Environmental discounts for Swedish ports and fairways: A ship owner perspective

Citation for the original published paper (version of record):
Parsmo, R., Ytreberg, E., Verdaasdonk, M. et al (2024). Environmental discounts for Swedish ports and fairways: A ship owner perspective. Marine Policy, 159.
http://dx.doi.org/10.1016/j.marpol.2023.105950

Marine Policy 159 (2024) 105950

Contents lists available at ScienceDirect

Marine Policy

journal homepage: www.elsevier.com/locate/marpol

Environmental discounts for Swedish ports and fairways: A ship owner perspective

Rasmus Parsmo [a,b,*], Erik Ytreberg [b], Maarten Verdaasdonk [c], Erik Fridell [a,b]

[a] IVL Swedish Environmental Research Institute, P.O. Box 53021, 400 14 Gothenburg, Sweden
[b] Department of Mechanics and Maritime Sciences, Chalmers University of Technology, SE 412 96 Gothenburg, Sweden
[c] Daesdonck, Bouvignedreef 1, 4836 AL Breda, the Netherlands

ARTICLE INFO

Keywords:
Environmentally differentiated port fees
Cost of abatement
Antifouling paint
Onshore power supply
Marine battery
Selective catalytic reduction

ABSTRACT

Sweden has adopted environmental discounts for ships arriving at fairways and in some ports to encourage investment in measures to reduce shipping's impact on climate change, air quality and marine environment. The present study investigates the impact of these discounts in 2020 on investment decisions made by ship-owners. As a starting point, this impact was assessed by comparing the potential annual benefits of the discounts with the annualized costs of retrofitting four selected abatement technologies. The results indicate that, while the port discounts are relatively small when compared to the costs of abatement, the fairway discounts could be significant for ships frequently calling at Swedish ports under specific conditions. However, we conclude that the discounts alone are insufficient to incentivize ship-owners to invest in abatement technologies for older ships. To improve the usefulness of these discounts, the design should incorporate a more precise internalization of abatement costs. This could be achieved by implementing individual discounts for different abatement strategies, establishing dedicated subsidies for high-cost innovative technologies, enhancing scoring systems, and by better matching the discount with other market-based policies internationally.

1. Introduction

One of the most polluted and most trafficked sea areas in the world is the Baltic Sea [17]. Due to its semi-enclosed character and low biodiversity, the Baltic Sea is particularly sensitive to environmental pressures since inputs of nutrients or contaminants from the drainage area accumulate in the Baltic Sea resulting in elevated concentrations [11]. As a result, the Baltic Sea suffers from both eutrophication and receives high loads of contaminants [17]. Recent studies have shown shipping to be an important source of both nitrogen (deposition from NO_X) [25] and copper (Cu) (from antifouling paints) to the Baltic Sea [48]. This was also addressed by Ytreberg et al. [47] who quantify the societal damage costs of shipping emissions due to the degradation of human welfare in the Baltic Sea region. The result showed the annual damage costs resulting from emissions of NO_X (impacts on human health and marine eutrophication) and emissions of copper from antifouling paints (impacts on marine ecotoxicity) to be substantial, 1.4 billion € and 0.55 billion €, respectively [48]. In response to these environmental impacts, several global regulations have been established by the International Maritime Organization (IMO). While regulations exist to control some emissions, such as NO_X and SO_X, there is a need for further global regulations to meet the IMO's objective of reducing greenhouse gases emissions (GHGs) by 50% by 2050, and new policy instruments are therefore being discussed. Also antifouling paint is only partly regulated globally where the International Convention on the Control of Harmful Anti-Fouling Systems on Ships prohibit the use of the organotins, and with amendment in 2023 also cybutryne [20]. Furthermore, international regulations and agreements are complex, and these types of processes often take time due to the involvement of multiple actors and the need to balance competing interests [1,42]. Adoptions of regulations in the maritime sector is further hindered by the fact that ships in general have long lifetimes and several regulations only apply on newly built ships.

In addition to the global regulations, ports have the ability to adopt market-based policy instruments to address the environmental impact from shipping. In Sweden, many ports and all fairways have adopted discounts on their fees based on the ships' environmental performance [37]. The environmental performance of these discounts is evaluated using two indices: Clean Shipping Index (CSI) and Environmental Ship Index (ESI). CSI considers both emissions to air and to water, while ESI

* Corresponding author at: IVL Swedish Environmental Research Institute, P.O. Box 53021, 400 14 Gothenburg, Sweden.
E-mail address: parsmo@chalmers.se (R. Parsmo).

https://doi.org/10.1016/j.marpol.2023.105950
Received 16 May 2023; Received in revised form 15 November 2023; Accepted 17 November 2023
Available online 24 November 2023

only considers emissions to air [9,12]. The purpose of the indices is to distinguish which ships have lower environmental impact and thereby have a lower damage cost to society. Studies suggest that it is beneficial from a socio-economic perspective to abate ship's emissions of NO_X, CO_2, and Cu [28,31,45]. However, it is also of interest to evaluate if and how the benefits of the discounts compare to the additional costs to invest in abatement technologies from a ship owner's perspective. Since these discounts are market-based incentives and are not mandatory, reduced emissions will only happen if ship owners choose to invest in and apply different abatement measures. In general, there are many different incentives for shipping globally [8], and the interaction between these policies is important, as the combined benefit and cost of several incentives could be enough to induce change.

