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The role of sea ports in end-to-end maritime transport chain emissions

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HIGHLIGHTS

- Investigates role of ports in mitigating GHG emissions in the end-to-end maritime transport chain.
- Emissions generated both by ports and by ships calling at ports are analysed.
- Shipping's emissions are far greater than those generated by port activities.
- Ports may have more impact through focusing efforts on reducing shipping's emissions.
- Options for ports to support and drive change in the maritime sector also considered.

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ABSTRACT

This paper's purpose is to investigate the role of sea ports in helping to mitigate the GHG emissions associated with the end-to-end maritime transport chain. The analysis is primarily focused on the UK, but is international in application. The paper is based on both the analysis of secondary data and information on actions taken by ports to reduce their emissions, with the latter data collected for the main UK ports via their published reports and/or via interviews. Only a small number of ports (representing 32% of UK port activity) actually measure and report their carbon emissions in the UK context. The emissions generated by ships calling at these ports are analysed using a method based on Department for Transport Maritime Statistics Data. In addition, a case example (Felixstowe) of emissions associated with HGV movements to and from ports is presented, and data on vessel emissions at berth are also considered.

Our analyses indicate that emissions generated by ships during their voyages between ports are of a far greater magnitude than those generated by the port activities. Thus while reducing the ports' own emissions is worthwhile, the results suggest that ports might have more impact through focusing their efforts on reducing shipping emissions.

1. Introduction

Environmental issues have long been a concern for ports, with the impacts mostly occurring through compliance with legal frameworks. These have included issues such as air quality, noise, water quality, biodiversity and natural habitat (dredging) (OECD, 2011). Among these, air quality issues, such as the generation of dust, particulate matter and nitrogen and sulphur oxides (NO_x and SO_x), have traditionally been considered by ports as a local pollution problem, particularly in cases where ports are close to urban centres. Only relatively recently, with rising concerns about anthropogenic CO_2 and its impact on climate change, have ports started to introduce specific programmes and policies to address their greenhouse gas emissions. In 2007, the International Association of Ports and Harbours (IAPH) (2007) published the 'Resolution on Clean Air Programs for Ports' which stresses the need 'to draw more attention to air quality of port areas and undertake as many efforts as possible to reduce air emissions from port operations'. A survey by the European Sea Ports Organisation (ESPO) (2010) of member ports found that 37% of respondent ports measured/estimated their carbon footprint, 51% were taking measures to reduce their carbon footprint, 57% had programmes to increase energy efficiency, and 20% of ports produced some form of renewable energy. In 2008 a group of 55 ports worldwide launched the World Ports Climate Initiative (WPCI).[1] The WPCI uses the GHG Protocol[2] which categorises emissions into the following three groups:

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[1] See ⟨wpci.iaphworldports.org⟩ for details.
[2] See ⟨www.ghgprotocol.org/standards⟩.

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- *Scope 1*: direct GHG emissions from sources owned or controlled by the company and under the day-to-day operational control of the port.
- *Scope 2*: GHG emissions which result indirectly from the port's electricity demand.
- *Scope 3*: other indirect emissions from the activities of the port including employee travel, outsourced activities, movement of vessels and trucks, and construction activities.

The WPCI has promoted a number of initiatives including On-Shore Power Supply, the Environmental Ship Index (ESI), intermodal transport, LNG-fuelled vessels and carbon footprinting to address these different aspects of maritime-related emissions. Individual port members have led on these different initiatives. For example, the Port of Los Angeles has led on carbon footprinting and subsequently shared its expertise on carbon footprint calculations for port operations with other member ports (IAPH, 2010). These measurements covered emission sources from all scopes, such as port-owned and leased vehicles, buildings, port-owned and operated cargo handling equipment (scope 1), port purchased electricity for port administration-owned buildings and operations (scope 2), tenant operations or employee commuting (scope 3). This and related experience resulted in the publication by the IAPH of a ‘toolbox’ for Port Clean Air Programs (IAPH, 2009). In this document, possible strategies for air quality improvement are provided, covering the following operational areas: Ocean Going Vessels; harbour craft; cargo handling equipment; heavy duty vehicles/trucks; light duty vehicles; locomotives and rail and construction equipment. Similarly, some UK ports also began to address measuring and reducing their own greenhouse gas emissions following the stimulus to action provided by the UK's Climate Change Act of 2008.

The purpose of this paper is to investigate the role of ports in helping to mitigate the greenhouse gas emissions of the end-to-end maritime transport chain. The analysis is primarily focused on the UK, but is international in application. The boundaries of port-related emissions are examined through a comparative analysis of port and shipping emissions, and potential emissions reduction strategies are evaluated. A systems approach is adopted in that ports are considered as part of a wider supply chain system and thus included in our focus are strategies with effects that may cross a port's physical and organisational boundaries. The paper attempts to assess the differences in magnitude of emissions at different points in the UK maritime sector; emissions generated by port operations (as reported by the ports themselves), by the vessels at berth (mainly emissions from auxiliary engines), and the emissions generated by the seaborne trade handled at these ports. This segmentation is important because each segment may require different mitigation strategies. Having established this overview, a list of possible strategies that are currently being applied or tested by leading ports are reviewed, and their applicability is discussed in the UK context.

Data sources used for the analysis in this paper include secondary data taken from published and on-line reports, industry websites and government statistics. In addition telephone interviews and email exchanges were conducted with staff at the following ports/port groups: ABP; Port of Dover; Port of Los Angeles; Port of Felixstowe; Milford Haven; and Port of London.

Previous contributions to this journal have explored the topic of GHG emissions from ports—Villalba and Gemchu (2011) examined the emissions from Barcelona Port in the context of those from the contiguous city; the system boundary of that study was one nautical mile on the sea side of the port. The study reported in this paper endeavours to extend the system boundary further and consider port emissions in the context of the wider end-to-end maritime transport chain. While Villalba and Gemchu's approach consists in measuring emissions from one port, our approach aims at reproducing a similar analysis, but at a higher level, for a group of UK ports. In our study, the calculations of land-based emissions are based on the ports' own GHG inventories (see Section 2). These port emissions include those from handling equipment, buildings, lighting, harbour vessels (such as tugs), but exclude Ocean Going Vessels emissions at berth. In our definition, sea side emissions include both emissions from the maritime transport chain (outlined in Section 3) and emissions at berth (outlined in Section 4). These two emissions sources were calculated utilising two independent approaches: end-to-end emissions were estimated using the model described in Section 3; while emissions at berth were estimated from a study conducted by Entec for Defra (Entec, 2010) using the approach described in Section 4. By contrast, Villalba and Gemchu (2011) include emissions due to vessel movements (arrival, departure, hotelling and manoeuvering) within Barcelona's port emissions and categorise these as sea-based emissions. Our view is that these emissions are out with the direct responsibility of the port operators even though, as we demonstrate, they may be amenable to actions taken by the port.

