotives (RL). Containerised cargo volume trend Port DPM, NO_x, SO_x, CO_{2e} emissions trend	2001
Long Beach	Port-related emissions (PM_{10}, $PM_{2.5}$, DPM, NO_x, SO_x, carbon monoxide (CO), HC) by category: OGV, HC, CHE, RL, HDV. Port-related GHG emissions (CO_{2E}, CO2, N_2O, CH_4) by category: OGV, HC, CHE, RL, HDV.	2002
Seattle	Total airshed emissions (NO_x, VOC, CO, SO_2, PM_{10}, $PM_{2.5}$, DPM, $CO2_e$) by source category: OGV, harbour vessels, RL, CHE, HDV, fleet vehicles	
New York - New Jersey	GHG emissions (CO_2, CH_4, N_2O, HFCs, PFCs, SF_6) by the category "Port Commerce" (commercial marine vessels, CHE, RL, HDV, buildings, landfill, fleet vehicles) Port commerce emission per TEU handled Total Criteria Air Pollutant (CAP) emission (NO_x, NO_2, PM)	2006
Oakland	Particulate Matter (PM, including diesel), NO_x, SO_2, Reactive Organic Gas (RO), and CO emissions by source category: ships, HC, CHE, RL, trucks.	2005
Vancouver	Common Air Contaminants (CACs): NO_x, SO_x, CO, VOCs, PM_{10}, $PM_{2.5}$, NH_3, GHGs – CO_2, CH_4, N_2O by source group (administration, CHE, on road, rail).	2005
Shanghai	Air pollutant emissions (NO_x, SO_2, PM, VOC, CO) of ships (ships of international shipping lines, ships registered at ports and managed by local maritime authorities, ships travelling along the coast, hotelling, internal rivers).	2006
Gothenburg	GHG emissions by: *Direct emissions: operational vessels, operational vehicles, heating buildings (by fuel usage), fire equipment *Energy indirect emissions: electricity usage, direct heating *Other indirect emissions: business flights gallons per annum, business travel by car	2010

	gallons per annum, terminals, vessels at the quay/ traffic area, loading of gasoline, leakage of pipelines, carpool	
Barcelona	Air emissions at Darsena Sud and Port Vell: SO_2, H_2S, NO_2, C_6H_6, PM_{10}.	2004
Hamburg	Direct CO_2 emissions Indirect CO_2 emissions CO_2 emissions by equipment type: straddle carriers, OGVs, container/ rail gantry cranes, reefer containers, storage cranes	2011
Houston	Maritime related emissions (NO_x, VOC, CO, SO_2, PM_{10}, $PM_{2.5}$, CO_2) by source category: OGV, heavy-duty diesel-fuelled vehicles, CHE RL, harbour vessels	2007
Melbourne	CO_2 emissions by activity: commercial vessels, cargo handling & Tenants, rail, road	2011
Helsinki	Nitrogen dioxide concentrations, monthly average Sulphur dioxide concentrations, monthly average Vessel waste waters received by Port of Helsinki Vessel waste waters pumped into sewage systems in Helsinki	2010

Source: Own data collection based on information provided by port authorities.

In addition, there is a considerable amount of case studies of ports and port-cities that calculate the shipping-related emissions on the area. These studies apply a variety of different methodologies and definitions, as can be illustrated by Table 3 below, the outcomes of these studies are difficult to compare with each other (Mueller *et al*. 2011). Main differences in method are between calculations based on fuel consumption and activity based; the last type of studies takes into account the activity of the ship (such as the hours spent cruising, manoeuvring and hotelling), whereas the first approach is looking at fuel accounts of ships to estimate emissions. The focus of the estimations differs with respect to geographical demarcations (only port area, or also territorial waters), with respect to the ships included (only ocean-going vessels, or also port vessels (such as tugs) and inland river vessels), and with respect to other port activities included, such as other transport modes within the port (port trucks and locomotives) and cargo handling equipment, such as cranes and other equipment.

For this paper, we prepared a database with the main findings of these studies, modified in such a way that it allows for comparison. For this purpose, we took only the shipping emissions in ports into account for ocean going vessels at berth in hotelling and manoeuvring mode. We did not include other vessels, nor equipment, nor port trucks and locomotives.

Table 3. **Academic studies on shipping emissions in ports**

Port	Method	Emissions of:	Source
Hong Kong (China)	Activity based (AIS)	OGVs in territorial waters	Yau et al. 2012
Hong Kong (China)	Activity based (AIS)	OGVs in territorial waters	Ng et al. 2013
Shanghai (China)	Activity based	OGV and inland barges	Yang et al. 2007
Yangshan (China)	Activity-based (AIS)	Vessels in port area	Song 2014
Busan (Korea)	Activity based	Vessels in port area	Song & Shon 2014
Busan (Korea)	Activity based	Vessels, equipment, port trucks, trains	Shin & Cheong 2011
Incheon (Korea)	Activity based	Vessels, equipment, port trucks, trains	Han et al. 2011
Kaohsiung (Tapei)	Activity based	Vessels and trucks in port area	Berechman & Tseng 2012
Kaohsiung (Tapei)	Cargo capacity, activity time	Merchant vessels	Liu et al. 2014
Klaipeda (Lithuania)	Activity based (LMIU)	Marine ships	Abrutyte et al. 2014
Taranto (Italy)	Air quality measurement	Shipping, industry and urban traffic	Gariazzo et al. 2007
Ravenna (Italy)	Fuel consumption	Vessels in port area	Lucialli et al. 2007
Venice, Piombino (Italy)	Fuel consumption	Marine ships in port area	Trozzi et al. 1996
Venice (Italy)	Air quality measurement	Vessels in port area	Contini et al. 2011
Brindisi (Italy)		Vessels and port equipment	Donateo et al. 2014
Ambarli (Turkey)	Activity based	Vessels in port area	Deniz & Kilic 2009
Izmir (Turkey)	Activity based	Vessels in port area	Saraçoglu et al. 2013
Barcelona (Spain)	Activity based	Vessels, electricity, heating, cargo handling, vehicles, trucks, waste	Villalba&Gemechu 2011
Piraeus (Greece)	Fuel based & activity based	Vessels in port area	Tzanattos 2010a

Victoria, BC (Canada)	Air quality measurement	Cruise ships	Poplawski et al. 2011
Göteborg (Sweden)	Air quality measurement	Ships entering the inner part of port	Isakson et al. 2001
Copenhagen (Denmark)	Air quality measurement	Vessels in ports	Saxe & Larsen 2004
Mumbai (India)	Activity based	OGVs in port area	Joseph et al. 2009
Aberdeen (UK)	Air quality survey	Ships and trucks in the port area	Marr et al. 2007
13 main Spanish ports	Activity based	Vessels manoeuvring and hotelling	Castells Sanabra et al. 2014
Rotterdam (Netherlands)	Fuel consumption	Ships at berth	Hulskotte & Denier van der Gon, 2010

Source: Own data collection.

The largest part of emissions in ports is generally from shipping activity; this can be concluded from this collection of studies on emissions in ports. Between 70% to 100% of emissions in ports in developed countries can be attributed to shipping; trucks and locomotives represent up one fifth, whereas emissions from equipment rarely exceed 15%. The picture is different for ports in developing countries where regulations on truck fuels are less strict and where a larger share of the total emssions in ports is taken up by trucks and locomotives. E.g. in the port of Mumbai, the NO_x emissions from port trucks are almost 20% higher than those from ships; and PM_{10} emissions from trucks are 26 times higher than from ships (Joseph et al. 2009).

Shipping emissions in ports can represent a substantial share of total emissions in the port-city. Much depends on the size of the port, the size of the city and the character of the city, such as industrialisation rate. In some large port-cities, such as Hong Kong and Los Angeles/Long Beach, the share of SO_2 emissions can reach half of the total emissions in the city; for NO_x and particulate matter emission levels that represent up to a fifth of total urban emission are not rare (Table 4).

Table 4. **Shipping emissions as share of total emissions in port-city**

Port	SO_2	PM	NO_x	Source
Hong Kong	54%	-	33%	Civic Exchange 2009
Shanghai	7%	-	10%	Hong et al. 2013
Los Angeles/Long Beach	45%	-	9%	Starcrest 2011
Rotterdam	-	10-15%	13-25%	Merk 2013
Kaohsiung	4-10%	-	-	Liu et al. 2014
Hong Kong	11%	16%	17%	Yau et al. 2012
Taranto	7%	-	3-17%	Gariazzo et al 2007
Izmir	10%	1%	8%	Saraçoglu et al. 2013
Venice	-	1-8%	-	Contini et al. 2010
Brindisi	-	1%	8%	Di Sabatino et al. 2012
Los Angeles/Long Beach	-	1-9%	-	Agrawal et al. 2009
Melila	-	2-4%	-	Viana et al. 2009
Algeciras	-	3-7%	-	Pandolfi et al. 2011

Source: Own data collection.