The aim of this study was to evaluate whether environmental discounts provided at Swedish ports and fairways could have a decisive impact on ship-owners, and consequently, determine whether the discounts potentially could lead to a reduction in emissions to the Baltic Sea. By “decisive”, it is meant whether these discounts could incentivize ship-owners to invest in abatement technologies to mitigate emissions. The study was conducted by comparing the annualized costs of installing and operating different abatement technologies with the potential annual benefits obtained by the ship owner due to two policy instruments (discounts in ports and fairway fees). Seven model ships were used in the evaluation and the following abatement technologies (retrofitted) were included: selective catalytic reduction (SCR) to reduce NO_X emissions; onshore power supply (OPS) and batteries to reduce emissions of GHG, NO_X, and SO_X; and biocide-free antifouling paints instead of copper-based paints to reduce emissions of copper.

2. Material and methods

This study evaluated how policy instruments potentially can affect a ship owner's decision to invest in an abatement strategy. The evaluations were performed using so-called *model-ships* that represents different ship segments operating in Swedish fairways and with calls in Swedish ports. The following sections only give a brief overview of the costs of the abatement strategies and benefits of the discounts. The model ships were constructed to represent typical ships in 7 important ship segments and the assumed number of port calls are based on data from the Swedish Maritime Administration (SMA). Further descriptions about the model-ships, theory on international regulation of shipping pollution and input data can be found in Supplementary material A and B.

2.1. Abatement strategies and costs components

All costs in this study were annualized to be able to compare investments costs with operational expenditures [6]. The private cost perspective was used as a baseline for investments since that reflects whether a company is likely to invest in a technology or not. The private cost was calculated using an interest rate of 10% over a deprecation period of 10 years, or alternatively the lifetime of the technology if this is believed to be shorter [18]. Only the costs of rebuilding ships (retrofit) were considered, and not installations in new built ships, since the effect on the current fleet was analyzed rather than the future fleet. A brief overview of the four selected technologies is given below. A more detailed description of the costs of the four abatement technologies can be found in Supplementary material A and B.

2.1.1. SCR

The model ships were assumed to use SCR to reduce NO_X at sea, since SCR is the most commonly used NO_X reducing technologies on ships today [19] and that it is possible to retrofit existing ships with SCR [46]. The abatement potential is presumed to be the same as if a ship reaches the Tier III level. The costs included in the analysis were the costs of investment, urea consumption, catalyst replacement and labor. In this study SCR was only assumed to be used at sea.

2.1.2. Antifouling paint

The antifouling abatement strategy was evaluated by assuming that the ship owners switch from a conventional biocidal copper-based antifouling coating to a non-biocidal foul-release silicone coating. Two scenarios were used: Case 1, the ship owner needs to blast and repaint the entire ship as a result of switching from a copper-based-coating to silicon coating (i.e., the full grit blasting cost is not considered for the copper-based-coating) and Case 2, a full blasting of the hull is performed regardless of whether a silicone or a copper-based coating is to be applied on the hull (i.e., the investment cost for switching to a silicone-coating comprises complete blasting and repainting of the hull). The economic costs for the ship owner included labor costs (painting, washing and blasting), and the cost of the paint. These costs were in turn divided into an investment cost which involved a complete blasting and repainting of the hull, and maintenance costs, which involved regular spot blasting and repainting occurring at each drydock interval. The maintenance needs of the two antifouling systems were assumed to differ, since copper-based coating typically needs to be repainted at each dry docking while the silicone paint typically only needs to be partly applied at each dry docking [31]. Further details on assumptions and assumed default costs are included in Supporting Material B and Supporting Material A S2. *Cost components & distribution.*

2.1.3. Onshore Power Supply (OPS)

The costs for Onshore Power Supply (OPS) were determined by combining the annualized installation expenses with the annual electricity costs, and then subtracting the annual fuel costs. OPS was assumed to cover the ships entire electricity use at Swedish ports, i.e., excluding any electricity used in other countries. The investment cost of the onboard equipment for OPS only included the onboard cost of components such as the transformer, main switchboard, control panel, cabling and cable reel system. The cost of installations on shore was instead assumed to be paid for by the port.

2.1.4. Plug-in hybrid ship: battery storage

This study only included installation of a relatively small battery (1 000 kWh), since none of the investigated model ships, except the RoPax ship, were considered suitable to operate with electric power only. The retrofitting cost of installing the battery was based on two ships that have been retrofitted with a battery in Sweden [22,41]. State of charge (SOC) was assumed to be 80% implying that only 800 kWh were used between two ports.

2.1.5. Uncertainties

The uncertainty range for the cost components was modeled with a Monte Carlo simulation varying the cost components according to either a normal or a triangular distribution. The Monte Carlo simulations were performed with the risk analysis tool @RISK [32]. All costs were calculated to correspond to 2019 price levels using OECD [30] and exchange rates from the European Central Bank [13]. The cost data and key assumptions are presented in Supplementary material B and all assumptions and costs used are further described for respective technology in Supplementary material A - Tables S1 and S2.

2.2. Annual benefit of port and fairway discounts

This study examined two different *market-based* policy instruments in Sweden and two index systems, on which the policies are based. The annual benefit, which was compared to the costs, was based on these two policy instruments.