Another previous contribution to this journal—Fitzgerald et al. (2011)—utilised a similar approach to assess end-to-end emissions at the national level, using New Zealand as a case study. As is the case for the United Kingdom (Rigot-Müller et al., 2012), most of New Zealand's trade in tonnage is conducted by sea, so in this case maritime statistics represent a large proportion of total traded tonnage. However, Fitzgerald et al. use trade statistics, whereas we utilise cargo statistics by origin and destination, consolidated from ports. Our approach to estimate emission factors is also different, since we use vessel average size from Eurostat data and not vessel specifications from the Advance Notices of Arrival. Fitzgerald et al. (2011) also exclude port related emissions (manoeuvering, loading/unloading, hotelling) from their calculations. Despite these methodological differences, the general purpose of our approach aims to achieve similar results to that of Fitzgerald et al. (2011) as regards an analysis of emissions resulting from maritime transport, but applied to the UK.

2. Carbon footprint of port operations: the case of UK ports

The first carbon footprint projects for UK ports' operations started in the late 2000s. For example the port of Dover began monitoring emissions in 2008, based on data from 2006 to 2008, while Associated British Ports (ABP) also started measuring emissions using 2006–2008 data, and were subsequently awarded the Carbon Trust Standard in 2009 (Associated British Ports, 2010). Such measurements were frequently made in anticipation of the Carbon Reduction Commitment (CRC) Energy Efficiency Scheme, a carbon trading scheme applicable to all organisations with more than 6000 mWh consumption measured through a half hourly electricity metre. The Carbon Reduction Commitment applies to all Harbour Authorities in England and Wales responsible for Ports dealing with over 10 million t of commercial cargo annually. The following port companies are covered by the CRC; ABP Harbour Authority (Hull, Humber, Immingham, Southampton), Dover Harbour Board, Harwich Haven Authority, Mersey Docks and Harbour Company, Milford Haven Port Authority, PD Teesport Ltd., Port of London Authority, Port of Sheerness Ltd. and The Felixstowe Dock and Railway Company.

In 2011 five port companies in the UK were already reporting and publishing their carbon emissions from port operations: Associated British Ports, the Felixstowe Dock and Railway Company, the Dover Harbour Board, Aberdeen Harbour Board and Poole Harbour Commissioners. These companies manage 12 UK ports (Cardiff, Goole, Hull, Immingham, Ipswich, Plymouth, Port

Table 1
CO_2 emissions from British port companies and total cargo handled (2008).
Data sources: DfT Maritime Statistics, Port companies.

Port Company	CO_2 (t)	Cargo (kt)	kg CO_2/t
ABP	82,671	118,516	0.70
HPH–Felixstowe	71,545	24,988	2.86
Dover	17,151	24,344	0.70
Aberdeen	1163	4833	0.24
Poole	1800	1518	1.19
Total	174,330	174,199	1.00
All UK ports	548,075		
% share of all UK ports (in t)	32		

Talbot, Southampton, Dover, Felixstowe, Poole and Aberdeen) accounting for 32% of all tonnage handled in UK ports in 2008 according to UK Department for Transport (DfT) Maritime Statistics (Table 1). The emissions reported by these ports cover the port operations themselves (scopes 1 and 2), but exclude scope 3 emissions from Ocean Going Vessels (at sea or at berth) or from landside traffic. Other ports, such as Harwich, Milford Haven and the Port of London also report emissions, but their scope is limited to the port authority organisation and thus do not include the terminals themselves.

When comparing the results from the different port companies, it can be observed that the ratio between the kg of CO_2 generated per tonne of cargo handled is different from port to port. This can be explained by the activity profiles of the ports, with Felixstowe for example primarily focused on container handling, quite an intensive energy consuming activity.

These available CO_2 emission data from the ports companies are used to analyse the relative importance of port emissions in the UK maritime sector. Even though the current reporting port companies do not represent all the UK ports, the available dataset covers 32% of all UK tonnages and thus represents a key component of the UK's port activity for the purpose of this analysis.

In the next section, emissions from the international seaborne trade of all cargo moving from and to these ports are examined. This could be considered as a first attempt to measure part of the 'scope 3' emissions for UK ports, given that such emissions are a consequence of the port activity.

3. Carbon footprint of international shipping: the case of UK seaborne trade

In order to assess CO_2 emissions related to the cargo handled by those port companies listed in Table 1, it was necessary to adopt a method using emission factors in gCO_2/t km—these were analysed by ship type and ship size as provided by the International Maritime Organisation (IMO) (2009). This allowed shipping emissions to be allocated to the appropriate port. The average ship size calling at ports (by ship type and by port) was assessed using Eurostat data, and then UK Department for Transport (DfT) Maritime Statistics were used to assess seaborne trade from, and to, UK ports.

Using this approach, the emissions from UK international seaborne trade were assessed. This is a more conservative measure than the actual emissions from all ships making calls at UK ports. This measurement provides an overview that considers only the 'share' of emissions from cargo handled in UK ports. Moreover, emissions from transhipped traffic are not considered here, since DfT statistics only provide data until the next/last port of unloading/loading. Table 2 illustrates the tonnes of cargo handled at the ports considered in this study, using DfT statistics.

Table 2
Cargo handled at UK ports by type.
Data source: DfT Maritime Statistics.

1000 t handled at port, international traffic (Data for 2008)						
Port	Dry bulk	Liquid bulk	Lo–Lo containers	Other general cargo	Roll-on/ roll-off	Total
Aberdeen	178	313	13	620	14	1138
Cardiff	178	183	121	545		1028
Dover	21		0	221	23,912	24,154
Felixstowe	4	35	21,646	16	2725	24,427
Goole	479	15	519	1137		2149
Hull	3350	1619	1465	1228	3982	11,644
Immingham	23,507	17,572	1165	1484	14,447	58,176
Ipswich	1377	23		183	407	1991
Plymouth	672	22		9	110	813
Poole	150			190	1015	1355
Port Talbot	7831			55		7886
Southampton	1011	22,696	8272	66	1224	33,270
Total	38,758	42,480	33,202	5753	47,836	168,028

Table 3
Average ship size calling at specified UK ports by ship type (GT).
Data source: Eurostat (2008).

Avg ship size (GT) at Port, all traffic (Eurostat)					
Port	Dry bulk	Liquid bulk	Lo–Lo containers	Other general cargo	Roll-on/ roll-off
Aberdeen	2952	5326	5801	10,461	10,888
Cardiff	5884	14,520	9682	4134	
Dover	17,311		9088	29,947	299
Felixstowe	23,689	12,654	47,090	19,737	18,966
Goole	3457	2783	2901	2864	
Hull	29,156	9811	7173	29,125	21,437
Immingham	77,808	23,306	7554	22,820	20,036
Ipswich	5402	6506	5221	6519	6519
Plymouth	5009	11,222		21,002	9595
Poole	3644			2000	798
Port Talbot	111,306			3901	
Southampton	43,999	25,069	61,448	39,655	61,064

In order to use consistent emission factors for the ship journeys, the average ship size calling at the ports was assessed using Eurostat data. DfT data were not used for this because their segmentation is less detailed, especially for larger ships. The average ship sizes used for the ports analysed in this study are listed in Table 3. This value is in fact a 'weighted average', weighted by the number of calls. This weighting approach assumes that the ship size is a proxy for the amount of cargo loaded and unloaded in the port. In this way we can associate the actual cargo data loaded and/or unloaded at the port (directly collected from DfT) with an average cargo size. In other words, a port with several calls of large vessels and few calls of small vessels will have a rather large average ship size associated with all cargoes loaded and unloaded at this port, for a specific ship type.