The approach in this paper is to provide a comparative overview of shipping emissions in ports. This makes it possible to compare the different emissions in port-cities and go beyond the incidental case studies whose values are difficult to compare to each other. At the same time, it also refines the literature on global shipping emissions in ports by using a more precise dataset on time spent in ports.

3. METHODOLOGY

Several methodologies have been used to estimate emissions from shipping, which can basically be summarized in four models, depending on whether *emission evaluation* is top-down or bottom up, and whether the *geographical characterisation of emissions* is top-down or bottom-up (Miola and Ciuffo, 2011):

- In a full top-down approach, total emissions are calculated without considering the vessel characteristics and are after the calculation geographically located and assigned to the different ships. The first studies on ship emissions took this approach and used international marine fuel usage statistics to estimate ship emissions, but results from this approach were later considered to be unreliable.
- In the second approach, a full bottom up approach, air pollutants emitted by a ship in a specific position are calculated; aggregating these estimates over time and over the fleet gives an estimation of the total emissions. This approach can be considered much more reliable, but the data required for such an approach have only recently come available, so for the moment there is a limited amount of studies using this approach. As a result, a considerable amount of studies take approaches that are more hybrid.
- There is a model that is bottom up in the evaluations of total emissions and top down in their geographical characterisation. In this approach, the aggregation of the emissions produced by all the ships gives an estimate of the total emissions; the emissions are then geographically characterised based on assumptions, e.g. ship activities or single geographic cells. A fairly recent approach is to use Automatic Identification System (AIS) data to refine the maritime data.
- The fourth approach is top down in the evaluation of total emissions plus bottom up in the geographic characterisation. In this approach the global activity carried out within a single maritime route or a single geographic cell is evaluated. Emissions from individual cells are aggregated to calculate total emissions and assumptions are made in order to assign total emissions to the different ships.

Our approach here is to use a bottom up-approach with respect to both ship characteristics (horsepower of the engines) and geographical characterisation, that is: the actual time spent in ports (in hours and minutes) by vessels. Following Joseph et al. (2009), the following equation is used to estimate shipping-related emissions at ports:

$$E = P*LF*EF*T$$

Where:

E	emissions in units of pollutant
P	maximum power output of auxiliary engine in kW
LF	load factor for auxiliary engines, as a fraction of maximum installed power capacity
EF	emission factor (pollutant specific) in mass emitted per work output of the auxiliary engine in manoeuvring and hotelling mode, g/kWh and
T	time in manoeuvring and hotelling mode in hours

The principle behind this equation is to apply emission factors to activity rates, as generally the case when estimating emissions. The activity rate of the individual vessels in our database is estimated using rules of thumb indicated and explained below. Ships use auxiliary power whilst being at berth. The maximum power of auxiliary engines in a vessel is estimated based on auxiliary engine power ratios and an estimation of a vessel's main engine horsepower as a function of dead weight tonnage.

We have made calculations for four different ship categories:

- Container ships (fully cellular containerships).
- Tankers (including crude oil tankers, chemical tankers, combined tankers and product tankers).
- Bulk carriers.
- Roll on/Roll off- (Ro/Ro)-ships.

These ship types include the large majority of commercial vessels used to transport freight. We did not include general cargo ships. We only concentrate on cargo, so did not include passenger ships either.

The auxiliary to main engine power ratio is assumed to be:

- 0.220 for container vessels;
- 0.211 for tankers;
- 0.222 for bulk carriers;
- 0.191 for Ro/Ro-ships.

The estimation of main engine horsepower for different vessels is assumed to follow the equations based on EPA (2000):

- (0.80*dwt -/- 749.4) for container vessels;
- (0.1083*dwt + 6579) for tankers;
- (0.0985*dwt + 6726) for bulk carriers;
- (0.288*dwt + 3046) for Ro/Ro-ships.

The total deadweight tonnage of each vessel in the database is known. The load factor for auxiliary engines in manoeuvring and hotelling modes is based on Starcrest (2004) and Starcrest (2007) and considered to be:

- 18% for container vessels;
- 26% for tankers;
- 10% for bulk carriers;
- 26% for RoRo-ships

The emission factors for auxiliary engines during transit, manoeuvring and hotelling1 depend on the type of fuel used (CARB, 2008):

Table 5. **Auxiliary Engine Emission Factors** (g/kW-hr)

Fuel	**CH_4**	**CO**	**CO_2**	**NO_x**	**PM_{10}**	**$PM_{2.5}$**	**SO_x**
Marine Distillate (0.1% S)	0.09	1.10	690	13.9	0.25	0.35	0.40
Marine Distillate (0.5% S)	0.09	1.10	690	13.9	0.38	0.35	2.10
Heavy Fuel Oil	0.09	1.10	722	14.7	1.50	1.46	11.10

Source: California Air Resources Board (2008)

The values that have been calculated in this way have been corrected for the effects of policies to mitigate air emissions of shipping in ports, in particular: i) shore power facilities in ports; ii) emission control areas (ECAs) and iii) other fuel switch programmes (either mandatory or voluntary).

i) Shore power facilities

Shore power facilities in ports allow ships to shut off their auxiliary engine and use the power of the grid in the port. Ships that use shore power minimize their emissions – and are considered to be negligible during their stay in the port. We have collected information on the availability of shore power facilities for different ship types in world ports. On the basis of this dataset, we have corrected our calculations for the different ship categories in these ports: containerships, Ro/Ro-ships, tankers and bulk carriers. Whereas shore power facilities are relatively frequently available in container terminals and Ro/Ro-terminals, this is not the case for tankers and bulk carriers. The port of Long Beach is the only port that provides shore power facilities for tankers.[2]

The shore power facilities are not available in all of the container- and Ro/Ro-terminals in the ports below, so the correction of the calculated emission should only apply for the traffic share that these terminals in the total container and Ro/Ro-traffic of the port. Moreover, not all ships are equipped to be connected to shore power facilities, so we have made corrections based on assumptions on how often these facilities are actually used. The estimations of traffic shares of the terminals and of assumed actual use of the shore power facilities are coming from the respective port authorities that we have asked to provide us with this information.

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1 The character of the dataset is such that for the vast majority of ports the time in port denotes the arrival at or departure from the port jurisdiction. For the top 10 ports in terms of port calls there is a complexity to size and variation vessels using that port, so the times denote arrival at, or sailing from berth. For these largest ports an estimation has been made for the emissions from manoeuvring, based on a literature study on the shares of hotelling and manoeuvring in the shipping emission in ports. In most studies it is observed that hotelling presents 70-80% of the ship emissions in the largest world ports such as Hong Kong, Shanghai and Kaohsiung (Song, 2014; Yau *et al*. 2012; Liu *et al*. 2014). For the ten ports with the largest number of calls it is thus assumed that manoeuvring emissions represent 25% of the gross emissions from hotelling (Gross emissions meaning here emissions without taking into account shore power facilities).

2 Shore power facilities for other ship categories such as cruise ships, ferries and river ships are not included in this table

Table 6. **Shore power facilities in ports in 2011**

Port	Country	Ship type	Traffic share of terminal(s) with shore power	Frequency of use shore power facilities
Antwerp	Belgium	Containers	n.a.	0%
Prince Rupert	Canada	Containers	-	(25%)
Shanghai	China	Containers	-	(25%)
Shekou	China	Containers	-	(25%)
Long Beach	USA	Containers	100%	50%
Los Angeles	USA	Containers	-	(25%)
Oakland	USA	Containers	100%	38%
Zeebrugge	Belgium	RoRo	28%	45%
Luebeck	Germany	RoRo	n.a.	11%
Kemi	Finland	RoRo	100%	55%
Osaka	Japan	RoRo	-	(25%)
Gothenburg	Sweden	RoRo	100%	40%
Trelleborg	Sweden	RoRo	34%	0%
Tacoma	USA	RoRo	8%	100%
Long Beach	RoRo	Tankers	-	0%

Source: own data collection based on information provided by the port authorities

Note: The Port of Long Beach does not track data on shore power visits, but under the shore power regulation, fleets must plug in 50% of their visits. The estimation of usage of container terminals at the port of Oakland are based on statistics from January-July 2014. The percentages between brackets are assumptions, as the ports in question never responded to our inquiry.

ii) Emission control areas

The picture is further complicated by emission control areas (ECAs). These ECAs are sea areas in which stricter controls are established to minimize airborne emissions from ships as defined by Annex VI of the 1997 MARPOL Protocol which came into effect in May 2005.[3] This Annex VI contains provisions for emission and fuel quality requirements regarding SO_x, PM and NO_x, a global requirement and more stringent controls in the emission control areas. There are currently four ECAs: one for the Baltic Sea, for the North Sea, the North American ECA covering most of the US and Canadian coast and the US Caribbean ECA, including Puerto Rico and the US Virgin Islands. In 2011, the year of the dataset on which the analysis is based, only the Baltic Sea ECA and the North Sea ECA were in effect (Table 7); the other two ECAs have by now entered into force which will be of relevance for the projections of shipping emissions in ports. The SO_x and particulate matter emissions allowed inside and outside ECAs are indicated in Table 8. Although there is speculation about new ECA's, we have not included these in our projections. From 1st January 2016 more stringent NO_x regulations will be in force in the North American and US Caribbean ECAs: all new-built vessels from that date operating in these ECAs should have Tier III engines, which have much lower maximum NO_x emissions (3.4 g/kWh at lowest speed). In our long-term projections, we have taken this into account, assuming that the whole fleet in these ECAs will have been renewed by 2050, so that the relevant NO_x emission factor for these ports in 2050 is 3.4 g/kWh in hotelling mode.