2.2.1. The environmentally differentiated fairway fee in Sweden

Ships that transport goods or passengers to or from Sweden pay a fee to the Swedish Maritime Administration (SMA). In 2020 the fairway fee was divided in three categories: (1.) port call (2.) readiness and (3.) pilot [38,39]. It was only possible to get an environmental discount on (1.), i. e. the port call share of the fairway fee. This port call fee, paid to SMA, should not be confused with the port fee charged by the port (see next section). To distinguish between these fees, SMA's port call fee is therefore referred to as fairway fee´in this study. The fairway fee is used to finance SMA and any lost revenue needs to be covered with a higher fairway fee, for the SMA budget to be in balance. The environmentally differentiated fairway fee is therefore indirectly financed by ships not getting the discount (rather than by taxpayers though SMA), in principle like a bonus-malus system. The environmentally differentiated fairway fee is based on points scored in Clean Shipping Index (CSI) further described below.

In Sweden, environmentally differentiated fairway fees have been in place since 1998 where ship owners receive a rebate on the fairway fee depending on the vessels' environmental performance [28]. The concepts, results and the discussion in this study are based on the scoring system that was in place 2020. See Supplementary material A - Table S3 for further information about the discount scheme.

2.2.2. Environmentally differentiated port fees

When a ship makes a call to a port, the port charges a port fee for the provided services. The port fee is not always a fixed amount; most of the time it depends on the ship size (vessel dues) and/or the volume of cargo/passengers (un)loaded (cargo dues). This study only considered the port fees based on vessel dues, as environmental discounts are related to these.

19 of 32 ports in Sweden use some type of environmentally differentiated port fee [3] and the discounts based on environmental performance are given in different ways. Most ports give rebates directly based on a ship's score in one of the two indices, ESI and/or CSI. Information about the discounts for the four ports included in this study (Port of: Stockholm, Gothenburg, Gävle and Brofjorden), can be found in Supplementary material A - Table S5. The port fees are used to finance respective ports daily operations, and environmentally differentiated port fees are therefore indirectly financed by ship not getting the discount.

2.2.3. Clean Shipping Index and Environmental Ship Index

Each ship arriving to a Swedish fairway may get a discount based on its score in the CSI, ranging from Class A to E [37]. In the index, a ship obtains scores based on the environmental performance beyond legal compliance in five different categories. The five categories are CO_2, NO_x, Water and Waste, SO_x/PM and Chemicals, and each category is divided in different subcategories or abatement strategies [9]. SMA discounted 3.6 million euros in 2018 and 5.8 million in 2019 to the shipping industry [23]. See Supplementary material A - Table S4 for further information about the scores used in this study.

In ESI, ships can obtain scores based on their environmental performance beyond legal compliance in the air emissions categories NO_X, SO_X and CO_2. Besides this, additional points can be obtained when onshore power supply installation is installed. The detailed methodology is described on the ESI website [12].

2.2.4. Economic benefit

The annual benefit for model ships was estimated based on the annual discount received for fairway and port fees for one year. However, the fairway fee discount is divided into three different discount steps, as illustrated in Fig. 1. For this study, only the most extreme case was considered and analyzed, which is when a ship moves from class C to class B. This change could be achieved in several ways, for example if the ship is currently not having any NO_X reducing measure it may move to a higher class by installing NO_X abatement equipment on all main engines. The annual benefit calculated in this study was set to represent the maximum discount possible when a ship moves from one environmental class to the next, including the discount on port fees. This discount step was selected because it represents the best possible benefit a ship owner could get from improving their scores in the indices.

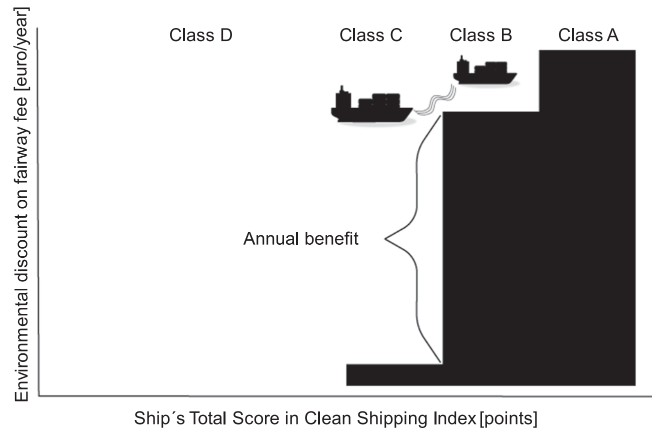

Fig. 1. Systematic illustration showing how the annual environmental discount on the fairway fee changes as a ship gets a higher score in the CSI. This benefit may be achieved in several ways, depending on which abatement strategies the ship is already using.

The annual benefit was calculated by first evaluating the number of port- and fairway discounts each model ship received in one year. However, the maximal number of discounts in the fairway fee system was 42 arrivals per year (or 3.5 per month) [39], which was also used in this study as an upper boundary of the benefit. The number of discounts was then multiplied by the benefit when the model ship moves from class C to class B (euros/discount). For all ports, except the port of Stockholm, the environmental discounts were only based on one discount step, implying that the model ship got the entire discount, see Supplementary material A – Table S5 for more detailed information. In the port of Stockholm, the rebate was assumed to be 0.1 SEK/GT, which corresponds to about 30 scores in the ESI index, which corresponds to an investment in one single abatement strategy.

The uncertainties associated with the benefits of the discounts were assessed by performing a sensitivity analysis on the depreciation time for costs (5 and 2 years). This analysis was used to illustrate the impact that changes in discount systems could have on ship owners in the short and medium term.

