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Payback period for emissions abatement alternatives: the role of regulation and fuel prices

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ABSTRACT

As of January 2015, the new maximum limit of fuel sulfur content for ships sailing within Emission Control Areas (ECA) was reduced to 0.1%. A critical decision for shipowners in advance of the new limits was the selection of an abatement method that complies with this new set of regulations. Two main options exist, involving the investment to scrubber systems that remove SO_2 emissions from the exhaust, or switching to low-sulfur fuel when sailing in regulated waters. The first option would involve significant capital costs, while the latter would lead to operating cost increases due to the higher price of the fuel used. This paper conducts a literature review on emissions abatement options and relevant research in this field. A cost/benefit methodology to assess emission reduction investments from shipowners is also developed. Also examined in this study are the effects of recent bunker fuel price drops to the payback period of a potential scrubber investment. The results show that lower prices would significantly delay the payback period of such investments, up to 2 times in some cases. The case studies present the emissions generation through each option for representative short sea shipping routes. The repercussions of low sulfur policies on large emission reduction investments including cold ironing are briefly examined, along with implications of slow steaming to their respective payback periods. Recommendations are made for future research in anticipation of future regulations and technological improvements.

INTRODUCTION

A recurring theme in maritime shipping is the effective management of the sector's environmental impacts. Shipping is considered the most efficient transport mode in terms of carbon emissions per ton-km moved (1). Its percentage share to the global anthropogenic CO_2 emissions has seen a decline in the last years from 2.7% in 2008 (2) down to 2.2% in 2013 (3). Over the last few decades a number of environmental regulations and policies have been proposed to tackle the issue of air emissions from shipping, with some focusing on carbon emissions and other measures targeting other pollutant species. Despite these initiatives, emission outputs have continued increasing in absolute terms. Furthermore, maritime transport is not as clean in terms of other pollutant emissions. Bunker fuel used in marine engines is of considerably lower quality compared to fuel used in other modes of transport.

The amount of SO_2 released in the atmosphere through fossil fuel combustion is proportional to the sulfur content present in the fuel. As a result, there have been efforts to produce cleaner fuel with lower sulfur content and regulate the maximum allowed content. The most notable regulation has been implemented by the International Maritime Organization (IMO) which has set progressively stricter limits of sulfur content allowed in fuel. The IMO has also specified designated Emission Control Areas (ECA) where even tighter limits apply (4). In fact, since January 1st 2015, within such areas, vessels must use fuels of a maximum 0.1% sulfur content or deploy additional abatement measures that achieve the same reduction in SO_2 emissions. Similar strict limits (0.1% maximum since 2008) were also in place by the European Union for vessels sailing through inland waterways and during port stays longer than 4 hours.

As such, shipowners have the option to either use Marine Gas Oil (MGO) that satisfies the imposed limits, or invest in scrubber systems. These are emission control devices that are installed onboard a vessel and treat the exhaust gases to remove particulate matter (PM) and SO_2 emissions. Scrubber systems are characterized by significant installation costs, but allow the use of bunker fuel which is cheaper. Therefore, for vessels sailing in ECA a critical decision is which abatement solution is economically more beneficial. A similar decision problem can be identified for vessels calling at ports where the use of low sulfur fuel is mandatory. An additional option for these vessels would be to invest in cold ironing retrofits if the port is able to provide shore power, which in turn depends on the investment costs per cold ironing berth. The ship operator's decision on using cold ironing depends on the prices of each type of fuel, the costs of installing scrubber systems, the costs of vessel retrofits with cold ironing equipment, and the cost per kWh as supplied by the port.

The first section of this paper includes a literature review on the different abatement options considered. The repercussions of fuel price fluctuations to the shipping sector over the last decades are also discussed. The subsequent section presents a cost/benefit analysis method for the assessment of potential investments. The case studies highlight the importance of trip characteristics and fuel prices and how these can affect the payback time of large investments in abatement technologies. The environmental implications of each decision are finally considered. The paper concludes with remarks on the importance of the volatility of fuel prices which may change the effectiveness of proposed regulatory environmental measures.