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[3] A more stringent Annex VI was enforced with significantly tightened emission limits

Table 7. **Emission control areas in force**

Emission control area	Limited compounds	Adopted	In effect from
Baltic Sea	SO_x	26/09/1997	19/05/2006
North Sea	SO_x	22/07/2005	22/11/2007
North American	SO_x, NO_x, PM	26/03/2010	01/08/2012
US Caribbean Sea	SO_x, NO_x, PM	26/07/2011	01/01/2014

Source: www.imo.org

Table 8. **Allowed sulphur emissions inside and outside ECAs**

Outside an ECA	Inside an ECA
4.50% prior to 1st January 2012	1.50% prior to 1st July 2010
3.50% between 1st January 2012 and 2020	1.00% between 1st July 2010 and 1st January 2015
0.50% from 1st January 2020	0.10% from 1st January 2015

Source: www.imo.org

iii) Other fuel switch programmes

An additional third element to take into account is the existence of other mandatory or voluntary fuel switch programmes. An important regulation in that respect is the EU Sulphur Directive that prescribes that ships at berth in EU ports need to use fuels with a maximum of 0.1% sulphur content, which is in place since January 2010. We take this into account in our analysis by applying the emission factors related to Marine Distillate 0.1% S for all EU ports in our analysis, assuming that the regulation is fully applied. Another piece of regulation covers the State of California. Its legislation requires the use of low sulphur fuel within 24 nautical miles of the California coast; the rules applied in 2011 stipulated the use of Marine gas oil (DMA) at or below 1.5% sulphur, or Marine diesel oil (DMB) at or below 0.5% sulphur (CARB, 2011). The maximum allowed sulphur content has since been reduced to 0.1%.

Voluntary fuel switch programmes are applied in various ports and provide incentives to shipping lines to use low sulphur fuel (Table 9). These incentives are either in the form of compensations to shipping lines for the additional fuel costs due to their fuel switches, or lower port dues and tariffs. Both the programmes in Seattle and Houston give reimbursements to shipping lines based on the volume of low-sulphur fuel burned during each port call. In contrast, the Green Port Programme in Singapore gives a 15% reduction of port dues for vessels that switch to clean fuel (or use approved scrubbers or other abatement measures). These programmes usually take the form of collaboration between the port administration and one or more shipping lines. E.g. the programme in Houston is exclusively with the shipping line CMA*CGM, whereas the Fair Winds Charter in Hong Kong was with the main 17 shipping lines calling the port. A brief questionnaire was sent to the relevant port authorities; the answers to this questionnaire were used to identify the extent of coverage of these programmes (the share of ships of total ships that actually used low-sulphur fuel when they were in the port). These data were taken into account when calculating the shipping emissions in these ports.

Table 9. **Voluntary Fuel switch programmes in ports in 2011**

Port	**Country**	**Programme**	**Max. sulphur level:**	**Coverage**
Hong Kong	China	Fair Winds Charter	0.5%	19%
Seattle	US	ABC Fuels	0.5%	73%[4]
Vancouver	Canada	EcoAction Program	0.5%	18%[5]
Singapore	Singapore	Green Port Program	1%	0.4%
New York/New Jersey	US	OGV Low sulphur program	0.2%	(10%)
Houston	US	DERA Fuel Switch Program	0.2%	(10%)

Source: own data collection based on information provided by the port authorities. Numbers for Singapore cover 2012. The percentages between brackets are assumptions, as the ports in question never responded to our inquiry.

Other green port policies have not been taken into account, because they do not have an impact on air emissions in the port. E.g. there was no need to correct for the Vessel Reduction Programme operational in the Port of Long Beach; even if reduced speed decreases air emissions within the 20 nautical miles where the programme applies, it is not relevant to the air emissions of ships at berth. There was no need either to correct for differentiated port dues based on schemes such as the environmental ship index (ESI), that scores ships according to their environmental performance. The first reason is that almost all ports that participated in the programme in 2011 were European ports (where the EU Sulphur directorate applied); the second reason is that the share of ships with an ESI certification is marginal in comparison with the global ship fleet.

4. DATASET

The data used are vessel movements of ships world-wide, as collected by Lloyd’s Maritime Intelligence Unit (LMIU) The dataset includes data per ship, their characteristics, their arrival and departure time in a port, and their next port of call. On the basis of these raw data, we constructed a database with ship turnaround time per ship per port, which can be aggregated in ship turnaround times per port. The main ship categories included in the database are: container ships, Ro/Ro-ships, tankers and bulk carriers. The database covers exclusively ocean-going vessels, so river barges, which make up a significant part of ship calls in some ports, are excluded from this analysis. The dataset has a very high coverage of the world fleet: close to all vessels in the world are covered by the Lloyd’s database.

For budgetary reasons we used a database that covers only May 2011. This month is considered to be a representative month by Lloyd’s Maritime Intelligence Unit. Our own observations confirm this. We constructed a database with monthly port volumes of a

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[4] This percentage represents the share of total vessels in 2011 that used distillate fuels with a maximum sulphur content of 0.5% for all hotelling auxiliary engine operations.

[5] This percentage represents the share of total vessels in 2011 that used distillate fuels with a maximum sulphur content of 0.5% for all hotelling auxiliary engine operations

selection of world ports, which shows that the month of May is in most ports and in most years a month that is has neither consistently lower nor higher volumes than the other months.

Of the total port calls of 20 771 vessels (larger than 100 gt) a small number of observations were excluded because of missing arrival and departure data and some observations are excluded because they were considered to be extreme values that would skew the results; these are the vessel calls with a stay in one port of more than 10 days. What resulted was a database with 100 693 port calls (in 874 ports), of which 93% have precise arrival and departure time in hours and minutes.

For a large majority of ship calls, the precise turnaround time in the port is known. In some cases less precise measurements (ship turnaround time in days, not in hours and minutes) was the only available information. For these missing values, it is assumed that the port time for vessels arriving and leaving the same day is 12 hours, leaving the next day is equivalent to 36 hours, with a port stay of two days equivalent to 50 hours etc. This was necessary for some ports with only a very limited set of precise time observations was available, so taking exclusively these and extrapolate these would risk to be inaccurate.

5. RESULTS

5.1 Shipping emissions in ports in 2011

Shipping emissions in ports are substantial and accounted for 18 million tonnes of CO_2 emissions, 0.4 million tonnes of NO_X emissions, 0.2 million of SO_x emissions and 0.03 million tonnes of PM_{10}-emisions in 2011, as well as various other emissions (Table 1). These shipping emissions in ports present on average approximately 2% of the total shipping emissions, for the different emission types, as calculated in various studies referenced in the Literature Review (section 2). This share is lower than the one found by Dalsøren *et al*. (2008) who estimated that emissions due to ships' activities around or in ports account for five per cent of total emissions from shipping. This might be explained by the fact that our study does not take shipping emissions from ships other than ocean-going vessels into account, such as inland barges.