3. Results and discussion

3.1. Cost and benefits of selected abatement strategies

The costs and benefits of each abatement strategy are separately compared in the following section. The results are illustrated for the case that a ship is close to reaching the higher environmental class (threshold). Some further discussions about cost uncertainties and limitations can be found in chapter 5 in supplementary material B.

3.1.1. Selective catalytic reduction system and NO_X reduction

Fig. 2 shows the SCR annualized investment and annual operational costs as well as the potential annual discount for the seven model ships. The results indicate that only the tanker feeder would receive an annual discount in port and fairway fees that exceeds the annualized investment and annual operational costs for an SCR system. However, the additional discounts could cover the operational costs of the RoRo and the RoPax model-ships, implying that the number of annual visits to Sweden is an important parameter for the total rebate, since these model ships pay the maximum of 42 fairway fees per year.

The findings support the idea that the rebates offered at Swedish ports and fairways for NO_X abatement are insufficient [28]. Furthermore, compared to the old discount structure the discount is lacking in

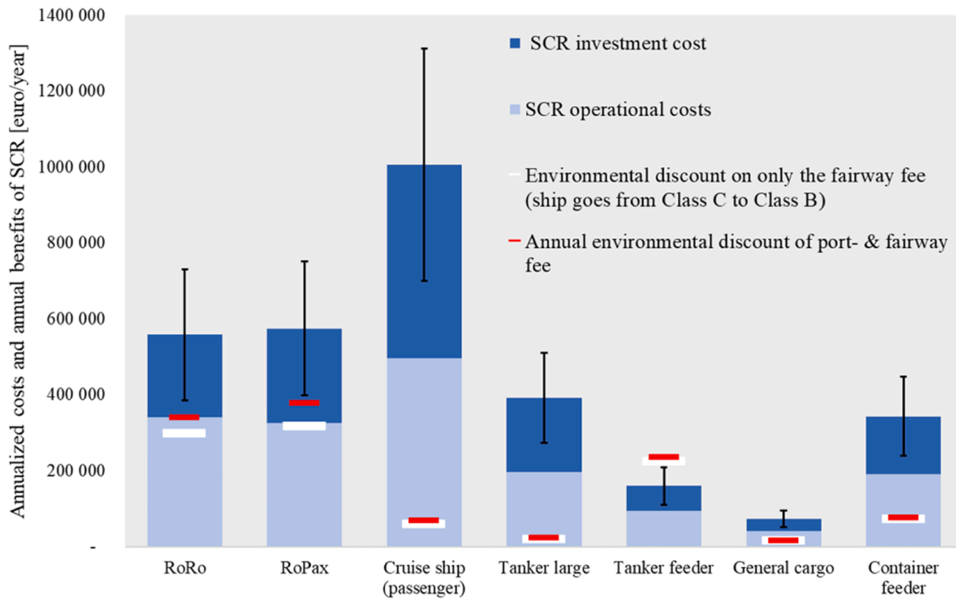

Fig. 2. Comparing the annualized cost of SCR (bars) with the benefit of a reduction of the port and fairway fee (dot and square) for retrofitting seven different model-ships, under the assumption that the SCR is operating all the time. The error bars represent the two-standard deviation of all cost. The uncertainty range of the benefit is described in Section 3.2.

accuracy, since the CSI scoring corresponding to class B could be achieved without any NO_X score at all. This is not ideal given that the discounts currently act as the primary incentive for commercial traffic to reduce NO_X emissions arriving and departing from Sweden, since the international strict Tier III regulations only apply to ships built after 2021. Additionally, these discounts provide a low economic incentive compared to the investment support available to ship owners from the NO_X fund in Norway [36], or the previous support scheme for Swedish fairway fees. Initially, the previous support scheme in Sweden included subsidies for the installation of SCR and the discounts were limited to NO_X and SO_X emissions. In contrast, CSI includes five environmental parameters categorized into over 20 abatement measures ([40]:58, [3,9,28]). In Norway, the policy is structured such that the industry pays a fee to a fund based on their NO_X emissions. The industry can then apply for investment support from the same fund for operating or investing in abatement technologies, also known as refundable emission payments [16,35,36]. This type of market-based policy instrument is in general considered to be efficient in terms of abating NO_X emissions since the money is used for real improvements and creates opportunities for innovations [5,42,43].

3.1.2. Antifouling paint

The results presented in Fig. 3 show two different cases, case 1 represents the scenario when full grit blasting was not necessary, while case 2 represents the scenario when the ship owner would need to fully blast and fully repaint the ship. As can be seen in Fig. 3 the cost of repainting the ship with silicone based antifouling paint is well below the annual discount level of the fairway fee for four of the model ships,