LITERATURE REVIEW

Previous research in the field mainly focused on the estimation and reduction of the environmental impacts of the maritime sector through operational practices. Slow steaming refers to the practice of mitigating fuel costs by reducing sailing speed. It first came to prominence after increase in bunker prices in the early seventies, and resurfaced as an option following the increased prices in 2008. Currently most shipping lines have adopted slow steaming, and new vessels are designed to sail at lower speeds. Propulsion engines are typically designed to operate in between 70 and 85% of their maximum continuous rating (MCR) where their specific fuel oil consumption (SFOC) is near its minimum value (5). For this reason, considering that slow steaming is expected to continue as a practice in the future, there have emerged some complementary technological measures. The propulsion engines may be derated to have lower SFOC at the lower engine loads operated, an action that can be reversed (6). Alternatively, on a strategic level new vessels built may be equipped with smaller engines so that their design speed is at a lower level. In both cases, the fuel consumption will increase if the vessel requires increasing its speed, or sailing through bad weather at the same speed.

Fuel Price and its role on speed

Several studies in the past have attempted to calculate the optimal sailing speed of individual vessels or entire fleets, in order to minimize fuel consumption. Shipping lines are expecting to continue the practice of slow steaming in the near future, despite the recent drop in fuel prices. Lower sailing speeds for the same transport demand would lead in additional vessels deployed in order to satisfy demand. Despite the higher number of vessels deployed, there can be lower emissions due to the fuel economy as shown in the literature. (7). However, for each vessel there is a breakeven point for bunker price, where for lower prices slow steaming is no longer sustainable (5). This price will also depend on the value of cargo carried, as for more expensive commodities the inventory costs may be more significant than the potential fuel savings of slow steaming, and in such voyages the optimal speed may be higher (5).

The payback time of an investment in technology that allows the use of cheap fuel (e.g. scrubbers or LNG engines) will depend on the fuel consumption of the engine. An increase in speed would result in more trips per year at higher fuel costs per trip, which in turn reduces the payback time of such investments.

Market Response and Fuel Availability

Following the designation of ECA, there have been several technical studies that considered the issue of low sulfur fuel availability (8) and assessed the feasibility of the various alternatives (9). There have been concerns on the availability of low-sulfur fuel following the stricter limits from 2015, but studies conclude that the issue will initially be economic and not technical (11). Refineries will need to produce additional quantities of low sulfur fuel to be used in Europe and the North America coasts. This is expect to result in new refineries in these countries focusing on the production of low sulfur fuel, and their residual oil to be shipped in countries where its use is allowed. This change in supply chains may also affect the price differential between the different fuel types in the coming years.

The response of the market to the increasing bunker prices within ECA, was to apply the Bunker Adjustment Factor (BAF) - a series of surcharges to freight rates imposed on shippers (12). However, there have been examples of shipping companies that have terminated some routes following the new sulfur limits from 2015, as these routes were no longer profitable. A survey conducted by Lloyd’s List on sulfur abatement, showed that most shipowners were considering using distillate fuel as the preferred abatement method until 2020. Following that period, a switch to LNG for new builds, or the use of Scrubber systems (provided these are proven effective) is the anticipated response (13). At the same time various shipping companies have started installing scrubber systems in some of their vessels. The decision to merely retrofit a portion of a company's fleet and using MGO in the remaining vessels may reduce the risk of investing heavily to retrofit all vessels. However, such decisions were taken before the unexpected drop in fuel prices that started in 2014.

Expansion of ECA and new regulation tier

Currently, the major implications of sulfur requirements affect vessels spending part of their journeys within regulated waters. According to the IMO regulation, the maximum allowed sulfur content will be 0.5% for all regions outside ECA from 2020 and therefore refineries will have to meet the new levels of demand for low sulfur fuel. The implementation of the new lower limit may be postponed until 2025. The designation of additional ECA could affect short sea shipping and could lead to modal shifts or longer sailing routes to avoid regulated waters. A case study on a possible designation of the Mediterranean as an ECA predicts an important modal shift towards road or rail modes due to the higher transport costs via the maritime routes (14). However, this modal shift could result in lower carbon emissions for some routes due to the lower distances travelled, the high sailing speeds of specific vessels, and the unutilized capacity on some vessels.

Speed Optimization in ECA

For vessels sailing within and outside ECA, speed optimization has been suggested to reduce fuel operating costs (15, 16, 17). The principle behind speed optimization lies in the reduction of fuel consumption for pricier MGO through sailing at lower speeds. Higher speeds are then used to make up for lost time by increasing speed in waters where HFO use is permitted. The ECA refraction problem has also been considered to describe the concept of reducing the necessary length of travel within regulated (18). Both problems have been proven to have an economic benefit, but environmentally lead to higher CO_2 emissions due to the overall higher fuel consumption. The percentage increase in carbon emissions will depend on the relative lengths of segments within and outside ECA. At the same time, the speed differentiation will lead to even lower sulfur emissions locally due to the lower activity within the ECA.