Since the data in Eurostat are given in gross tonnes (GT), they were converted into deadweight tonnage (DWT) based on the average ratio for the worldwide fleet in 2008 (Lloyd's Register/Fairplay, 2009).

Based on the ship types calling at ports and on their average size, it is possible to choose the appropriate ship emission factor to assess the total CO_2 emissions. Emission factors are expressed in gCO_2/t nm, (where lower figures represent greater efficiency). Values are derived from the aforementioned 2009 IMO GHG Study and are listed in Table 5. These emission factors are applied to all vessel voyages with an origin or arrival from or to a particular port.

Table 4
Average ship size calling at specified UK ports by ship type (DWT).
Data source: adapted and converted from Eurostat (2008).

Avg ship size (DWT) at Port, all traffic					
Port	Dry bulk	Liquid bulk	Lo–Lo containers	Other general cargo	Roll-on/ roll-off
Aberdeen	5379	9882	6730	14,906	2858
Cardiff	10,723	26,941	11,233	5891	
Dover	31,545		10,544	42,675	79
Felixstowe	43,167	23,479	54,634	28,126	4979
Goole	6299	5164	3365	4081	
Hull	53,129	18,205	8322	41,503	5628
Immingham	141,784	43,245	8764	32,519	5260
Ipswich	9843	12,072	6057	9290	1711
Plymouth	9127	20,824		29,928	2519
Poole	6641			2851	210
Port Talbot	202,826			5559	
Southampton	80,177	46,517	71,293	56,508	16,031

Table 5
Ship efficiency applied for the ship voyage per port and by ship type.
Source: IMO (2009).

Ship Efficiency applied in gCO_2/t nm (IMO GHG 2009 study)					
Port	Dry bulk	Liquid bulk	Lo–Lo containers	Other general cargo	Roll-on/ roll-off
Aberdeen	54.1	45.2	83.5	26.9	91.7
Cardiff	54.1	30.6	67.2	25.7	
Dover	14.6		67.2	25.2	111.7
Felixstowe	14.6	27.0	30.7	22.0	91.7
Goole	54.1	83.3	67.2	28.6	
Hull	14.6	44.7	69.1	30.6	91.7
Immingham	9.0	18.2	70.3	35.6	91.7
Ipswich	54.1	56.0	67.2	32.9	91.7
Plymouth	54.1	22.8		22.0	91.7
Poole	54.1			25.7	111.7
Port Talbot	5.6			25.7	
Southampton	10.6	18.2	36.2	25.4	91.7

Table 6
Average distance applied for ship voyage per port and by ship type.
Source: calculated from Distance Database Website (2013); ⟨www.distances.com⟩.

Average distance travelled to/from the UK (nm)						
Port	Dry bulk	Liquid bulk	Lo–Lo containers	Other general cargo	Roll-on/ roll-off	Total
Aberdeen	649	1021	1745	2298	566	1727
Cardiff	1839	607	2347	1917		1966
Dover	601		141	3721	68	2617
Felixstowe	1006	693	4333	5659	121	4372
Goole	984	95	477	1027		936
Hull	1578	1617	3315	1794	385	1873
Immingham	2222	1730	2473	1867	1358	1954
Ipswich	1348	480	1107	2063	131	1378
Plymouth	1066	369		800	385	946
Poole	599			733	578	647
Port Talbot	3152			725		2821
Southampton	1302	2339	4961	4168	4546	3555
Total	1560	1836	3905	2499	2794	2557

For example, the average DWT for Dry Bulk vessels in Aberdeen was 5379 (as reported in Table 4); from the IMO 2009 study we can directly associate this ship size to the ship class ‘under 10,000 DWT’ which has an average emission factor of 54.1 gCO_2/t nm, as outlined in Table 5 (line 1, column 1).

It is possible from DfT Maritime Statistics to discriminate between the country destination for each ship type and UK port. The total ship work (distance × tonnes of cargo) is calculated by multiplying the two values. For each origin—destination traffic a standard route was defined (for example Suez-Malacca for UK–China traffic). Emissions were then calculated using the actual distance for each standard route associated with each possible origin—destination. The average distances for voyages by each port and ship type are shown in Table 6. This average distance corresponds to the average distance of all standard routes associated with all origins and destinations leaving or arriving at this port.

Table 7 illustrates the CO_2 emissions from UK international seaborne traffic resulting from the cargo handled in the UK ports examined—this shows an overall result of approximately 10 mt of CO_2. Current estimates, produced by the Tyndall Centre (Gilbert et al., 2010) and the UK's Committee on Climate Change (2011) suggest a range between 11 mt CO_2 and 41 mt CO_2 in 2006 for all UK international shipping emissions. The IMO estimate for all international shipping worldwide is 870 mt CO_2 in 2007.

When this result is compared with the emissions generated by the UK ports themselves (174 kt of CO_2, Table 1) it is evident that emissions from port operations represent a minor share of total emissions (less than 2% in the context of the analysis in this paper). Even if we note that our analysis only includes a proportion of UK ports (albeit representing 32% of UK port freight tonnage), the percentage share for all ports, if such data were available, would likely still be small. Furthermore, it is important to stress that the CO_2 emissions from ports concern all port traffic (passenger and freight, domestic and international), and that this result is compared with the *seaborne international freight only*. Thus, the actual port emissions corresponding to this activity should be even lower, but such segmentation is not provided by ports. This result suggests that ports' own emissions, ceteris paribus, are relatively minor compared to the emissions that result from seaborne trade at those ports. Assuming that ports are able to influence shipping emissions, ‘sea side’ strategies should be considered by ports as an important component of their greenhouse gas policies.

3.1. Case study example: analysing GHG ‘scope 3’ emissions for the Port of Felixstowe

Before turning to an analysis of emissions from ships at berth and potential port strategies to reduce overall CO_2 emissions, it is worthwhile to briefly consider the impact of landside traffic, which could also be an important source of emissions. While an analysis for all UK ports has not been attempted, a simplified analysis for the case of road traffic at the port of Felixstowe (the UK's busiest container port) is presented to provide an indication of the relative magnitude of landside emissions. An annual traffic of 1.248 million HGVs per year was estimated (based on a daily traffic volume of 4000 HGV at the port), and an average haulage distance of 120 km assumed (the UK average length of haul according to the DfT's Road Freight Statistics). The road emissions factor used is provided by the UK's Department for Environment, Food and Rural Affairs (Defra). The simplified calculation results in a total of 138 kt of CO_2 from HGVs (Table 8). This result is substantially less than the emissions from shipping, but it is still higher than emissions from the Felixstowe port operations themselves (71.5 kt of CO_2). This suggests that ‘land side’ emissions are also an important source of CO_2 emissions that should be considered by ports in any reduction strategies (see Fig. 1).

From this analysis, it can be concluded that UK port operations are not the main contributor to greenhouse gas emissions in the maritime supply chain, since they contribute far less than the Ocean Going Vessels using those ports. Given this result, it would appear to be more efficient for ports—from a systems point of view

Table 7
Ship emissions from UK international seaborne trade per port by ship type.