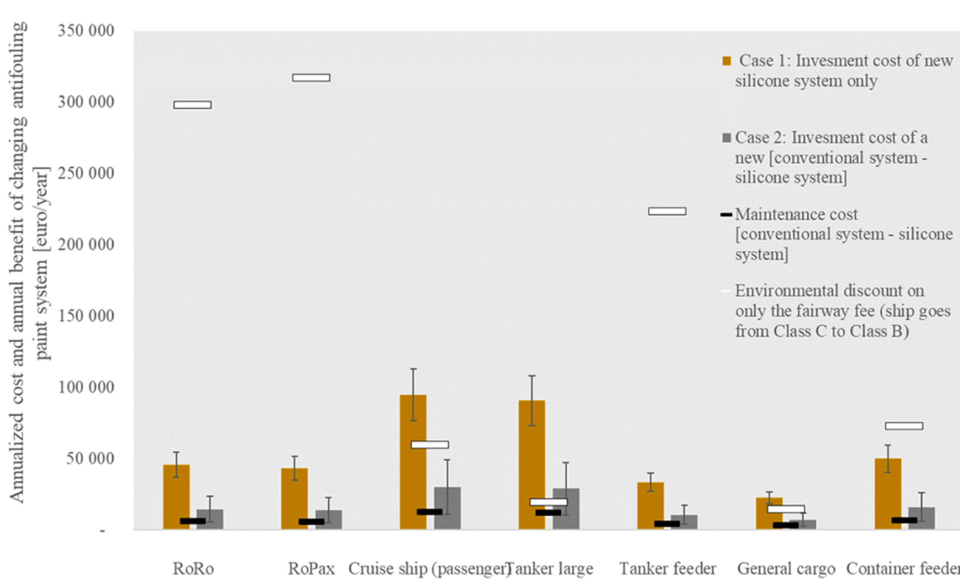

Fig. 3. Costs associated with changing from copper-based coating or silicone-based coating, when full grit blasting is not-necessary (yellow bar) and necessary (grey bar). The difference between the maintenance cost for the conventional antifouling paint and the silicone paint is indicated with black line. The error bars represent the two-standard deviation of all costs. The uncertainty range of the benefit is discussed in Section 3.2.

regardless of which case is used. Even though the maintenance cost for silicone is lower than for using copper-based paint (as indicated by the black line), this cost reduction would not be enough to compensate for the additional cost of replacing the old paint (Case 1).

In a recent study by Oliveira et al. [31], it was shown that operator cost (bunker and hull maintenance) for ships operating in the Baltic Sea region were similar when the vessel is using copper-based coatings or silicone-coatings. Considering this, as well as the fact that silicone-coating is as good or sometimes even better than copper-coating in preventing marine growth on the hull, it is worth observing that only a few ships are using silicone system today [27]. Lagerström et al. [27] summarize some potential market barriers, including general skepticism towards non-biocidal coatings and knowledge gaps. The knowledge gaps include unawareness of the newest generation of efficient silicone antifouling paint or simply that the life cycle cost of the paint is not being considered. Moreover, Oliveira et al. [31] show that the antifouling paint influence on bunker fuel consumption (not included in this study) potentially has a larger uncertainty than all other costs associated with the coating. This type of uncertainty could also have an impact on the ship owners ́ investment decisions, since status quo alternatives in general are favored in decision making processes [33].

3.1.3. Onshore-power supply

The results in Fig. 4 illustrate that the overall cost associated with the installation and operation of an OPS exceeds the benefits derived from reduced fuel consumption. This indicates that, in the absence of incentives (like the discounts indicated by the red marker), the installation (retrofitting) and operation of an OPS may be more costly. This outcome depends on two key factors. Firstly, in some cases, the total cost of electricity (comprising network charges, power fees, and electricity costs) surpasses the total cost of fuel (indicated by the yellow marker), despite the fact that electricity is priced lower than fuel. This is primarily due to the fixed monthly power fee, which becomes the dominant cost component when ships use the connection infrequently. Secondly, the investment cost constitutes a larger proportion of the total cost when ships spend less time at a port equipped with an OPS (as exemplified by large tanker ship in Fig. 4).

The cost structure of the network tariff (power fee, fixed and network fee) is relevant for ship owners, see supplementary material B for more detailed information. One particularly important challenge is the cost of high peak power demand for ships. An individual ship typically pays the same amount of money for the fixed part of the power fee, regardless of the number of times it arrives each month. This power fee dominates the cost structure, as ships tend to have similar peak power demands. Furthermore, it would be profitable for all simulated ships in the study to use grid electricity in Sweden instead of their auxiliary engines at berth if all operational fixed monthly costs (such as the power fee and the fixed network tariff) are divided by more than one ship or by a single ship spending for example the double amount of time at berth. This would ensure that the overall network cost at one connection point is not too high. However, this may not apply to other countries where the overall electricity price may be higher or lower due to factors such as taxes, network fees, or spot prices.

The uncertainty calculation for the electricity produced by the grid or auxiliary engines, as shown in Supplementary material B, reveals that the ship owner would have a lower overall cost by keeping all fixed monthly costs down, regardless of whether the ship has an environmental differentiated port or fairway fee. In addition, if the grid electricity prices are too high, the ship can choose to produce electricity with the auxiliary engine, as in the case with the high gas price in Europe [49], thus reducing the financial risk for the ship owner.

3.1.4. Plug-in-battery

The results in Fig. 5 show that the cost of installing a battery (1 000 kWh) is high compared to all operational expenses (assuming 10% interest rate and 10 years depreciation period). Compared to the cost of operating OPS the “power fee” becomes low, since the power demand could be spread out over a long charging period (6–32 h), implying lower peak power and resulting in an overall lower power fee. The results also indicate that the operational expenses (black, yellow, and blue bars) are lower than the benefit of reduced fuel consumption (yellow rhombus). It is also possible to see that the benefits of reduced fuel consumption increase if ships have more port calls per year, e.g. the RoPax ship is assumed to charge 610 times/year while the RoRo ship is assumed to charge only 300 times/year.