It should be noted that considering the next tier on sulphur limits from 2020 (or 2025) onwards, it can be expected that speed differentiation will not have as significant savings in the future due to the anticipated lower price differential of fuel used in and out ECA. The installation of scrubber systems would constitute the two speed optimization problem obsolete as the fuel cost per NM will be the same for all areas.

Abatement methods

The available options to ensure adherence to regulatory standards include the use of scrubber systems, fuel switching to MGO, considering dual fuel engines that can use LNG or rely to shorepower for covering energy requirements at berth. These are summarized in Figure 1.

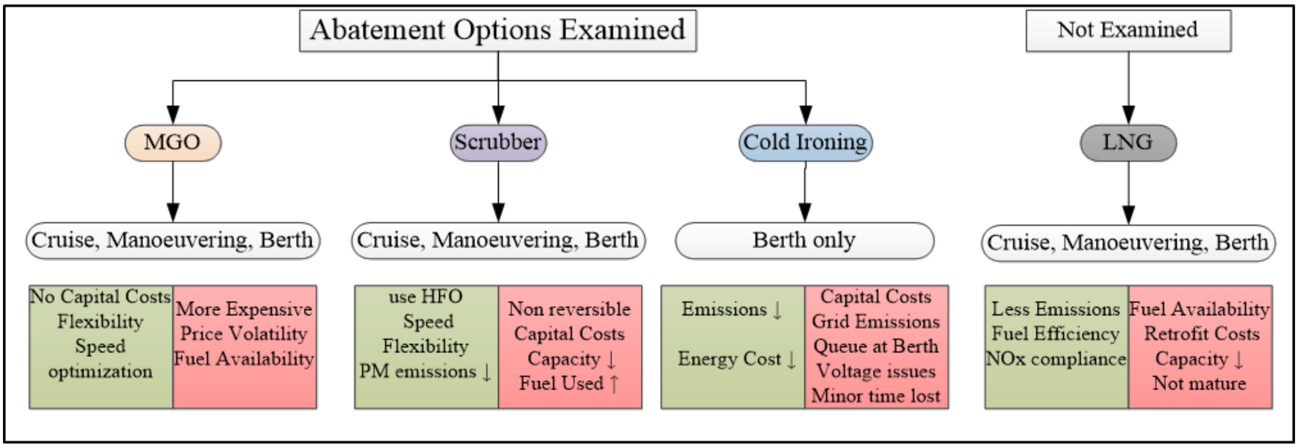

FIGURE 1 Abatement Options that comply with sulphur regulation in ECA and EU ports

Figure 1 shows the activities where each solution can be used, and also presents briefly their main advantages and disadvantages. This section will present these solutions in more detail.

Marine Gas Oil

MGO is pure distillate oil with sulfur content lower than 0.1% which constitutes it the only fuel that can be used in conventional marine engines within regulated waters. There are no major modifications required for marine engines to run on MGO. However, the fuel needs to be stored in different tanks when a vessel uses both types. There are some implications of switching to MGO that may affect the engine’s performance. MGO has a lower viscosity and there may be need for additional lubrication to avoid damage in the engine’s fuel pumps. However, such impacts will not be considered in this paper.

MGO price

MGO has been historically more expensive than HFO due to higher processing for its production. Forecasting future fuel prices and price differentials between different fuel types is a very difficult task (19). MGO is considered to increase its price faster than HFO due to the higher demand for low sulfur fuel (20). In 2013 the price difference was at $230 per ton (MGO 43% more expensive), whereas following the recent drop in crude oil price this difference is now at $178 and 56% (source: www.bunkerworld.com). It is interesting to note that MGO currently has similar prices as HFO had two years ago. Feasibility studies had predicted a constant increase in fuel prices which may have constituted scrubber systems and cold ironing as more attractive options.

Scrubber Systems

The main principle of a scrubber system is to filter the exhaust gases through water in order to neutralize the sulphur oxides resulting in sulfates.
There are three main types of scrubber systems available depending on the origin of water used to wash out SO_x:

- seawater scrubbing,
- freshwater scrubbing,
- and hybrid systems.