Ship emissions (tonnes of CO_2)						
Port	Dry bulk	Liquid bulk	Lo–Lo containers	Other general cargo	Roll-on/roll-off	Total
Aberdeen	6171	7462	702	31,829	747	46,911
Cardiff	21,242	2930	9336	20,879		54,386
Dover	246		2	20,801	181,568	202,617
Felixstowe	65	807	4,230,182	3111	30,221	4,264,387
Goole	19,994	122	21,235	18,331		59,682
Hull	74,982	102,907	37,687	58,266	58,696	332,538
Immingham	743,927	563,839	42,220	82,016	507,891	1,939,893
Ipswich	75,803	412		5290	5190	86,695
Plymouth	35,070	66		145	4168	39,449
Poole	7245			1608	19,294	28,147
Port Talbot	227,624			378		228,002
Southampton	16,073	671,362	1,924,443	5856	423,944	3,041,677
Total	1,228,443	1,349,906	6,265,807	248,509	1,231,719	10,324,384

Table 8
Emissions from landside operations at Felixstowe.
Data Source: authors' analysis.

Mode	HGVs/year	Avg distance (km)	tCO_2/vehicle-km	Emissions (tCO_2)
Road	1,248,000	121	0.000917	138,474

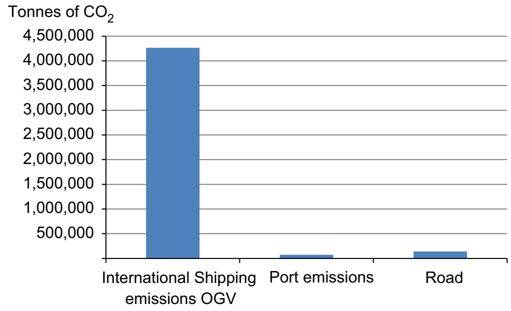

Fig. 1. Comparison of CO_2 emission sources at Felixstowe port (tonnes of CO_2).

—to direct their efforts towards encouraging the reduction of ship emissions, rather than giving priority to their own emissions, albeit that these also need to be addressed.

Whether vessels are at berth, approaching the port, or at sea, ports may have different means to influence their emissions. The next section attempts to address the issue of vessel emissions at berth through an analysis and review of previous studies carried out in recent years and also through emissions calculations.

4. Emissions from vessels at berth: the case of UK ports

Previous studies indicate a range of estimates for the proportion of emissions derived from vessels at berth. Maes et al. (2006) estimate that about 74% of CO_2 emissions occur during the sailing period and the remainder of emissions occur in the mooring periods (including hotelling and anchoring—'hotelling' refers to a ship's operations at anchor, and includes providing electric power for lights and loading equipment, climate control for cargo and crew, etc.). Habibi and Rehmatulla (2009) estimate that average emissions in port (both loading and discharge at port) account for just under 10% of total ship emissions, while Fitzgerald et al. (2011) estimate port activities by vessels to contribute less than 6% of the total.

Table 9
Ship emissions from vessels at berth, 2007.
Source: adapted from Entec (2010).

Average results based on Entec (2010)						
'000 t Baseline year : 2007	Fuel consumption	Emissions				
		CO_2	SO_2	NO_x	$PM_{2.5}$	VOC
Vessels at berth in UK ports	578	1839	12.6	34.6	1.4	1.7

Following the approach outlined in the introduction, the purpose of this section is to assess the amount of greenhouse gas emissions generated by ships in UK ports while at berth. A comprehensive study, conducted by Entec for Defra (Entec, 2010), estimated that the emissions from vessels at berth (within the UK 12 nm zone) were 1.8 mt of CO_2 in 2007. This study was based on data from Lloyds Maritime Intelligence Unit (LMIU) (database on vessels' movements) and from the DfT. Even though this result aggregates emissions from all ports, it can be observed that in 2008 they represented more than 10 times the emissions from the port companies considered in this paper (174 kt CO_2—Table 1), suggesting that emissions from vessels at berth are also a significant share of port-related CO_2 emissions.

It is important to stress, however, that such measures are subject to uncertainties, which are listed in Entec's study. Most specifically, for the case of emissions at berth, assumptions on engine load factor at berth have some impact. Two studies, conducted by the Port of Rotterdam (for containers, Doves, 2006) and by Chalmers University (for Ro–Ro vessels and oil tankers, Ericsson and Fazlagic, 2008), have addressed this issue. The study from the Port of Rotterdam made an effort to collect direct measures of the power used at berth by auxiliary engines. However, these measures concerned different ports and vessels, so they will not be considered here. In the Entec study that is used here as our baseline, the auxiliary engine load factor at berth was assumed to be 40% of Maximum Continuous Rating (MCR), and the main engine load factor for tankers while at berth, 20% of MCR. Table 9 shows the resulting fuel consumption and emissions for the baseline year 2007.

We will focus here on emissions from auxiliary engines only, since main engines are usually not in operation while the vessel is at berth (except during some liquid bulk operations that will not be considered here). In order to calculate such emissions, traditionally the following equation is used (Browning and Bailey, 2006):

$$E = P \times \mathrm{LF} \times A \times \mathrm{EF} \quad (1)$$

Table 10
Ship emission factors from vessels at berth, 2007. Total kWh consumed at berth: 2,663,594,470.
Source: adapted from Entec (2010).

	Specific fuel consumption	Emissions factors						
		CO_2	SO_2	NO_x	$PM_{2.5}$	VOC		
Average emission factor at berth (g/kWh)	217	690	4.7	13.0	0.5	0.6		
Engine type/fuel type	NO_x pre-2000 engine	NO_x post-2000 engine	NO_x fleet average	SO_2	CO_2	VOC	PM	sfc
M/H SD/MGO	13.9	11.5	13.0	0.9	690	0.4	0.3	217
M/H SD/MDO	13.9	11.5	13.0	6.5	690	0.4	0.4	217
M/H SD/RO	14.7	12.2	13.8	12.3	722	0.4	0.8	227

where E is the emissions (g), P is the maximum continuous rating power (kW), LF is the load factor (% of vessel's total power), A is the activity (h), EF is the emission factor (g/kWh).

In the case here, because we start from a known result, we will use an approach that aims to define the average emission factor for vessels at berth, using the following equations:

$$E = \mathrm{EP} \times \mathrm{EF}, \tag{2}$$

and

$$\mathrm{EP} = \mathrm{FC}/\mathrm{SFC} \tag{3}$$

where E is the emissions (g), EP is the energy produced (kWh), EF is the emission factor (g/kWh), FC is the fuel consumption (g), SFC is the specific fuel consumption (g/kWh).

Auxiliary engines using Marine Gas Oil (MGO) and Marine Diesel Oil (MDO) are assumed to have a specific consumption of 217 gfuel/kWh (Entec, 2010). We use this value in our assessment, using it also as a proxy for emissions that could have been generated by tankers' main engines or by engines using residual oil. This choice allows a simplified calculation, but introduces two uncertainties. Firstly, for the main engines' emissions, most tankers (76%) have slow speed diesel main engines, with a SFC in a range between 204 and 215 gfuel/kWh, thus creating up to 6% error for emissions generated by main engines [(217 − 204)/217]. Secondly, it is assumed that some auxiliary engines would be using residual oil (RO), which has a SFC of 227 g/kWh. In our case, we will presume that all engines are using either MGO or MDO, which could generate a discrepancy of 4.6% [(227 − 217)/217] for such emissions.