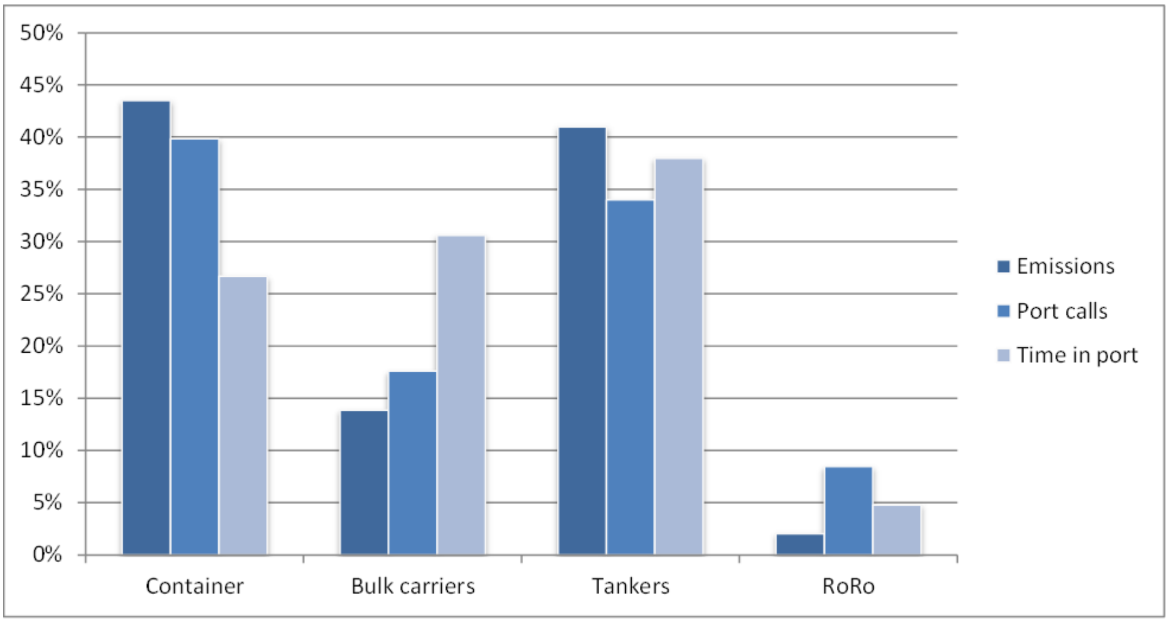
Table 10. **Estimated shipping emissions in ports (2011)**

	Shipping emissions in ports (mln tonnes)
CO_2	18.3
NO_x	0.4
SO_x	0.2
PM_{10}	0.03
$PM_{2.5}$	0.03
CO	0.03
CH_4	0.002

Source: Author's calculations and elaborations, based on data from Lloyds Marine Intelligence Unit

Around 85% of these emissions come from containerships and tankers. This is partly explained by their dominant presence in terms of port calls, around three quarters of all calls. Both containerships and tankers have more emissions than could be expected based on the number of port calls. For tankers this can be explained by their relatively long turnaround time in ports. However, this is not the case for containerships: their time in port is approximately 27% of the port time of vessels, whereas these represent 40% of the calls. So containerships have relatively short stays in ports, but have relatively high emissions during these stays. The inverse is the case for bulk carriers: they have long turnaround times, but have relatively fewer emissions during their stays in ports. Also Roll-on/roll-off (Ro/Ro) -ships are relatively clean: representing 8% of port calls and 5% of port time, they only represent 2% of the total shipping emissions in ports (Figure 1).

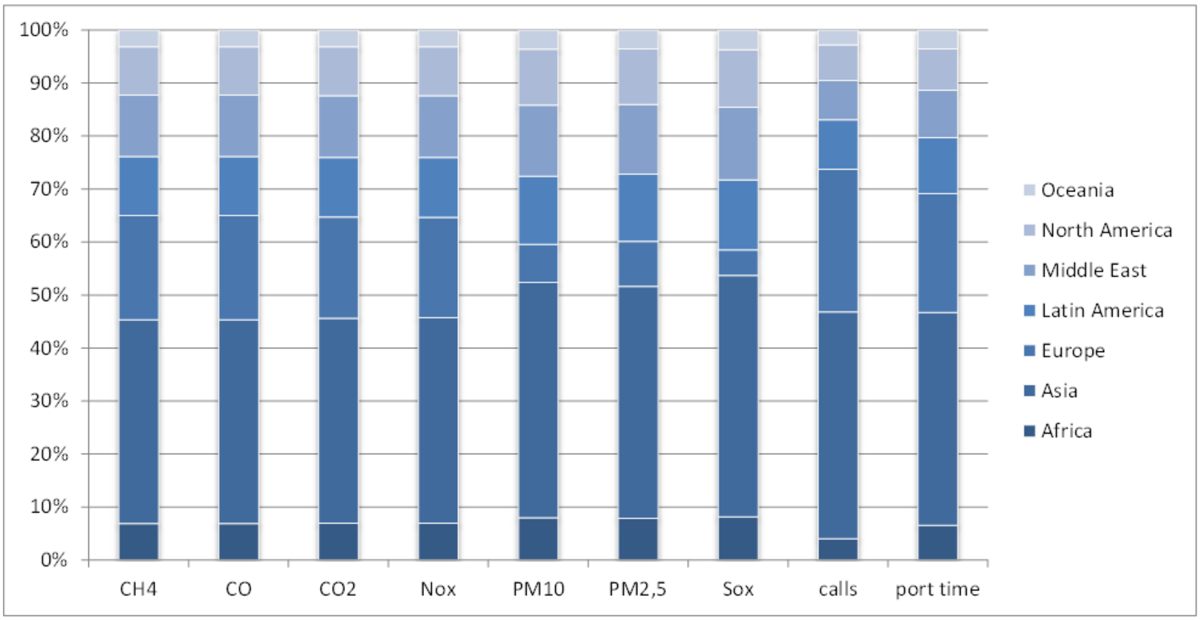
Figure 1. **Ship types and their shares in emissions, port calls and port time** (2011)



Source: Author's calculations and elaborations, based on data from Lloyds Marine Intelligence Unit

Most of the shipping emissions in ports are concentrated in Asia and Europe, e.g. 58% of the CO2-emissions. This is logical if one considers that most of world's port activity is taking place there: Asia and Europe represent 70% of total port calls. Both Asia and Europe have relatively time efficient ports, considering that their calculated time in a port is only 62%, considerably less than their share of port calls. Moreover, European ports have much less emissions of SOx (5% of world total), PM10 (7%) and PM2,5 (8%) than their share of port calls (22%) would suggest, which can be explained by the EU regulation to use low sulphur fuels at berth. Also its share of CO2-emissions (19%) is relatively low, due to port air emissions policies, such as shore power facilities and incentives for fuel switching. Ports with high emissions relative to their port traffic can be found in Africa, the Middle East, Latin America, and – to a slightly lesser extent – in North America (Figure 2).

Figure 2. **Shipping emissions, port calls and port time per continent** (2011)



Source: Author's calculations and elaborations, based on data from Lloyds Marine Intelligence Unit

The ports with the largest absolute emission levels due to shipping are Singapore, Hong Kong (China), Tianjin (China) and Port Klang (Malaysia). In all emission categories the port of Singapore shows highest emission levels, for the other ports their position is different with respect to the different emission categories. The top 10 port rankings for CO2 emissions are similar to those of NOx; and the rankings of SOx and PM are similar as well. This correlation also applies to the whole dataset: there is complete correlation (R2 is 1) between CO2 and NOx shipping emissions per ports, as well as for PM and SOx (R2 of 0.9 for the other relationships). The emission levels per port have been compared with the corrected emissions as calculated in the various studies referenced in the literature review (section); depending on the emission types, the results show high to very high correlations[6]. The list of ports with largest emissions is not very surprising: most of these ports belong to the largest ports in the world with the highest shipping activity. The difference between the rankings with respect to CO2 emissions and SOx emissions could be explained by policy, in particular the EU directive on low sulphur fuel.

The ten ports with largest emissions represent almost a fifth of the total shipping emissions in ports: 19% for CO2 emissions and 22% for SOx emissions. This illustrates the highly skewed nature of shipping emissions in ports. In line with this: the 50 ports with largest emissions have 37% of the CO2 and 44% of the total SOx emissions related to shipping.

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[6] R^2 scores of 0.5 up to 0.9 depending on the emission types.

Table 11. **Ports with the largest absolute emissions**

Top 10 ports (CO_2 emissions)	**Share of total**	**Top 10 ports (SO_x emissions)**	**Share of total**
1. Singapore	5.9%	1. Singapore	6.5%
2. Hong Kong	2.2%	2. Hong Kong	2.3%
3. Rotterdam	2.0%	3. Port Klang	2.2%
4. Port Klang	1.9%	4. Tianjin	2.1%
5. Tianjin	1.8%	5. Shanghai	2.0%
6. Shanghai	1.7%	6. Fujairah	2.0%
7. Fujairah	1.7%	7. Busan	1.7%
8. Busan	1.4%	8. Kaohsiung	1.6%
9. Kaohsiung	1.4%	9. Ulsan	1.0%
10. Antwerp	1.2%	10. Beilun	0.9%
Total Top 10	**19.0%**	**Total Top 10**	**22.3%**

Source: Author’s calculations and elaborations, based on data from Lloyds Marine Intelligence Unit

The ports with the lowest relative emissions come from Japan, Greece, UK, US and Sweden. These are the shipping emissions per ship call in each port. The port with the lowest relative CO2 emissions is Kitakyushu (Japan); the port of Kyllini (Greece) has the lowest SOx emissions. As with the absolute rankings, the rankings with respect to CO2 and NOx are similar, as well as the ones for PM and SOx. The ranking is dominated by ports specialised in Ro/Ro-traffic, with Ro/Ro-vessels having relatively low emission levels compared to other ship types. The difference between the rankings with respect to CO2 emissions and SOx emissions could be explained by the EU directive on low sulphur fuel at berth.