The first type is using seawater to neutralize the acidic exhaust gases, whereas in waters where alkalinity is too low (e.g. in the Baltic Sea or Alaska) fresh water scrubbers must be used (21).

Hybrid systems are allowing the change of water used. Scrubbers can be installed on new builds, or older vessels can be retrofitted. Retrofitting a vessel typically costs more and will also reduce the capacity of the vessel due to the space required for the installation. This paper will only consider freshwater scrubbers as a retrofit option for a vessel.

Environmental implications of freshwater scrubbers

Freshwater scrubbers are reported to reduce SO_x by up to 97% and PM emissions by around 30 to 60% when HFO containing 3.5% sulfur is used (8). However, the use of scrubber systems requires energy and therefore an increase in the overall fuel consumption per trip is expected. This is estimated at a range of 1-3% for sea-water scrubbers and 0.5-1.5% for freshwater systems.

Cold Ironing

Cold ironing is a term used to describe the process of covering the energy demands of vessels at berth with power from the grid. Vessels that rely on shore power, may switch off their auxiliary engines and the only source of emissions during berth are the ship boilers that are used to maintain fuel temperatures. In the European Union, cold ironing has been used as an emission abatement option for vessels at berth than need to comply with the low sulfur content requirement. In California, despite the low sulfur requirement (0.1% within 24 NM of the coast), cold ironing is mandatory for ocean going vessels. While cold ironing is an attractive solution to reduce emissions at the port, there are important economic and environmental considerations.

Environmental performance of cold ironing

Cold ironing has the potential of significantly reducing the emissions generation in the port proximity; however there are induced emissions generated at the power source (22). These will depend on the energy mixture powering the cold ironing facility. There are also transmission and energy conversion losses associated with cold ironing (2 and 8% respectively) that have to be included in the energy cost and emissions generation calculations.

Liquefied Natural Gas

Natural Gas is an alternative option that complies with the low sulfur mandates. Dual fuel engines have been designed that can use LNG for ship propulsion. In the past, only LNG carriers would use part of their cargo as fuel, in order to maintain the cargo tank pressure. The LNG carrier fleet has increased significantly over the last decade, and many ports are now offering or plan LNG bunkering facilities. LNG has significant advantages as it results in lower emissions generation, higher fuel efficiency and lower fuel costs than both MGO and HFO. LNG as marine fuel for containerships is expected to play a significant role in the future years, especially for new vessels as the fuel economy and compliance with regulation can outweigh the higher building costs. The main challenge associated with LNG is the limited number of bunkering ports at this stage. As of 2014, a very small number of ports within ECA offered LNG bunkering facilities (23), and therefore for the purposes of this work the use of LNG as an abatement option is not relevant.

METHODOLOGY

This section will briefly present the activity based methodology used to model fuel consumption and emissions generation for each scenario. The cost effectiveness of each option will be examined in terms of cost per ton of abated pollutant. The last criterion to be used in the analysis, is the estimation of the payback period for emissions reduction investments that are alternatives to the use of MGO.

Fuel Consumption of Marine Engines

Marine vessels require energy to sail and power the electricity demands on-board (lighting, refrigerating, heating, communications etc.). Each port to port trip can be decomposed into three main distinct activity phases; cruise (S), maneuvering (M) and hoteling at berth (B). An additional anchorage hoteling activity can occur when a vessel is held near the port until a berth or a pilot is available to process the vessel's arrival. These phases are depicted in Figure 2.