Considering then that 578 kt of fuel were consumed at berth in 2007 with an average SFC of 217 gfuel/kWh, we obtain total energy consumption at berth of 2,663,594,470 kWh for the year 2007. Table 10 shows the resulting average emission factors for such energy demanded at berth, which are compared with the average emission factors for auxiliary engines using different fuel types.

The resulting average emission factors are consistent with those provided by Cooper and Gustafsson (2004) and reused by Entec (2005) for auxiliary engines. The high average emission factor at berth obtained for volatile organic compounds (VOC) and particulate matter (PM) (0.6 and 0.5 respectively) can be explained by the emissions generated by the main engines of liquid bulk vessels using residual oil (1.8 and 2.4 respectively). When comparing this result with those from our UK ports, we can see that greenhouse gas emissions from vessels at berth are important, and probably of comparable size to those from port operations themselves. The study of Barcelona by Villalba and Gemchu (2011) shows similar results, with emissions from vessel activity in port slightly greater than those from port activities. Overall then, emissions at berth, plus those from shipping trade at the ports and landside operations, are greater than those from ports' own operations. While UK ports have mainly focused their efforts on reducing their own emissions, this analysis suggests that any policy and actions to reduce greenhouse gas emissions by ports could have a greater impact by focusing on influencing the behaviour of those vessels using the ports.

In the next section, the possible strategies for UK ports to mitigate emissions and to be drivers for change in the sector are discussed.

5. A review of possible actions for UK ports

Following the previous results concerning the sources of greenhouse gas emissions from ports and from shipping, the focus here is upon possible actions for ports covering the ‘sea side’ i.e., emissions from Ocean Going Vessels (OGVs), since OGV emissions during their journey and at berth should be considered by ports as the major potential source of greenhouse gas reduction.

The list below of port-related strategies is based on several sources, including the WPCI website[3]; the IAPH Toolbox (IAPH, 2009); The International Institute for Sustainable Seaports (2010) inventory of technologies specified for the scope ‘Air Emissions’ (those concerning OGVs); the US agency EPA list (Vessels Strategies scope)[4] and the ICCT report on Air Pollution and Greenhouse Gases from Ocean Going Vessels (International Council on Clean Transportation (2007)). Solutions from technology providers such as Hamworthy plc, Marine Exhaust Solutions Inc., Cavotec and ABB have also been reviewed.

The strategies and approaches comprise:

- Vessel speed reduction
  - Voluntary programmes
  - Virtual arrival
- Green ship promotion
  - Based on ship fuel consumption profile
  - Based on ship specifications
- On-Shore Power Supply
- Automated Mooring Systems
- Exhaust gases control for auxiliary engines

5.1. Vessel speed reduction

Ports can act on vessel speed reduction in three different ways: through mandatory actions, voluntary actions or actions based on port queuing management—also called virtual arrival (managing ports' operational delays). Given that mandatory speed reduction could have an impact on ports' competitiveness (thus making it more difficult to be accepted by the port industry) and that such

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[3] 〈wpci.iaphworldports.org〉.

[4] 〈epa.gov/region1/eco/diesel/sp-vessels.html〉.

policy is not widely observed in the port industry, we will focus on successful examples for the two other options to reduce emissions: voluntary programmes and virtual arrival.

5.1.1. Voluntary actions

This involves voluntary speed reduction by vessels within a certain distance of the port. For example, the San Pedro Bay Ports' Clean Air Action Plan[5,6] (CAAP) involves container ships slowing speed from an average 18–25 knots to 12 knots within 20 nautical miles from Point Fermin (for Port of Los Angeles and Port of Long Beach). This reduces the main engine load factor from 80% to 10%, with consequent reduced CO_2, NO_x, SO_x and PM emissions. However, vessels do incur a time penalty with the reduction in speed. More than 90% of vessels voluntarily reduced speed in 2009, reducing air pollution in return for reduced port fees of 15%. The latter is a product of the CAAP's Green Flag Program which gives incentives for vessel speed reduction. Vessel operators that participate in this programme earn port fee reductions, up to 25% if they slow speed down to 12 knots from 40 nautical miles to the port, and 15% if they slow from 20 nautical miles to the port. The speed limit is managed in a flexible way, where ships having an environmentally optimal slow speed higher than 12 knots are allowed to use this speed after verification. An annual 90% compliance rate must be achieved in order to be eligible for the dock fee reduction. Evidence from the port of Long Beach indicates that more than 90% of vessels comply with the 20 nautical miles slow speed limit and 70% with the 40 nautical miles limit. The port anticipates awarding US$4 million in fee savings in 2011 and calculates that 40% of the vessel emissions′ reductions are due to the Green Flag Program. Long Beach has proposed extending the Green Flag zone to 40 nautical miles, with a fee discount of 25%. In Europe, Rotterdam port has also studied a speed reduction programme for possible future introduction.

For the UK, it is difficult to define precisely the potential for speed reduction for vessels approaching ports, as the vessels' speed when approaching ports is highly uncertain. However, the aforementioned Entec study for Defra provides an overall view of the emissions associated with such movements. It can be seen that within a 12 nm zone around the UK coast, vessel emissions at sea (i.e., those most likely to be affected by such measures) are estimated at 2677 kt CO_2 in 2007 (Table 11). Any potential reduction related to voluntary speed reduction for vessels approaching ports would be a fraction of this total amount.

Table 11
UK emission and fuel consumption estimates (kt) in 2007 within 12 nm zone.
Source: Entec (2010).

	NO_x	SO_2	CO_2	VOCs	$PM_{2.5}$	PM_{10}	Fuel consumption
At sea	62	28	2677	2.3	2.3	2.4	842
Manoeuvring	4	2	229	0.3	0.3	0.3	72
At berth	35	13	1839	1.7	1.4	1.5	578
Total	**100**	**43**	**4745**	**4.3**	**4.0**	**4.2**	**1493**

5.1.2. Virtual arrival

Virtual arrival consists in reducing ship speed when delays at the destination port are anticipated, avoiding the ‘hurry up and wait’ approach. This is a method to ensure a ‘just in time’ management of the traffic and a reduction in fuel consumption for the ship. Trials carried out by BP and Maersk with tankers showed promising results, with savings up to 27% in fuel consumption for some journeys, and average savings between 12% and 20% (Intertanko, 2010). Overall, BP′s estimations are that fuel savings across the (oil tanker) industry if virtual arrival was adopted could reach 9% (Lloyds List, 2011). Previous studies from the IMO (2000) provided estimations of 1–5% for the maritime sector.

However, these recent trials worked better in cases where port delays could already be observed, and in this specific trial Virtual Arrival was only applicable for one delivery to a UK port. Most cases concerned shipments from the Middle East to Australian and New Zealand ports (11 deliveries), which have structural capacity constraints. While virtual arrival may therefore have limited applicability in the UK at present, the future development of the liquid bulk industry in the UK through a rise in LNG imports by sea as a replacement for North Sea natural gas could increase tanker movements (Global Legal Group, 2011). This new potential traffic could generate new opportunities for virtual arrival developments.