The results in Table 1 show that the average fuel saving at sea by using a battery for auxiliary demand corresponds to between 0.1% and 1.2% of the calculated total fuel consumption for the model ships. The potential fuel savings for the model ship with a small battery pack (1 000 kWh) is low compared with the total yearly fuel consumption for the model ships. For the RoPax ship the saved fuel would correspond to about 334 tonnes CO_2 emission /year from tank to propeller, i.e. not including the upstream emission of the electricity or the fuel. This illustrates the importance of also finding alternative fuels or using larger battery packs in the marine sector to reduce CO_2 emissions, as argued by Gössling et al. [15]. Abatement costs are high for using alternative fuels

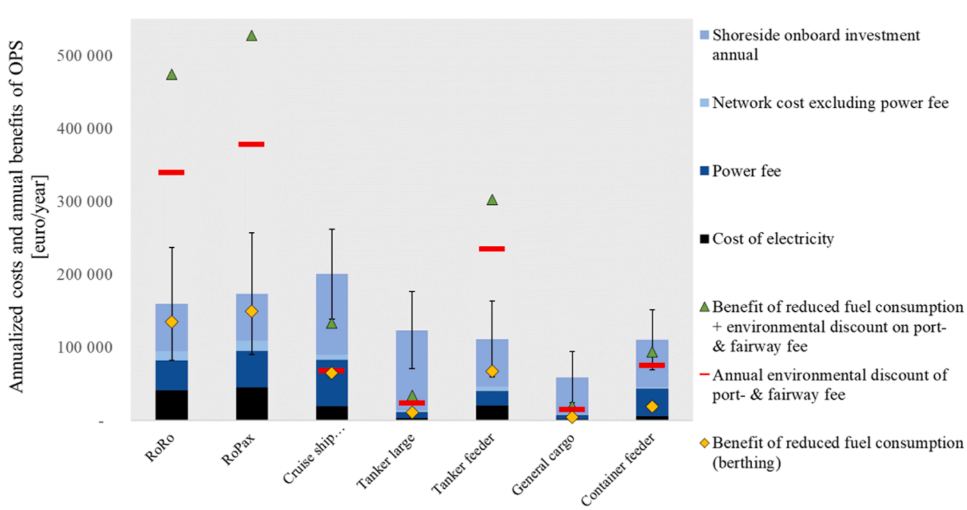

Fig. 4. Annualized cost of installing and operating an OPS system onboard a ship compared to annual benefit of using OPS. The standard deviations are based on Monte Carlo simulation. The uncertainty of the oil price and the electricity price is excluded in the error bars but is discussed in depth in Supplementary Material B. The error bars represent the two-standard deviation of all other costs. The uncertainty range of the benefit is described in Section 3.2.

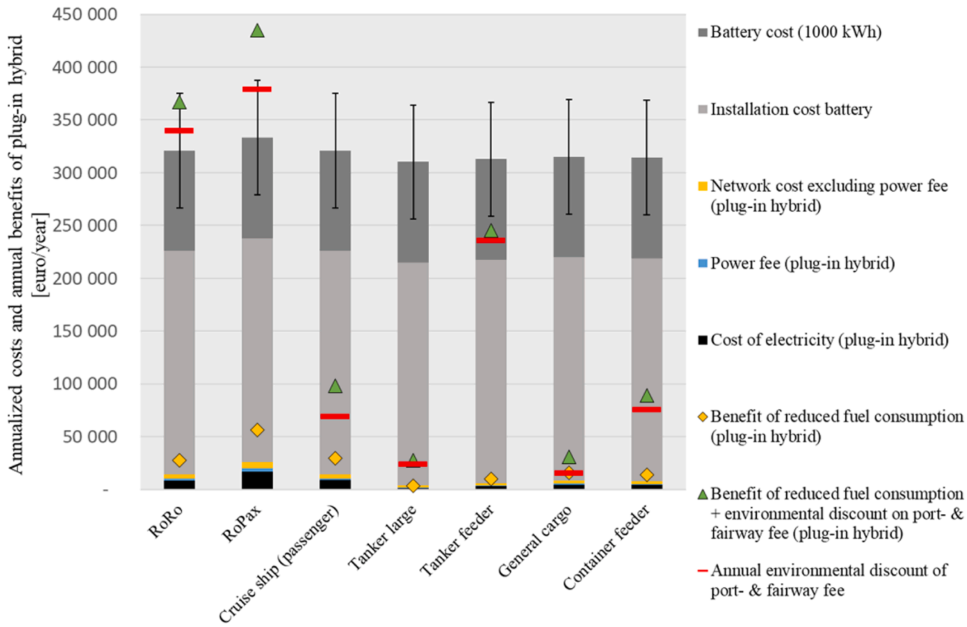

Fig. 5. Annualized cost of installing and using marine 1 000 kWh battery instead of MGO at berth. The uncertainty of the oil price and the electricity price is excluded in the error bars. The error bars represent the two-standard deviation of all other costs The uncertainty range of the benefit is described in Section 3.2.

Table 1
Fuel savings for model ships using batteries (1 000 kWh).