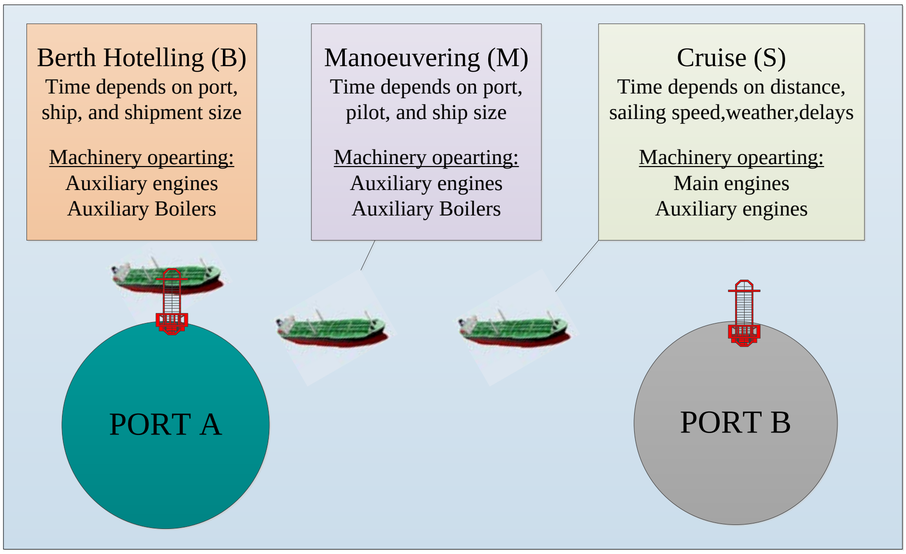

FIGURE 2 Activity phases in each trip and operating machinery

For each activity phase there are dedicated engines on board that provide the necessary power. The propulsion (or main) engines (m) are operating during the cruise phase, auxiliary engines (a) are operating at all activity phases, and there are additionally auxiliary boilers (b) that are used when the propulsion engines are not working (berth and maneuvering). Most activity based methodologies estimate fuel consumption $FC_{i,A,k}$ (kg) of engine i onboard vessel k during activity A as in equation 1.

$$FC_{i,A,k} = 10^{-3} \cdot SFOC_{i,A,k} \cdot EL_{i,A,k} \cdot EP_{i,k} \cdot t_{A,k} \qquad with\ i \in (m,a,b), A \in (S,M,B) \tag{1}$$

Therefore, $FC_{i,A,k}$ is a function of the installed engine power $EP_{i,k}$ (kW), the engine loads $EL_{i,A,k}$ (%) as percentage of MCR, the time of activity $t_{A,k}$ and the $SFOC_{i,A,k}$ (g/kWh). During sailing, $EL_{m,S,k}$ depends on the sailing speed, the weather conditions, and the amount of cargo loaded. In most studies (5, 6, 7, 21) a cubic relationship known as the propeller law is used to estimate the changes of engine load at different sailing speeds as in equation 2.

$$\frac{EL^1_{m,S,k}}{EL^2_{m,S,k}} = \left(\frac{V_{S1}}{V_{S2}}\right)^3 \tag{2}$$

However, for containerships and vessels with higher average sailing speeds, higher exponents would need to be used. Values between 3.2 and 3.5 are suggested for medium-sized vessels (tankers, feeder containerships) reaching up to 4.5 for fast containerships during extreme weather (24). For auxiliary engines, the value of $EL_{a,S,k}$ varies depending on the time of operation (for lighting requirements) and the cargo carried (more power is required for additional reefer containers). Power requirements at berth will depend on the number of reefers, the time of operation and the port visited. This study will use average values of 30% for $EL_{a,S,k}$ and 23% for $EL_{a,B,k}$ used in previous work (15). Finally, the manoeuvring activity phase has very different durations at different ports and for different vessels. An average value of 1 hour per call is used (including departure and arrival), and for the power requirements the suggested values of the POLA emissions inventory study are used. Finally, the SFOC of any engine is a function of its operating load and will increase for low loads. This paper is using SFOC-EL curves as published from engine manufacturing companies (25, 26) to estimate these values at the different operating conditions.

Fuel Emission Factors and Grid Emissions from Cold Ironing

Emission factors are used to link the amount of pollutant emissions released to the atmosphere with the quantity of fuel combusted during engine activity. Such factors are used when actual emission data through measurements are not available.

Fuel Emission Factors

Fuel emission factors are unitless and defined in terms of weight of pollutant divided by the weight of the fuel that generated the pollutants. The emissions ε^j (kg) of pollutant species *j* can be calculated by multiplying fuel consumption $FC_{i,k}$ of engine *i* on-board vessel *k* with the emission factor EF^i.

$$\varepsilon_A^i = FC_{e,k} \cdot EF_{e,k}^i \tag{3}$$

This study uses the emission factors for CO_2 as suggested from the third IMO greenhouse gas study, which are summarized in Table 1(considering engine operation without use of scrubber systems).