In terms of port motivation to introduce vessel speed reduction measures, in these recent experiments fuel and CO_2 savings have been shared between the ship owner (or operator) and the charterer with few obvious gains for ports. Port motivation is important, as for virtual arrival to be implemented successfully, ports must be able to implement pre-booking systems and identify and track all possible causes of port-related pre-berth delay (e.g., berth availability, cargo-handling equipment availability etc.). Another risk for the ports is to see a reduction in port services sold, since port delay in some cases can be an opportunity to sell services, such as preventive maintenance for instance. To ensure full port collaboration, it seems important to define a clear and transparent *ex-ante* decision-making process, formalised in a contractual basis. Port demurrage (waiting time compensation) fees reduction can be used as a motivational element for port commitment.

5.2. Green ship promotion

5.2.1. Green fees

There have been a number of voluntary award schemes developed to encourage vessels to be more environmentally-friendly through incentives based on port dues. One possibility is the introduction of green fees or ‘green passports’ in conjunction with port authorities, providing a right of entry and reduced port fees to those vessels meeting environmental requirements. The use of green fees for clean shipping promotion is a good example of a port-driven initiative (though at cost to the port) that can be undertaken in cooperation with shipping companies. The success of the WPCI working group in developing the Environmental Ship Index (ESI) is a good example of collective and proactive action by ports. The WPCI's Environmental Ship Index rates the environmental performance of ships in terms of the emissions of NO_x, SO_x and CO_2 on a scale from 0 to 100 (from highly polluting to emission-free). Ports set their own qualifying benchmarks—Amsterdam, for example, will issue rebates for scores of 20 or above. The WCPI scheme sees potential financial incentives in the form of higher port charges for non-clean ships; discounts for clean ships, and inspection to certify qualifying ships. Green ship promotion may also be a relevant consideration for some UK ports given that several major continental European ports are currently operating such policies (see Table 12).

As Table 12 indicates, several environmental indices exist and can be used. A brief review of such indices, their main focus and their advantages/disadvantages, follows (see also Table 13 for a summary).

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[5] Involves the Ports of Los Angeles and Long Beach.

[6] Port of Long Beach Green Flag Program. ⟨http://www.polb.com/environment/air/vessels/default.asp⟩.

Table 12
Ports applying discount rates based on environmental factors.
Source: port authorities.

Port	Criteria	Discount rate	Starting date
Hamburg	ESI	Up to 10%	01/07/2011
Rotterdam	ESI	5%	01/01/2011
Amsterdam	ESI	3.75% (300€/8000€)	01/01/2011
Moerdijk	ESI	yes	01/01/2011
Dordrecht	ESI	yes	01/01/2011
Antwerp	ESI	up to 10%	01/07/2011
Bremen	ESI	Not available	01/01/2012
Oslo	ESI	30%	01/01/2011
Zeebrugge	ESI	10% on tonnage duty	01/01/2012
Goteborg	SO_x/NO_x	Up to 0.20 SEK/GT	01/04/2010
Goteborg	CSI		01/01/2011
Los Angeles	SO_x		01/07/2008
Los Angeles	ESI		planned
Le Havre	ESI	Up to 10%	01/01/2012

Table 13
Focus, advantages and disadvantages of different ship indices.

Index	Focus	Advantages	Disadvantages
CSI	NO_x, SO_x, PM and CO_2 emissions, chemicals, water and waste control	A complete index.	Not widely used by ports yet. Database privately owned. Container emissions based on nominal capacity only.
EEDI	CO_2 emissions	Already mandatory at the IMO level for new vessels.	Currently only applied for new ships (long ramp-up). Not used by ports yet.
ESI	NO_x and SO_x emissions	Already in use in Ports in the English Channel. Data are owned by ports.	Focused on NO_x and SO_x emissions and CO_2 reporting only.

5.2.1.1. Environmental Ship Index (ESI). The ESI index was designed by ports and is mainly focused upon NO_x and SO_x reductions, although it also promotes reporting CO_2 emissions. It is the ship index most widely used among ports, and take up also seems to be spreading outside Europe, with adoption by the Port of Los Angeles from 1st July 2012 (Port Strategy, 2012). In the Los Angeles incentive scheme, operators calling at the port could achieve reductions of between US$250 to $5250 per ship by scoring 30 or more ESI points through the use of low sulphur fuel, on-shore power technology and a ship energy efficiency management plan.

5.2.1.2. The Clean Shipping Index (CSI). The Clean Shipping Index (CSI) scores a vessel's environmental performance based on SO_x and PM emissions, NO_x emissions, CO_2 emissions, chemicals, water and waste control (Clean Shipping Project, 2010). The CSI project, which began in 2007, was initially designed to unify the environmental requirements from cargo owners, under a single, simplified index. The initiative on CSI by the port of Gothenburg appears to be the first to be introduced thus far. Lloyd's Register offers a verification service to ship owners and operators wishing to demonstrate their success in reducing the environmental impact of their activities beyond the requirements of classification or statutory rules and regulations. The verification service is approved by the Clean Shipping Project, the organisation that developed the Clean Shipping Index. More than 1000 ships have been entered into their Clean Shipping Index database. Verification is the logical next step to provide assurance to all involved: ship operators with confidence that the Clean Shipping Index provides a level playing field; and cargo owners and shippers with confidence that the values can be used when purchasing shipping.

5.2.1.3. Energy Efficiency Design Index (EEDI). The EEDI is focused on CO_2 and is currently applicable only to new ships. However, the potential to apply EEDI to the current fleet is under consideration.

Some ports, such as Gothenburg and the port of Los Angeles, have initiated green fees independently of any shared index: Gothenburg applies lower dues for vessels using low sulphur and with reduced NO_x emissions, and the port of Los Angeles developed the Main Engine Low-Sulphur Fuel Incentive Program, where the port committed up to US$10 million for a one-year incentive program (in 2008/2009) to encourage vessel operators to use low sulphur (0.2% sulphur or less) Marine Gas Oil (MGO) or Marine Diesel Oil (MDO) in their main engines during their approach or departure, out to 20 or 40 nautical miles. Funding was provided by the Port to cover the cost differential between the cleaner burning low-sulphur fuel and the heavy bunker fuel typically used (Port of Long Beach, 2011). This policy was applied in anticipation of the forthcoming California Air Resource Board regulation on fuels. Both ports now appear to be looking at index-based approaches.

What are the main strengths of vessel indexing at port level? In our view the following points should be highlighted:

- They are focused on the ship, independently of the flag, ship-owner or shipping company. In other words, once a geographical group of ports decide to apply a fee based on the vessel, the avoidance risk is limited.
- So far, most applications work as a promotional system of differentiated dues, and not as a tax system which could affect ports' overall competitiveness.
- It is port-driven, which means that a single port or group of ports can launch such a policy, independently of a need for a worldwide consensus at the IMO level. In the case of ESI, a few

Northern European ports have been able to start this system independently of other constraints.

At the international level, promoting vessel environmental indexing is beneficial as a first step to allow the apportionment of international shipping emissions based on seaborne trade. Indeed, current attempts to measure international shipping emissions from international seaborne trade are limited due to the lack of information about emission factors on specific trade lanes. Also, national efforts to promote green shipping would only be 'visible' in statistics if ports or shipping companies could indicate the average emissions by trade lane for a selection of ports.