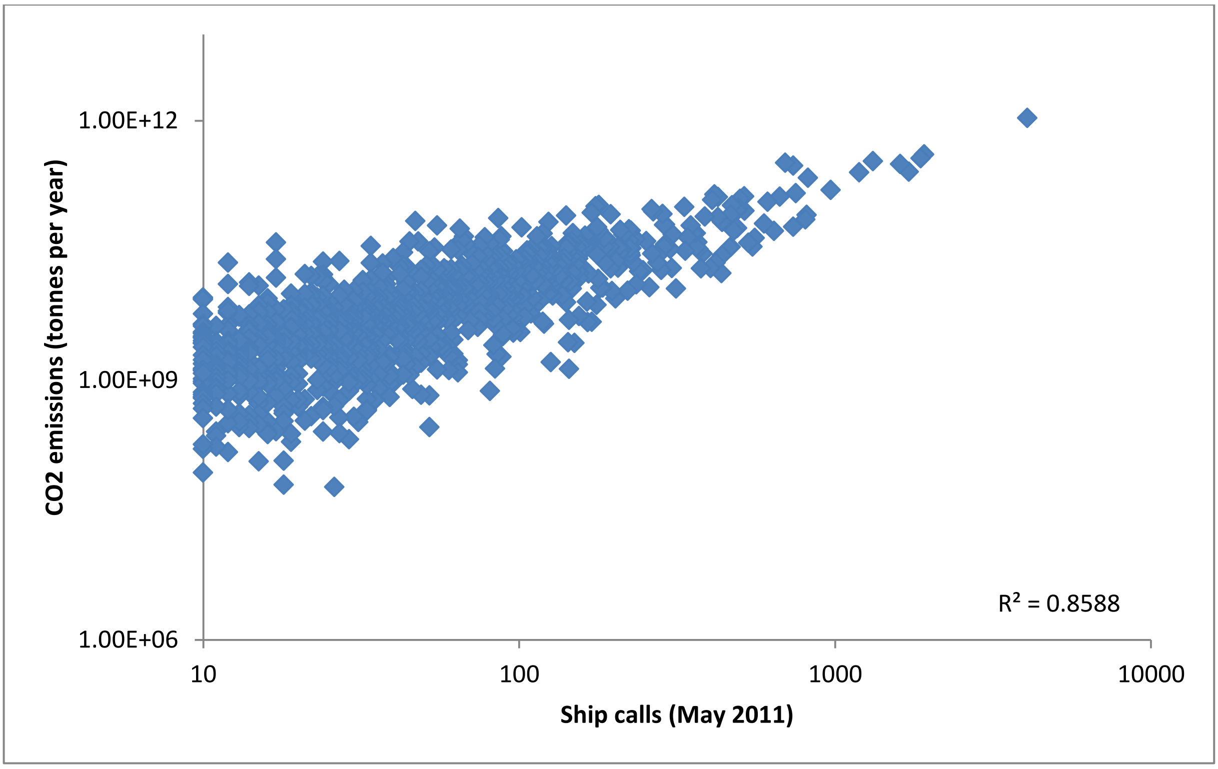
Table 12. Ports with the lowest relative emissions

Ports with lowest CO_2 emissions per ship call	**Country**	**Port with lowest SO_x emissions per ship call**	**Country**
1. Kitakyushu	Japan	1. Kyllini	Greece
2. Imabari	Japan	2. Guernsey	United Kingdom
3. Kyllini	Greece	3. Sundsvall	Sweden
4. Guernsey	United Kingdom	4. Troon	United Kingdom
5. Annapolis	USA	5. Trelleborg	Sweden
6. Grand Cayman	Cayman Islands	6. Heysham	United Kingdom
7. Sundsvall	Sweden	7. Marstal	Denmark
8. Troon	United Kingdom	8. Jersey	United Kingdom
9. Trelleborg	Sweden	9. Gourock	United Kingdom
10. Heysham	United Kingdom	10. Naxos	Greece

Source: Author’s calculations and elaborations, based on data from Lloyds Marine Intelligence Unit

The absolute levels of shipping emissions in ports can to a large extent be explained by port activity: the ports with more ship calls generally have higher levels of shipping emissions. This is particularly the case for CO2 (Figure 3) and NOx, with a correlation R2 of 0.86 for both emissions. This correlation is lower for SOx emissions (Figure 4); policies aimed at reducing these emissions in the port have to some extent managed to ‘decouple’ emissions from port activity. This can also be illustrated by the differences in size distribution of the different shipping emissions: whereas CO2 emissions to some extent correspond to the size-rule distribution (Figure 5), this is much less the case for SOx emissions (Figure 6).

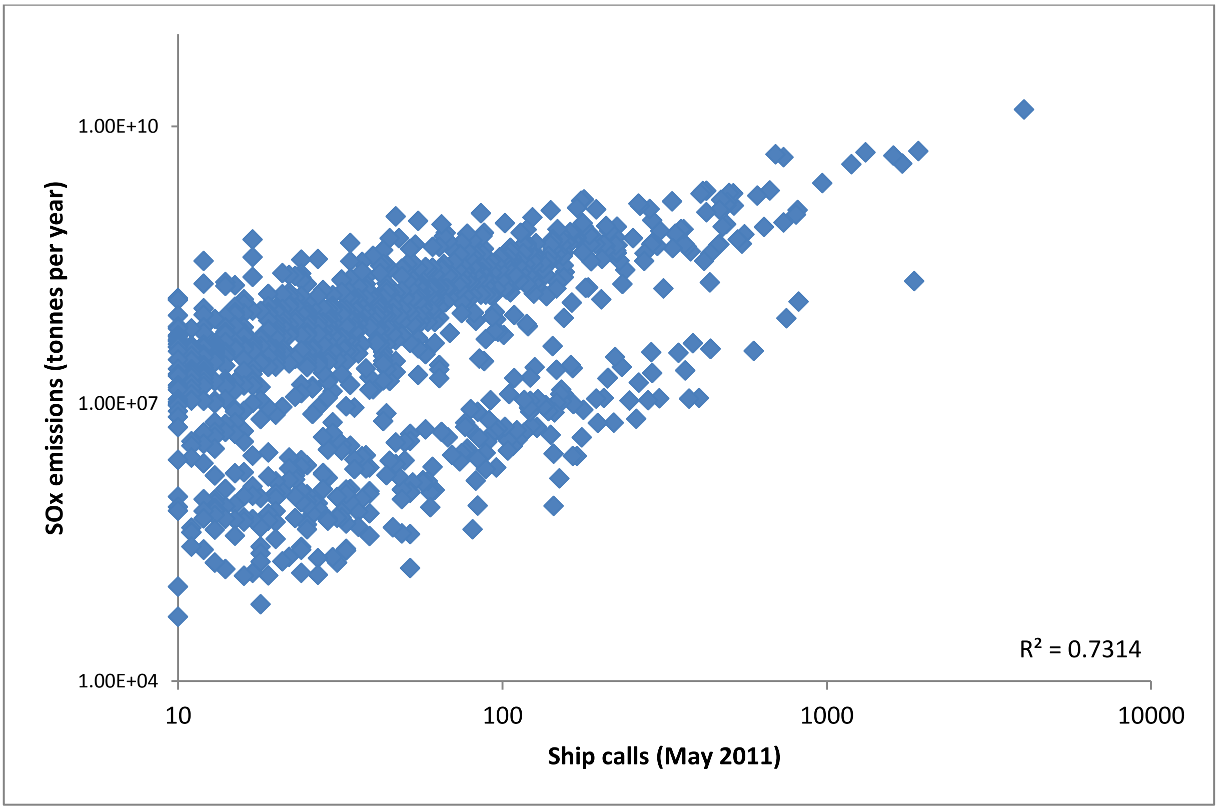
Figure 3. **Distribution of CO2 emissions and ship calls**



Source: Author's calculations and elaborations, based on data from Lloyds Marine Intelligence Unit

Note: The dots in the figure represent ports.