TABLE 1 Emission Factors used in this study

Fuel	*Emission Factor (g/g fuel) for different Pollutant species*			
	CO_2	*SO_2*	*NO_x*	*PM*
HFO	3.114	0.02·S%	main engines: 0.087 aux. engines: 0.057	0.00728
MGO	3.206			0.00634
LNG	2.750	0.00002	0.0078	0.00018

The SO_2 emission factors are proportional to the sulfur content S(%) present in the fuel. For MGO this is not exceeding 0.1% whereas for HFO the average value is 2.7%. NO_x emission factors used are suggested for Tier I ships. The IMO has different levels of control for NOx emissions depending on the date of construction of the vessel specified in Regulation 13 of the MARPOL Annex VI (4). As this study considers investments of scrubbers as retrofitting options, the case studies refer to older vessels. Finally, PM emissions are affected by the sulfur content in the fuel, and are influenced by the operating loads of the engine with significant increase at low loads.

Grid Emission Factors

Grid emission factors are expressed in grams of pollutant per kWh of energy generated. With the exception of countries relying heavily on fossil fuel and coal, the grid emission factors are usually lower than the equivalent factors of fossil fuel used in internal combustion engines and marine engines in particular. The efficiency of the grid is gradually improving over the years, aided by stricter regulation that requires the increase of RES participation in the energy mixture. Cold ironing units in a port that powers vessels at berth produce no emissions, and offer an option that reduces local and regional pollution.

Cost Elements

Scrubber Costs

Installation costs vary significantly based on the size of the ship and engines. In 2005, for ships with main engine capacity above 15,000kW, typical capital costs were estimated at 147 and 209 USD per kW installed for new builds and retrofits respectively (9). More recent figures on capital investment costs, suggested a value of 6 million USD for a feeder vessel with installed power of 16750kW and carrying capacity of 1700 TEU. It is however possible that these capital costs will be reduced as the technology matures.

Cold Ironing Costs

Older vessels need to be retrofitted in order to be able to use cold ironing. Typical costs depend on the size and type of the vessel ranging from $300,000 to 2 million. For European ports outside ECA, where the only fuel requirements are at berth, cold ironing is more attractive. In contrast, for ships sailing in the ECA and therefore need to comply with low sulphur requirements at all activity phases (cruise, maneuvering, berth), investing in scrubber systems may be preferable.

Payback Period

The payback period of an investment is the time required to reach a break-even point. In other words it indicates the necessary time until the net present value (NPV) of the investment is zero, and from that point onwards the investment becomes profitable. The NPV is defined as the sum of incoming and outgoing cash flows over a period of time that have been discounted back to the present value. Considering outgoing cash flows as negative, and incoming as positive, the NPV^i of an investment *i* can be estimated as:

$$NPV^i = CAPEX^i + \sum_{t=0}^{N} \frac{B_t^i - OPEX_t^i}{(1+r)^t} \tag{4}$$

where $CAPEX^i$ is the capital investment costs of the investment, $OPEX_t^i$ are the operating and maintenance expenses in period t, and r is the discount rate. B_t^i indicates the annual benefits of using option I, which can include social costs in the form of environmental benefits due to reduced emission levels. For the purposes of this paper, the payback period will be used as a tool to analyze whether investing in a specific emissions abatement technology is a good option from the ship operator's perspective without considering social benefits in the economic analysis.

For ship operators, the decision lies in selecting the least expensive solution that ensures compliance with the regulation. The option of using low/sulphur fuel can be perceived as the do nothing case which will be compared with the investments in technology options that will reduce operating costs. Therefore, the costs of installing scrubber systems will be contrasted with the price differential between MGO and HFO. This will allow the estimation of a payback time for the installation costs.

Payback Period of Cold Ironing for the Ship

The payback time of a decision to retrofit a vessel to receive shore power, will depend on the price of fuel, the price of power, and the time spent at ports that are able of providing power. It has to be noted, that a vessel that is retrofitted to use cold ironing, may still use HFO or MGO (depending on the calling port) if it is cheaper. Therefore, for ports where the use of low sulphur fuel is not mandatory a provision of some monetary incentive maybe necessary to convince ship operators to receive shore power.

Payback Period of Cold Ironing for the Port

Significant investments are also required for port authorities that seek to provide this technology, with initial capital costs estimated between 1.5 and 3 million per berth. From the ship operator's perspective, investing in cold ironing is an attractive option to reduce fuel costs at berth. Therefore, for ports where the use of low-sulphur fuel is mandatory, or where the cost of electricity is lower than the fuel costs of the auxiliary engines it can be a viable solution. The drop in oil prices has not resulted in a similar reduction in electricity cost, and therefore ships that are able of using cold ironing may opt to use their auxiliary engines. This will increase the payback period of the port due to the lower utilization of the cold ironing berth.