5.3. On-Shore Power Supply

There is considerable interest at many ports in using on-shore power supplies instead of the ship's engines when in port to reduce emissions (also termed 'cold ironing'). It is estimated that the greater efficiency and emissions abatement technologies of power generation plants compared to on-board generators can reduce CO_2 emissions by more than 30%, nitrogen oxides and particulates by more than 95% and eliminating noise pollution (Enel, 2011). In the UK, cold ironing is also encouraged by the UK Government in its Ports Policy Review which states[7]:

> "We would like to see ports work harder to reduce emissions from ships while alongside by the provision, where feasible, of shore-side fixed electrical power supplies to replace ships' generators while in port (a practice known as 'cold ironing'). This can substantially reduce emissions. Its application has been limited, to date, by problems of compatibility and technical standards covering the large range of ship sizes and types, and it is not yet clear that the benefits of adoption would in all cases outweigh the costs of installation and retro-fitting of equipment. However, we are actively supporting the development of an international standard for shore connection and we will in future expect newly developed terminals to make advanced provision for 'cold ironing' facilities. We will also expect major ports to formulate plans for introducing such facilities at existing terminals once a standard has been agreed" (Department for Transport, 2010).

However, the UK's House of Commons Environmental Audit Committee (2009; 33) reports a number of sceptical industry views about the potential benefit and likely implementation of cold ironing in the UK and calls for caution by government:

> "The provision of electricity to ships in berth is not a priority for climate change policy. Until grid electricity is decarbonised it would have little impact on carbon emissions, unless ports installed new renewable energy generating infrastructure; while this would be welcome, there might be considerable practical and economic obstacles in doing so, especially at existing facilities".

On-shore power supplies have been introduced by several ports around the world, but so far without agreement on an international standard (see Dutt (2010) for examples). Some EU ports have already introduced on-shore electricity at some of their terminals e.g., at Gothenburg (since 2000) and at Lübeck, as well as at ports outside the EU at Los Angeles, Seattle, Juneau and Vancouver. In the EU, Venice and La Spezia recently announced plans to become 'green ports' with cold ironing as their main objective. Antwerp has also introduced cold ironing for seagoing ships belonging to the Independent Container Line (ICL) as a trial for more widespread introduction. In the USA, the Clean Ports USA programme has been developed by the Environmental Protection Agency in conjunction with the American Association of Port Authorities with the aim of reducing emissions in US ports (AEA Energy and Environment, 2007). Recent developments have also been observed in several additional ports (Cooper and Gustafsson, 2004). However, the overall impact on emissions depends on how the shoreside electricity is generated—Gothenburg for example uses wind turbines. To date, no UK port has adopted such technology, and there has been controversy over the potential for on-shore power supplies to reduce CO_2 emissions given the UK's current reliance on fossil fuels for electricity generation, as the above Select Committee quotation illustrates.

Table 14
Ship types and OPS at ports.
Source: Dutt (2010).

Type of ships using OPS	
Inland barges	5 Ports (out of 17 ports responding to the survey question)
Ro/Ro	8 Ports (2 WPCI)
Container	2 Ports (1 WPCI)
Cruise	3 Ports (3 WPCI)
Ferry	3 Ports (1 WPCI)
ROPAX	4 Ports (1 WPCI)
Other	9 Ports (5 WPCI)

The move to cold ironing was given a financial impetus by the EU's Sulphur Directive (EC Directive 2005/33/EC) from 1st January 2010 which requires that vessels use diesel with 0.1% sulphur content when in port. The resultant higher fuel costs may make shore side electricity sources more attractive financially. A shift to shore-based electricity formed part of an agreement between Milieudefensie (FoE, Netherlands) and the Port of Rotterdam Authority on the environmental performance of the Second Maasvlakte port extension and has been introduced for the Stena Line terminal at the port (Green Port, 2012). However, studies by Rotterdam port indicated that large infrastructural investments were required for a relatively small environmental impact (Doves, 2006). The total cost per berth can vary from US$0.5 to 1.0 million. Some ships, such as tankers, will not be able to take advantage of cold ironing as the largest vessels require around 25 mW per ship—equivalent to the output of five large off-shore wind turbines (Gilbert et al., 2010). A study at the Port of Piraeus with cruise ships (Tzannatos, 2010) showed that even when using low-sulphur fuels, the financial return on such investment is very small. Only when social costs were included was a better return on investment observed and even then only for the ships with frequent calls. Where there are few social and environmental pressures from local populations in the immediate proximity of a port, it may be difficult to justify such investment on financial considerations alone.

A survey by WCPI of 53 ports worldwide indicated that 32% currently provide shore side electricity and 85% are considering introducing or expanding shore side power facilities in the next 5–10 years (Dutt, 2010). Those ports with shore side power were more likely to be considering expansion than those without—barriers for the latter included lack of cost effectiveness, lack of available power and no feasibility study conducted, as well as a majority of unspecified reasons. The reasons for introduction were for: environmental benefits (94%) (these were mainly for the impacts on NO_x, CO_2 and sulphur); for customers[8] (70%); and for reputation/goodwill (59%). Only 20% of respondents believed there

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[7] This can substantially reduce emissions.

[8] These were predefined categories in the survey. It is not clear if the category 'for customers' refers to demand from them or simply as service provision.

Table 15
Scope for UK CO_2e emissions reduction from On-Shore Power Supply.

Values used for our study (g/KWh)	Specific fuel consumption	Emissions factors								
		CO_2	SO_2	NO_X	PM	NMVOC	CH_4	N_2O	CO	
Average emission factor at berth	217	690	0.90	13.00	0.50	0.40	0.008	0.0310	0.9000	
Power plant avg emission factor		524	0.46	0.35	0.03	0.02	0.012	0.0096	0.0125	
Savings in t for 2.6 GWh		442,157	1172	33,694	1252	1012	10	57	2364	
GWP		1	–	–	–	–	21	310	–	
Savings in tCO_2e		442,157	–	–	–	–	212	17,694	–	459,638

were economic benefits to be gained (Dutt, 2010). The WPCI survey reveals that in many cases OPS has been developed for Ro–Ro vessels (Table 14). This can be explained by the profile of Ro–Ro vessels activity i.e., frequent calls in the same small number of ports. Moreover they are less sensitive to the voltage standardisation problem. Different voltage standards are required and ship owners are unwilling to install systems if these cannot work in every port. Hence vessels calling at the same small number of ports with predefined docks are better candidates for OPS. Given the UK's relatively large share of Europe's Ro–Ro shipping activity, there is potential for application of OPS therein as an emissions reduction strategy. Another downside to note however is that with Ro–Ro average duration of call is usually lower than is the case with other vessel categories, making it less attractive in terms of potential emissions reduction.

Turning now to consider the potential for GHG reduction using shore side power, one has to compare with the average emissions from the UK Grid (obtained from Defra, 2011). The analysis can then be extended to other GHG gases such as Nitrous oxide (N_2O) and methane (CH_4). Table 15 shows the maximum scope of reduction from On-Shore Power Supply.