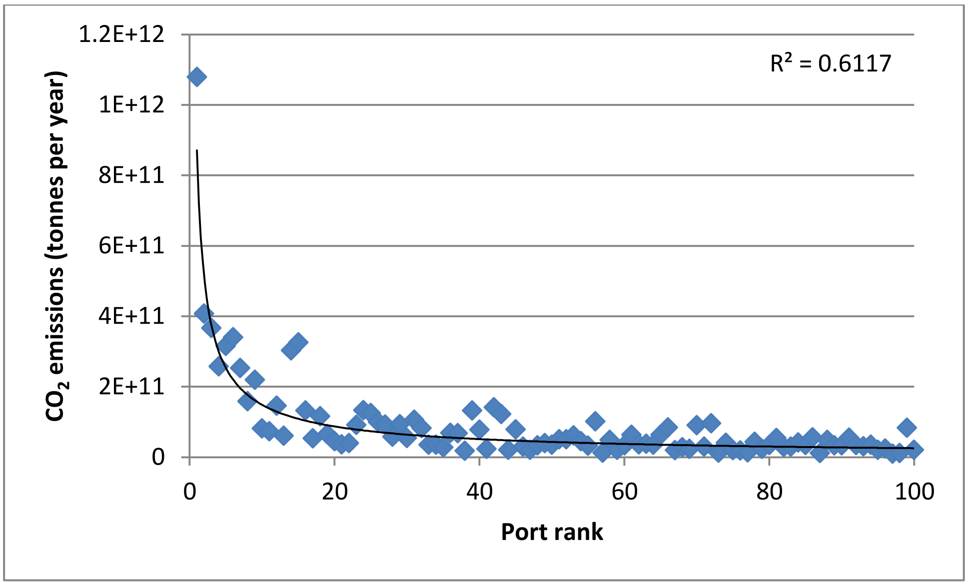
Figure 4. **Distribution of SOx emissions and ship calls**



Source: Author's calculations and elaborations, based on data from Lloyds Marine Intelligence Unit

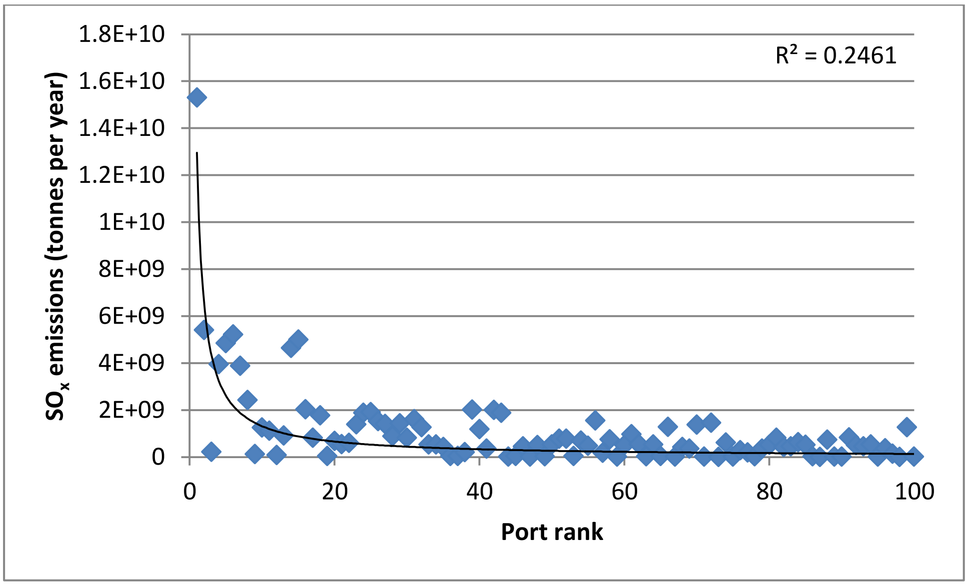
Note: The dots in the figure represent ports.

Figure 5. **Size distribution of CO2 emissions in 100 most active ports**



Source: Author's calculations and elaborations, based on data from Lloyds Marine Intelligence Unit

Figure 6. **Size distribution of SOx emissions in 100 most active ports**



Source: Author’s calculations and elaborations, based on data from Lloyds Marine Intelligence Unit

Shipping emissions in ports have large impacts on the population of their cities: approximately 230 million people are directly exposed to the emissions in the top 100 world ports in terms of shipping emissions. Around 40 million people are directly exposed to the ten ports with the largest SOx emissions, which concentrate 22% of the total shipping-related SOx emissions in ports.

Shipping emissions have considerable external costs in ports: almost EUR 12 billion per year in the 50 largest ports in the OECD for NOx, SOx and PM emissions (Figure 7), based on conservative assumptions. Our calculations follow the approaches in various studies to calculate the external costs of shipping emissions in specific port-cities (McArthur and Osland, 2013; Castells Sanabra et al. 2014). In these studies, like in our calculation, local impact calculation factors are used for a standard city with a population of 100,000 people that are scaled linearly to the respective populations, in our case to the cities or towns with the 50 largest OECD ports. The impact calculation factors used are EUR 33,000 of external costs per ton of PM2,5 emitted, EUR 6,000 for SO2 and EUR 4,200 for NOx, based on Holland and Watkiss (2002). Our calculations are conservative, because these calculation factors are on the lower bound of the factors applied in other studies, such as Holland et al. 2005.[7]

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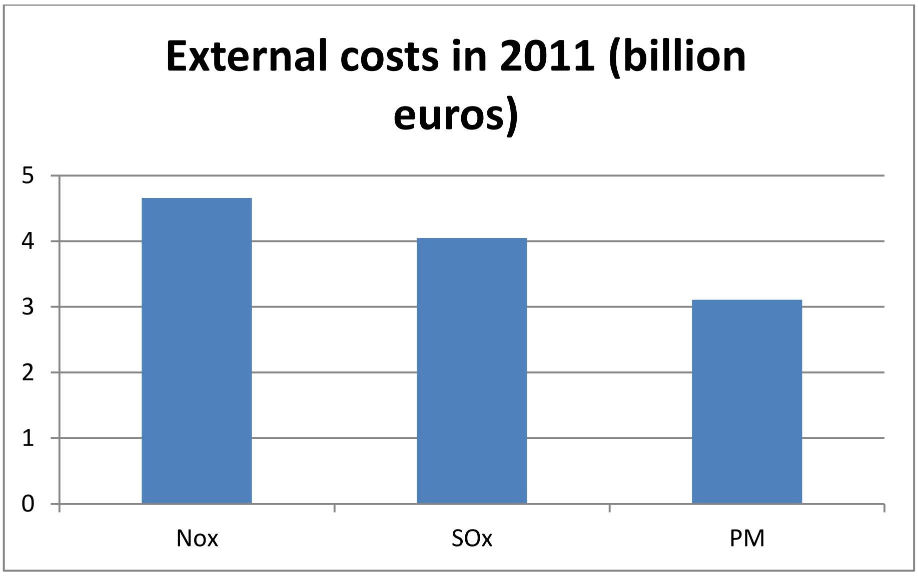
[7] Moreover, in our calculations the external costs were not adjusted for inflation.

Figure 7. **External costs of shipping emissions in top 50 OECD ports**

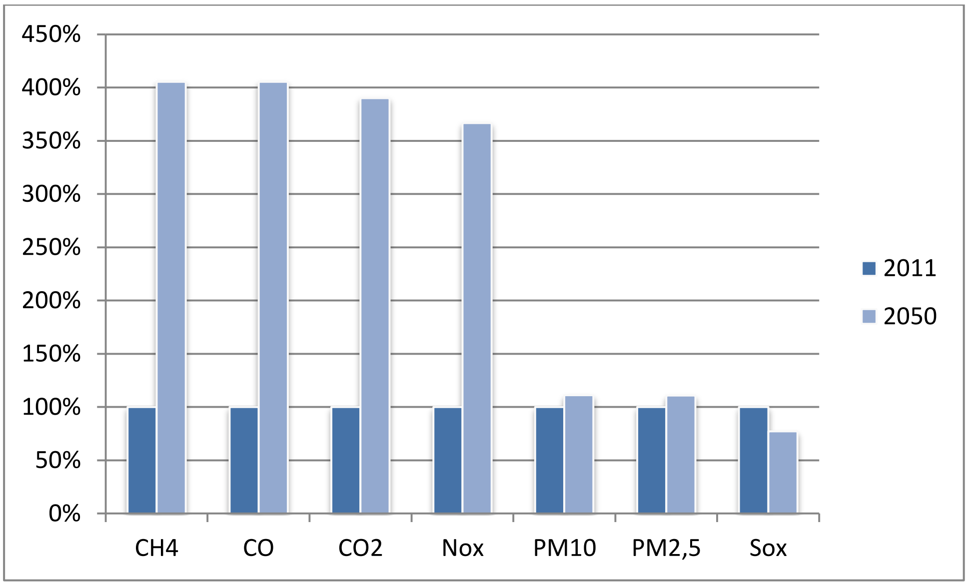


Source: Author's calculations and elaborations, based on data from Lloyds Marine Intelligence Unit