CASE STUDY

Three container ships are selected to consider a cost-benefit analysis of abatement options for compliance with ECA regulations. All ships are considered Tier I vessels, that spend considerable amount of their time within ECA. Their technical specifications are summarized in Table 2.

TABLE 2 Specifications of Examined Ships

						Fuel consumption (kg) HFO no scrubber		
Ship	***Capacity (TEU)***	***V_S (knots)***	***Engine Speed***	***EP_m (kW)***	***EP_a (kW)***	***Cruise (per NM)***	***Maneuvering (per call)***	***Berth (per hour)***
A	1500	13	Medium	4200	800	48.3	102.5	96.5
B	3500	16	Medium	17000	3500	110.6	358.4	281.7
C	5000	19	Slow	36000	7400	230.4	720.2	493

Voyage Data

Ship A has a weekly service that calls at Rotterdam-Dublin-Felixstowe-Rotterdam. The roundtrip distance is estimated at 1308NM, and 53% of this is within the North Sea ECA. All ports are European, and as a result there is a 0.1% sulfur requirement during berth. Ship B is running on a biweekly service that calls at Tacoma-Anchorage-Kodiak-Tacoma. The study assumes that 57% of this distance is within the North America ECA. Finally, ship C is a conceptual case study assumed to operate between Gothenburg and Felixstowe, two times each week, and the entire distance is within the North Sea and the Baltic Sea ECA. The voyage characteristics are shown in Table 3.

TABLE 3 Summary of Voyages Examined for Baseline Case

Ship	***Port Calls per year***	***Berth hours per call***	***ECA***	***Cruise Distance***		***Manoeuvring at each port***	***Annual Fuel Consumption (tons)***
				ECA	***Non ECA***		
A	156	13	North Sea	694	614	2.5	3496.9
B	78	21	North America	1636	1338	2	90414.1
C	208	9	Slow	1046	-	2.5	26136.5

The assumption is that the selected routes are not changing and there is no seasonal variation in the voyage frequency. The hours at berth are indicative based on published results of shipping companies operating these routes, and Table 3 only summarizes the average berth and maneuvering duration. The analysis assumes that the engine loads are the same for each port, and there is no seasonality in electricity requirements.

Use of MGO within ECA and at ports

This section considers that the ships are using MGO as an abatement option when sailing in ECA and when spending time at berth. The annual operating costs are summarized in Figure 3 considering average MGO and HFO prices of 2013 and 2015 for comparison purposes.

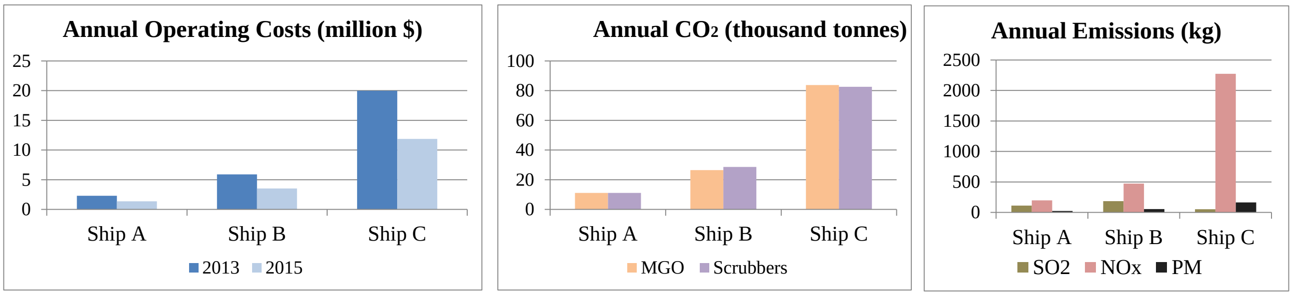

FIGURE 3 Annual Operating Costs and Environmental Impacts of using MGO vs Scrubbers

The emissions savings are estimated based on the emission factors in Figure 3 and assuming that the freshwater scrubbers are increasing fuel consumption by 1.5%, but reduce SO_2 by 97% and PM emissions by 45% if HFO is used. It can be seen that using MGO results in significantly higher SO_2 emissions for ship A, and this is attributed to the fact that the vessel spends considerable amounts of time operating outside ECA.