It can be seen from Table 15 that the maximum theoretical potential is relatively modest (-459 kt CO_2) if one considers that such scope represents an improbable hypothesis of 100% equipped ports and vessels. Also, one has to consider technical feasibility constraints, such as the connection and disconnection time at berth (1 h per call) and the economic feasibility for vessels that are not frequent callers. All of these limitations suggest that on-shore power will have a relatively limited impact on overall greenhouse gases emissions for the UK if use of the current electricity energy mix continues. Significant reductions are then only possible if ports are able to provide renewable energy for those ships.

However, on-shore power remains an effective way to reduce other pollutants, such as NO_x (by 97%), SO_2 (by 50%) and PM (by 89%) (Entec, 2005), as Table 15 also indicates. Table 16 shows the sources used to assess auxiliary engines and power plant emission factors. It is important to note that for the gases without global warming potential, European average values for power plants were used, whereas for CO_2, N_2O and CH_4 Defra's values for the UK mix were used.

The potential for on-shore power should perhaps be analysed more in terms of social costs, since such gases are well known pollutants for local populations.[9] Further research work could look at these effects other than greenhouse gases, using detailed, port-by-port approaches developed at the EU level and already applied for shore power (AEA Technologies, 2005; Tzannatos, 2010).

Table 16
Sources for auxiliary engines and power plants emission factors.

Emissions (t), connected aux. engine (MSD/MGO, 0.1%S)	Sources for aux. eng. emissions	Sources for power plant emissions
CO_2	Entec (2010)	Defra (2011)
CH_4	Cooper and Gustafsson (2004)	Defra (2011)
N_2O	Cooper and Gustafsson (2004)	Defra (2011)
NO_x	Entec (2010)	Entec (2005)
SO_2	Entec (2010)	Entec (2005)
CO	Cooper and Gustafsson (2004)	Entec (2005)
PM	Entec (2010)	Entec (2005)
NMVOC	Entec (2010)	Entec (2005)

5.4. *Automated Mooring Systems*

The mooring operation is the final vessel approach for an attachment to the quay. Such operations can easily take up to 30 min for a large container vessel, with a need for propulsion from tugs and the main vessel. Automated Mooring Systems are solutions that allow a quicker mooring (approximately 30 s) with a requirement for only one operator. The system works with a vacuum system that can pull the vessel towards the quay and keep it steady. With such systems, vessel emissions are reduced since mooring operation time is reduced to a few seconds only. Engines can be shut off approximately half an hour earlier. To date, solutions exist for dry bulk, liquid bulk, containers and Ro–Ro vessels.

However, we can see from Table 11 that emissions from manoeuvring operations were 229 kt of CO_2 in 2007, a small fraction of all emissions. Even if one considers that the CO_2 savings associated with such technology are higher than those calculated for on-shore power (due to the time reduction), automatic mooring systems appear to be more useful as a productivity tool than as a carbon reduction strategy, unless they are associated with vessel speed reduction.

5.5. *Exhaust gases control for auxiliary engines*

The use of sea water scrubbers to control exhaust gases from auxiliary engines is still at an early stage, but a few ports are driving change in partnership with shipping companies. The Ports of Los Angeles and Long Beach for example are testing such systems with the help of the State University of California (Port of Los Angeles, 2011). Tests are being carried out with a cargo vessel from American President Lines (from 2010, with US \$1.65 million investment) and a container vessel from Horizon Lines on a regular service between Los Angeles and Shanghai (investment: US\$1.8 million). These scrubbers are expected to

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[9] See for example the case of Chinese ports—BSR (2011) extending supply chain sustainability metrics to terminal operations. Available at ⟨www.bsr.org⟩.

reduce particulate matter by 85%, sulphur oxides by 50% and nitrogen oxides by 3%.

For UK ports, this solution could be seen as an alternative to On-Shore Power Supply, even though it is difficult to predict today the exact future potential of such technology for auxiliary engines, considering the lack of complete real scale tests. Emissions' reductions depend on the technology applied and, even though there have been recent controversies about the impact on CO_2 emissions, it is assumed that in any case greenhouse gas emissions are not drastically reduced via this technology (Hamworthy, 2007). Other consequences to be considered are the collection of sludge (expected to be minor) and the local impact on water quality if the system works with a seawater open loop.

6. Conclusion

The ports sector is increasingly acting as a driver for policies on carbon emissions reduction in the maritime sector. Ports working both individually and collectively have developed policies to reduce emissions not only from their own activities, but also to encourage shipping companies to reduce carbon emissions. There may be considerable future potential for port actions to have substantial global influence—as AEA Energy and Environment (2008; 54–55) state:

> “The ownership of the world′s key ports are limited to a small number of companies…over 50% of global container throughput is controlled by seven major companies. Given this relatively organised structure, it is possible that given the right incentives, ports will participate in the implementation of a range of changes that would allow GHG emission reductions from ships”.

Based on our analysis of operations at five major UK port companies, it has been demonstrated that emissions from shipping at berth (1.8 mt CO_2 in 2007—Table 9) are ten times greater than those from ports' own operations (174 kt CO_2 in 2008 for ports companies representing 32% of tonnages—Table 1). Moreover, it can be seen that shipping emissions associated with seaborne trade at those ports (approximately 10 mt CO_2—Table 7) are far more important than the ones generated by port operations. This evidence suggests that UK ports should include in their carbon footprint analysis the emissions from ships, probably as a ‘scope 3’ emission.[10]

Port mitigation strategies for Ocean Going Vessels exist and have been applied by several continental European ports. Measures analysed in Section 5.1 (vessel speed reduction) and Section 5.2 (green shipping promotion) require low capital investment and could be applied by UK ports, especially given that many competitor Northern European ports already apply some of them, reducing ports' concerns over maintaining competitiveness. Among those solutions that require higher levels of capital investment, on-shore power can represent an advantage for urban ports that aim to reduce NO_x, SO_x and PM emissions. However, the reduction of greenhouse gases seems limited through this technology, given the current UK electricity grid mix and reliance on fossil fuels. Further studies that focus on the social cost of NO_x, SO_x and PM should be carried out, preferably on a port-by-port basis to investigate the potential of on-shore power at the individual port level. Automatic mooring systems could be a solution with potential in the long run, with an increase in port productivity and the reduction of mooring times, but the actual scope for direct greenhouse gas reduction is limited if the use of such technology is not associated with vessel speed reduction.

In order to complete our vision on the potential for reduced carbon emissions in the maritime sector, further work should be focused on the analysis of long term trends on ports traffic, such as: the continued increase of container traffic, the potential impact of carbon capture and storage and the likely use of LNG-fuelled vessels. Some of the abatement options being considered by the shipping industry may depend on port authorities altering existing port infrastructure. For example, changes to hull design and ship dimensions as measures to improve energy efficiency may lead to changes in overall vessel dimensions with consequent demands for infrastructure changes. Some proposed propulsion technologies for shipping may need infrastructural change and meet with resistance from port authorities if they are perceived as dangerous (e.g., nuclear power, hydrogen fuel cells). Infrastructural change could also improve port congestion, though the impacts upon emissions are difficult to calculate as there is a poor understanding of port energy use both from port activities and from wasted fuel by ships awaiting berthing.

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[10] Similar conclusions are reached for a study of Jurong Port, Singapore (Jurong Port (2010) Carbon Footprint Report, Jurong Port Pte Ltd., Singapore).

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