5.2 Estimated shipping emissions in ports in 2050

Most shipping emissions in ports will grow fourfold up to 2050. This is the case for CH_4, CO, CO_2 and NO_x-emissions. This would bring CO_2-emissions from ships in ports to approximately 70 million tonnes in 2050 and NO_x-emissions up to 1.3 million tonnes. The level of PM_{10} and $PM_{2,5}$-emissions from ships in ports remains at the level of 2011 emissions and SO_x emissions decline slightly compared to the 2011 level (Figure 8). The growth in most shipping emissions is driven by growing demand for certain commodities and goods fuelled by growth of population, economy and trade. The projections are based on the ITF freight model that predicts the flows of 18 different cargo types between 226 places in 84 different countries. These growth rates for cargo types have been translated into growth projections of port calls of the corresponding ship types in each country. In this calculation we assume that ship turnaround times remain at a similar level and that all international obligations that have an impact on ship emissions will be implemented in the timelines currently foreseen, e.g. the reduction of the maximum allowed sulphur content in fuels to 0.5% by 2020, and to 0.1% by 2015 in emission control areas.

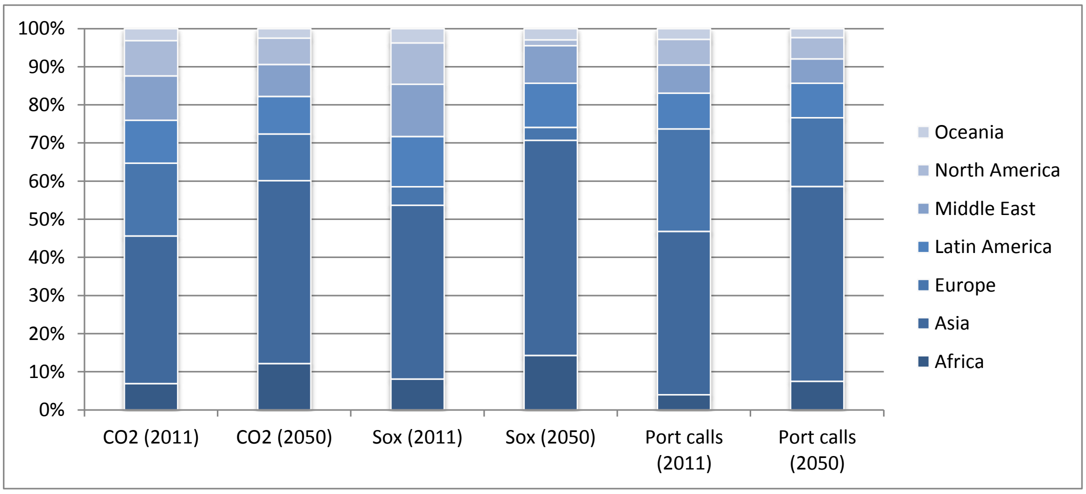
Figure 8. **Increase in shipping emissions in ports 2011-2050**



Source: Author's calculations and elaborations, based on data from Lloyds Marine Intelligence Unit

Asia and Africa will be subject the sharpest increases in emissions, due to their projected strong port traffic growth to 2050 and the lack of regional mitigation measures (such as ECAs). Asian port traffic is projected to reach half of the global total in 2050, which corresponds to the share of projected shipping emissions in Asian ports. European and North American ports show relative declines of emissions, due to relatively slower traffic growth and to stricter regulatory measures, such as emission control areas. For example, due to the emission control areas and the 0.1% maximally allowed sulphur content in these areas from 2015, SO_x-emissions in European and North European ports are projected to be 5% of the total SO_x-emissions in ports, whereas their total port traffic would account for 24% in 2050 (Figure 9).

Figure 9. **Shares of emissions and port calls, 2011 and 2050**



Source: Author's calculations and elaborations, based on data from Lloyds Marine Intelligence Unit

6. POLICY IMPLICATIONS

In order to reduce these projected emissions, strong abatement measures will be needed. These could be classified in four different categories (DNV, 2010):

i) *Alternative fuels or power sources.* Alternative fuels include gas-fuelled engines (such as LNG and LPG) and biofuels. Alternative energy sources to power ships could be solar power, wind and nuclear energy.

ii) *Operational measures.* These measures cover operation of the ship itself (hull condition, propeller condition, trim/draft optimisation) and routing measures, such as voyage execution and weather routing (avoiding navigation in areas with bad weather conditions).

iii) *Technical measures.* These cover the machinery (main and auxiliary engines) and measures under water (propeller and hull).

iv) *Structural changes.* These changes include port efficiency, vessel speed reduction (through fleet increase) and cold ironing (using shore power while at berth).

These four different categories of abatement measures determine to a large extent the room for policy responses. Significant progress in terms of global policy-making has been made with respect to operational and technical measures. The IMO amended the MARPOL Annex VI in 2011, adding a new chapter on “Regulations on Energy Efficiency for Ships”. It includes two measures that came into force in early 2013 and apply to all vessels over 400 GT (gross tonnage): the Energy Efficiency Design Index (EEDI) for all new ship constructions, and the Ship Energy Efficiency Management Plan (SEEMP) for existing ships. The EEDI phases in progressively stringent criteria into the building standards for different types and sizes of ships. Energy efficiency levels are measured in CO_2 emissions per capacity mile, and are designed to bear upon all production components of a given ship. The SEEMP constitutes a mechanism for benchmarking and improving operable ships, mainly through the Energy Efficiency Operator Indicator (EEOI) instrument. Under the SEEMP, owners and operators are periodically brought to review and upgrade their energy performance, focusing on such measures as engine tuning and monitoring, propeller upgrades, trim/draft improvement and enhanced hull coating.

An IMO-commissioned study has claimed that, under high uptake scenarios (30%), the EEDI and SEEMP should reduce global emissions below the status quo scenario by an average of 330 million tonnes (40%) annually by 2030, and increase savings in the shipping industry by USD 310 billion annually (Lloyd’s Register and DNV, 2011). Nevertheless, the model suggests that MARPOL measures will not be sufficient to bring about an overall reduction in emissions relative to 2010 levels. In each of the uptake scenarios tested, projected growth in trade will overwhelm any emissions reductions achieved through the EEDI and SEEMP, even if the upward trend will be reduced compared to status quo scenarios. As becomes clear from our calculation, the projected increase of air emissions from shipping is particularly high for CO_2, CO, CH_4 and NO_x.

Consensus on global market-based mechanisms – deemed necessary to reduce emissions to levels low enough to impact the pace of climate change – has been elusive within the IMO. Shipping could be included in global emissions trading schemes and climate finance schemes. At least 10 different market-based measures (MBMs) for GHG emissions reductions have been submitted by member-states to the IMO. However, for the moment, opinion has been highly divided within the IMO about the legitimate use of MBMs to bring down GHG emissions from shipping. Part of the difficulty encountered within the IMO discussions has been that any global GHG reduction plan established by the IMO might engage nations who currently have no GHG reduction targets under the Kyoto Protocol to accept these for the fleet of vessels under their registry. This, many nations fear, might establish an unwelcome precedent for the overall climate change negotiations being held under the auspices of the UNFCCC and in which the principle of "common but differentiated responsibilities" has been accepted (Crist, 2009). Nevertheless, some sort of compromise should be found, possibly by designing a system in which IMO principles can be upheld, while providing some compensatory measures and development support for some of the developing nations that are large flag states.

The levels of SO_x and particulate matter are not expected to increase up to 2050, due to regulations that will come in force in the coming years. These measures should evidently be implemented and the implementation should be controlled, so that the emission reductions will take place. Substantial decreases of SO_x and PM would be possible by extending the boundaries of existing ECAs and by introducing new ECAs. Extension of boundaries of existing ECAs could be considered in cases where certain ports outside ECAs could attract more traffic because of their cost advantage for shipping lines (e.g. in the case of Liverpool compared to other UK ports). New ECAs have been discussed for the Pearl River Delta (Merk and Li, 2013) and the Mediterranean Sea.