Scrubber Systems and Payback Period

The results of Table 3 can be used to estimate the payback time of an investment in scrubber systems from each ship operator’s perspective. This perspective is assumed to only consider the annual fuel savings achieved following the installation of the scrubbers. The annual costs in Figure 3 were considered in the respective year’s values, and for this reason the CAPEX for scrubber systems as estimated in the same year will be used as $290 and $358 per kWh. The discount rate r is assumed to be 5%, but it should be acknowledged that this value may vary for different technological solutions. For example, the EU awarded a large ferry operator with funding for the installation of scrubber systems on a number of vessels. Therefore, external funding for some technologies may make a particular solution more attractive for the decision maker.

Without considering the loss of revenue while each vessel is retrofitted, and assuming that the investment is paid back only by the reduced operating costs the payback periods are estimated in Table 4.

TABLE 4 Payback Period of Investments in Scrubbers

	Considering only Fuel Costs	
	Payback period (years)	
Year ***Ship***	2013	2015
A	4.2	9.7
B	6.5	17
C	2.3	5

Table 4 shows that the lowest payback period is observed for ship C, which can be mainly attributed to the fact that it is assumed to sail only within ECA. Ship B has the highest payback period, which is mainly a result of its lower utilization in one year (in terms of distance sailed). The most interesting result of Table 4 is the fact that the low fuel prices in 2015 have significantly increased the payback period for all ships. Therefore, a decision to invest in scrubbers in 2013 would be based on a payback period that would be shorter due to the expected increase in fuel prices. It must be acknowledged, that the case studies assumed that even in 2013 the alternative option would have been MGO. However, for the period 2013-2015 the use of fuel with a maximum sulfur content of 1% was allowed, with the exception of Californian waters (within 24 NM) and European ports where 0.1% was required. Finally, the lifetime of the project has not been considered but considering that the average lifetime of containerships is 25 years, and the examined ships were Tier I (constructed before 2001) the payback period in 2015 for Ship B may suggest that investing in scrubbers is not a good option.

CONCLUSIONS AND RECOMMENDATIONS FOR FURTHER WORK

This paper presented a conceptual approach to the issue of sulfur emissions abatement options available to ship owners. The results show that there are significant implications of the new sulfur limits to the payback period of emissions abatement investments, particularly following the unexpected drop in fuel prices. The decline in fuel prices, which resulted in equation of current MGO prices to HFO prices of 2013, may have significantly delayed the payback period anticipated by ship and port operators that invested in technological solutions ahead of the new sulfur requirements. Therefore, a potential delay in the starting date of implementation of the new global sulfur limits (0.5%) from 2020 to 2025 may also play a critical role in such investments. The suggested methodology will be enhanced to consider additional scenarios and conduct sensitivity analyses on a number of key parameters; fuel price differential, use of LNG as fuel, variation in operating patterns (speed, engine load, time at berth), discount rates, designation of additional ECA prior to the new global limits. A speed optimization approach for the fuel switching scenario will also improve the accuracy of the cost benefit analysis. The proposed analysis will allow ship operators to decide which technology option is better for a specific vessel, and policy makers to understand better the effects of coming regulation.

Effects of Slow Steaming on Payback Time

This paper did not consider explicitly the effects of a potential change in sailing speed on the payback period of such investments. Considering the case of scrubber systems, each installation is reducing operating costs due to the lower fuel costs. However, as indicated by various studies in the literature, a potential decrease in sailing speed would result in significantly lower fuel consumption per voyage, and additionally in fewer voyages per year. Therefore, slow steaming may actually delay the payback time of such investments. In addition, most studies assume that a vessel would have the same sailing speed whether it was running on MGO or using scrubber systems. An interesting next step is to examine the impact of an increase in sailing speed due to the low fuel costs on the payback time.

Inclusion of Social Costs

The inclusion of environmental improvements of emissions abatement of scrubbers vs MGO has been proposed in previous studies (20, 27). These studies suggest the valorization of environmental benefits in terms of $ per reduced ton of pollutant. Estimation of external costs is a complicated task and the values vary across different areas and pollutant species. A potential impact of the inclusion of the maritime sector in emissions trading schemes would be to significantly change the payback time of such investments, as the social cost estimations of SO_2, NO_x and PM emissions is extremely high (27). A critical question is whether to include environmental benefits of local pollutants reductions (SO_x, PM) that occur outside ECA due to scrubber systems installed.

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