Model ship	*Times charging battery [#/year]*	*Time per port call [h]*	*Fuel consumption sea (ton/year)*	*Battery replaces of total consumption at sea*
RoRo	300	*8*	21 200	0.2%
RoPax	610	*6*	20 900	0.5%
Cruise ship	320	*14*	31 400	0.2%
Tanker large	40	*32*	12 400	0.1%
Tanker feeder	110	*32*	6 100	0.3%
General cargo	170	*23*	2 600	1.2%
Container feeder	150	*25*	12 300	0.2%

or batteries at sea [24,44], and the port and fairway discounts are not enough to reduce CO_2 emissions to any large extent. Studies show that if there are large market barriers, the technology is immature, and if the potential is high, it may be beneficial in the long run from a societal perspective to financially support the new technology [4,14,21,34]. In the maritime sector one example of a policy instrument that created a type of "protected space" is the use of public procurement to introduce battery-electric solutions in Norway [2], where the installation of batteries on ships has increased rapidly.

3.2. Combined benefit of the discounts on port- and fairway fees and uncertainty of future benefit

Ships may need to invest in more than one technology to reach a new environmental class in CSI or ESI indices. Fig. 6 shows all the technologies that were investigated, with the left bar representing the baseline assumptions for each ship category. The comparison shows that the total costs (bars) of installing all technologies investigated, which could

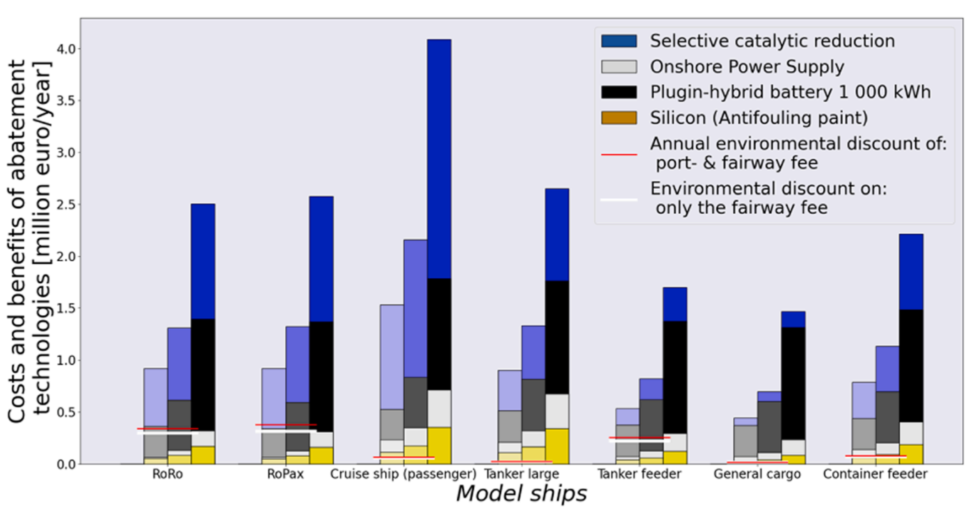

Fig. 6. Cost and benefit comparison for different deprecation period (10 years: left bar, 5 years: middle bar and 2 years: right bar). The figure also compares the overall results of retrofitting costs (bars) and benefits of policy instrument (lines) for four different abatement technologies.

potentially reduce emissions from shipping (primarily CO_2, NO_X and Cu), are higher than the benefits the ship owner would receive from a reduced port and fairway fees (red line).

The results in Fig. 6 also show that ships that arrive many times at Swedish ports (n > 40: RoRo, RoPax and tanker feeder) will have a notable portion of the costs covered by the reduced fairway fee. This prioritization of frequent visitors illustrates that the design of these discount schemes is directed towards ship with many arrivals, which implies that the discounts address the most relevant ship categories from a regional environmental perspective. However, even though these ships have a large portion of the costs covered, the suggested abatement technologies are not enough to reach the score of 100 in CSI alone, which is the threshold score that is required for a ship to be classified as a Class B ship. To reach this discount level, the ship owner would also need to invest in other abatement technologies than those analyzed in Fig. 6.

As previously described, there are many cost components with a varying degree of uncertainty included in the results. However, the uncertainty of the future benefit is also something that could affect the ship owner's willingness to invest. As described in Lindé et al. [28] the discount on the fairway fee has changed several times, also the scoring system itself has been updated several times [10]. These updates could reduce the economic lifetime of the investment for the ship owner, for example if the abatement strategy is removed from the indices (CSI or ESI) or if the discount is reduced. This uncertainty is illustrated in Fig. 6 by adopting different depreciation times; 10 (baseline), 5 and 2 years respectively. As can be seen in the figure the costs for OPS and silicone antifouling paint are still less than the benefits for some of the model ships, even under shorter depreciation times. However, the costs increase considerably, which illustrates the problem with adopting a policy instrument where the incentives are continuously paid and where the required technical measures have a high capital cost.

The results shown in Fig. 6 also illustrate that discounts on the port fees are small (2–16%) compared to the reduction of the fairway fee (the difference between the white and red lines). Even though the level of the port discounts in the selected ports are rather small in relation to the abatement costs it is also an issue that most ports the ships visit globally do not have discounts. Globally, one study has identified only about 85 ports that use environmental discounts [8],which is a small number compared to the total number of 6 651 ports worldwide, as identified in the Lloyd's Maritime Intelligence Unit's database by Keller et al. [26]. Mjelde et al. [29] even go as far as to suggest making it "mandatory for all ports to implement environmentally differentiated port fees" as a way of addressing this issue.