A lot could also be gained by policy initiatives of ports themselves. Various ports have developed infrastructure, regulation and incentives that mitigate shipping emissions in ports. Many of these instruments could be considered the fourth category of abatement measure indicated above: structural measures. An example of infrastructure that reduces ship emissions are shore power facilities that allow ports to shut of their engines when berthing in a port. Especially in Europe and North America, an increasing number of ports provide shore power to ships that come into their quays, following the lead of Gothenburg. Instead of using their diesel-fuelled auxiliary engines, these ships use power generated by the local grid, which significantly diminishes diesel- and other fuel-derived emissions while in port. Shore power not only requires an on-shore power connection, but also ships that are able to connect to this power source. For this reason, shore power is most feasible for point-to-point connections, such as ferries, container lines and Ro/Ro-ships.

Several European ports have begun promoting the use of liquefied natural gas (LNG) as a ship fuel. Bremenports, which is responsible for the management and development of Bremen and Bremerhaven, has decided to actively support the future use of LNG. In addition to the construction of an LNG depot in 2011, one of its main strategies is to use LNG itself, through the creation of ship services powered by LNG in 2012. It is hoped the use of LNG by the service fleet will set a precedent for other users in the port, and Bremenports has a policy of providing technical expertise on these matters to facilitate the popularisation of such technologies. The ports of Rotterdam and Gothenburg already run incentive schemes that subsidise the use of LNG by ships. Both ports are also investing in LNG facilities. Gothenburg and Rotterdam have already begun co-operating on standardisation efforts to ensure that LNG is handled in a uniform manner and to speed up the development and adoption of LNG as a fuel (Merk, 2013).

Port regulations have so far covered vessel speed reductions in proximity of the port and mandatory fuel switches. Incentives applied by ports include lower tariffs for ships that use cleaner fuels, are more energy efficient or reduce their speed when close to a port. E.g., the Port of Long Beach, through its Vessel Speed Reduction Programme (VSR), rewards ships that voluntarily lower their speeds within the harbour, through reduced docking fees for vessels that remain within a 12-knot speed limit. The goal of the VSR is to reduce NO_x emissions from ocean-going vessel by slowing their speeds as they approach or depart the port, generally at 20 nautical miles (nm) from Point Fermin (OECD, 2011).

Various ports have introduced environmentally differentiated port dues, based on the environmental ship index (ESI). The effect of these incentives is for the moment fairly small, as the number of vessels that qualify for reduced port dues is limited. As the number of ships integrated in the ESI is steadily rising, the prospective benefits will rise, but the rebates have not so far been financed by a rise in dues for the non-ESI vessels, which will have negative consequences for the budgets of the participating ports. So future schemes would arguably not only have to reward clean ships, but also to penalise dirty ships, as is the case in Sweden. This country has applied environmentally differentiated port dues since 1996, following an agreement between the Swedish Maritime Administration, Ports of Sweden and the Swedish Ship-Owners Association to reduce NO_x and SO_2 emissions from ships. This agreement has led to environmentally differentiated fairway and port dues.

Voluntary fuel switch programmes are applied in various ports and provide incentives to shipping lines to use low sulphur fuel. These incentives are either in the form of compensations to shipping lines for the additional fuel costs due to their fuel switches, or lower port dues and tariffs. Both the programmes in Seattle and Houston give reimbursements to shipping lines based on the volume of low-sulphur fuel burned during each port call. In contrast, the Green Port Programme in Singapore gives a 15% reduction of port dues for vessels that switch to clean fuel (or use approved scrubbers or other abatement measures). These programmes usually take the form of collaboration between the port administration and one or more shipping lines. E.g. the programme in Houston is exclusively with the shipping line CMA CGM, whereas the Fair Winds Charter in Hong Kong was with the main 17 shipping lines calling the port. An important port regulation with respect to fuel switching is the EU Sulphur Directive that prescribes that ships at berth in EU ports need to use fuels with a maximum of 0.1% sulphur content, which is in place since January 2010.

In various cases these instruments are combined or applied subsequently, e.g. when incentive schemes facilitate a transition to stricter regulation (Box 1). Many of the policy choices made will depend on the local situation, but the most convincing examples of policy performance involve a coherent package of inter-related instruments. Mitigating shipping emissions in ports requires the interplay of different levels of intervention, ranging from the local on up. Given the nature of the shipping industry, some environmental impacts of shipping are best tackled at the global level. Self-regulation of ports can work, but in most cases, external pressure is needed. The policy instruments mentioned above would need wider application in order for ship emissions in ports to be reduced.

Box 1. **San Pedro Bay Ports Clean Air Action Plan**

The San Pedro Bay Ports Clean Air Action Plan (CAAP) is a comprehensive strategy to reduce air pollution emissions from port-related cargo movement. The two San Pedro Bay ports, the largest seaport complex in North America, are also the single largest source of pollution in Southern California, according to the South Coast Air Quality Management District (SCAQMD). In 2005, the twin mega-ports of Los Angeles and Long Beach generated approximately 25% of the diesel pollution in the region (O'Brien, 2004). The CAAP aims to address the problem of the ports' growing operations and their increasing environmental impact. Its goal was to dramatically reduce emissions and associated health risks for the region without upsetting the continuous port development. The plan was first approved in 2006 and updated in 2010. Near-term plans through 2014 and long-term goals include reducing port-related emissions by 59% for NO_x, 93% for SO_x and 77% for DPM by 2023 and meeting standards to lower the residential cancer risk in the port area from diesel particulates. Under the plan, the twin ports have developed annual emission Inventories, which are made public, to track progress in achieving CAAP standards. The CAAP uses a combination of regulations, fees, grants and incentives to the cargo industry to promote cleaner technology and operational systems, such as the Clean Truck Program, the Vessel Speed Reduction Program and the Alternative Maritime Power Program. To support the development and demonstration of clean-air technology, the ports have also jointly created a Technology Advancement Program that has provided more than USD 9 million in funding to the industry since 2007.

The latest analysis in 2011 indicates that the two ports have substantially reduced the key air pollutants from port-related sources since 2005, including a 71% and a 75% reduction in airborne diesel particulates, respectively. Several pillar programmes have significantly contributed to reducing air pollution at the two ports, including the Clean Truck Program (CTP) and the Vessel Speed Reduction Program (VSR).

The CAAP marks a milestone for the port industry in mitigating the environmental impact of maritime operations. The plan was a co-operative venture, and the two ports initiated the concept and brought along industry stakeholders and agency leaders (Giuliano and Linder, 2011). The key factor in its success is the co-operation of port users, including terminal operators, truckers and shippers, as well as the support of federal, state and local regulatory bodies and local communities (Mongelluzzo, 2012). The ports were also under considerable social pressure. Community concern over the health risks of port-related diesel emissions had grown after a series of air quality studies was published on the correlation between cancer and respiratory disease rates and proximity to freight-movement corridors. Cargo volumes rose through 2004, in an expansion of capacity at the two ports, and public opposition, including a series of lawsuits, made plans for expansion difficult if not impossible. Political pressure for increased regulatory oversight also prompted the ports to respond to public dissatisfaction over air quality. This ultimately led to the adoption of a comprehensive plan. The CAAP was portrayed as a solution to build the credibility of the ports to obtain agreements on future projects as they engaged all the key stakeholders. One study describes the CAAP as "a response to the loss of social legitimacy and to social and regulatory pressures that were restricting the ability of the ports to expand" (Giuliano and Linder, 2011). The two ports' market influence also played a role in the mitigation efforts, since their gateway location gave them more room to impose fees on the industry and generate the revenue to implement environmental policies.

Source: Merk (2013), The Competitiveness of Global Port-Cities: Synthesis Report, OECD, Paris

Ship emissions in ports follow a highly skewed distribution pattern, with more than a third of the emissions occurring in only 50 ports. This points to the concentration of air pollution in selected environmental hotspots, but also suggests that policy interventions with respect to environmental externalities, such as on shore power supply, would be most effective if focussed on these places. Although we did not find indications of economies or diseconomies of scale with regards to relative emissions, there were certainly geographical differences. The shipping-related emissions in Asian and European ports are large in absolute terms, but small in relative terms: they represent 70% of total port calls, but only 51-58% of shipping-related emissions. The explanation for this is their favourable performance in time efficiency in Asia and Europe: shorter port times mean relatively lower emissions. In contrast, the ports in North America, Africa and Oceania have relatively high emissions. In the case of North American ports this is caused by a much larger vessel capacity calling the port, which might be caused be the relatively underdeveloped short sea shipping market in the US. In the case of African ports, the relatively high emissions are caused by unfavourable performance in time efficiency: vessels have longer port stays than on other continents, so the container ship emissions in port areas are larger. A relatively large literature on port efficiency has generated recommendations on how to improve this. Considering that most of the largest ports in the world are Asian or European ports, that is closer to the efficiency frontier, the opportunities of reducing global shipping emissions in ports by improving port efficiency remains essential, but might actually have relatively limited impact.

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