The calculation of benefits in this paper was based solely on a fixed number of port calls for the seven model ships. It's essential to highlight that while the total port call discount would steadily increase if a particular ship visited a port offering a discount more frequently, only a limited number of ships make enough calls to a Swedish port to bring the port call discount into a similar range as the fairway discount. Conversely, the refund obtained from the fairway fee will only experience an increase if the current arrivals of the ship are less than 3.5 times per month, considering that they already receive the maximum number of discounts.

3.3. *Scoring in fairway fee system*

The CSI scoring system contains many abatement strategies, which could be selected arbitrarily or strategically by the ship owner. If the ship owners decide to make a strategic choice based on the costs, each unique ship will face a unique cost curve. These cost curves are illustrated for the four selected abatement strategies in Fig. 7 by comparing the CSI scores and the technology costs for all model ships. In all cases, the cost per additional point in the CSI index is the highest for the battery, 100,000 €/point. The high cost per score, and the relatively costly investment (Fig. 6) implies that retrofitting a battery is expected to be less incentivized from the environmentally differentiated fairway fees, compared to the other abatement technologies. Furthermore, Fig. 7 shows that installing a 1000 kWh battery or repainting the ship (silicone) will only result in three and two additional points, respectively. These results indicate that the environmentally differentiated fairway fees will not likely be decisive for the ship owners' decision to invest in these two technologies if the ship is not very close to the threshold between environmental class C and B.

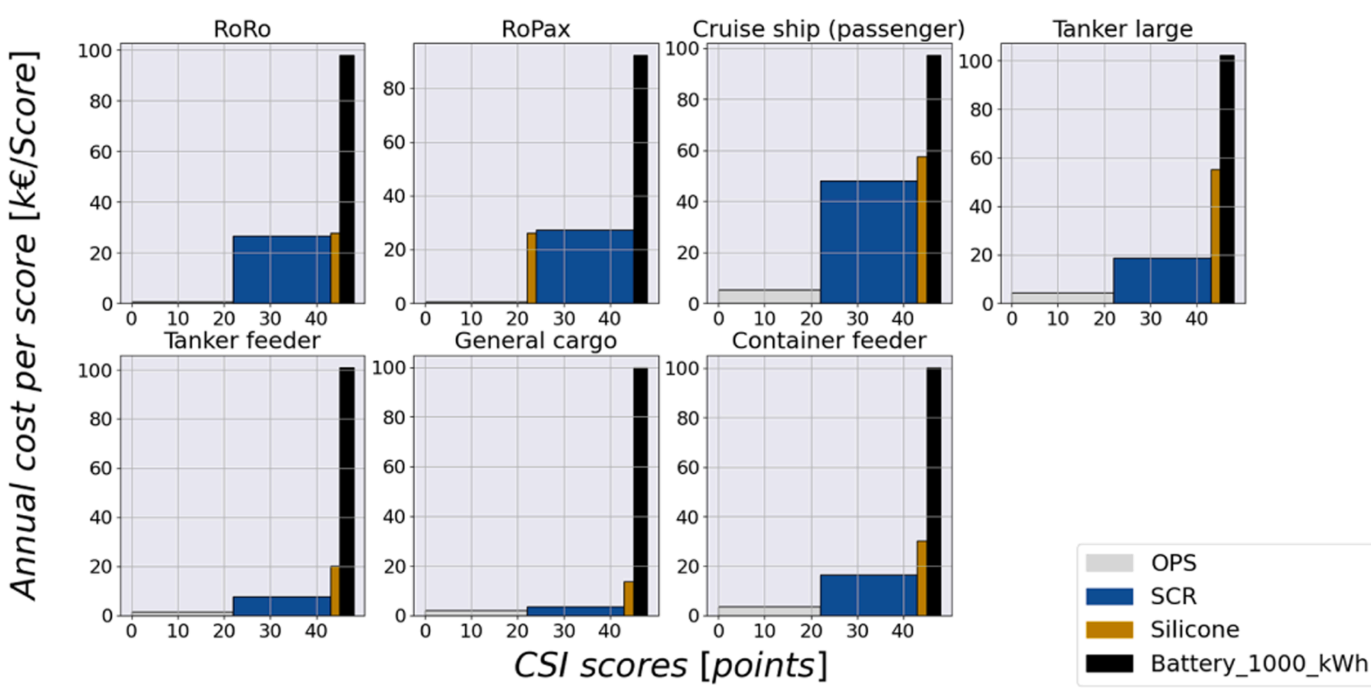

Fig. 7. Cost curves for four abatement technologies for seven different model ships. The figure illustrates the annualized cost per score in the Clean Shipping Index (CSI) for installing the specific technology compared to the total CSI score each ship owner could theoretically receive.

4. Policy recommendations

The comparison shows that from a private cost perspective, economic incentives alone are not enough to stimulate investments in all these technologies. Yet, studies have shown the environmental impacts related to ship emissions of e.g. NO_X and Cu emissions to be substantial in the Baltic Sea [47,48], and these types of measures would be beneficial from a socio-economic cost perspective [28,31,45].

Our findings show the selected abatement strategies have very different ranges of cost, uncertainties, and market barriers. However, the ports and SMA aggregate several abatement categories into only one (ports) or three (SMA) discount steps, respectively (except the port of Stockholm that has many incremental steps). A ship owner for example gets 65% discount of the fairway fees when going from environmental class C to B in the CSI index. Therefore, it is possible that a ship owner could benefit from, for example, repainting the ship using silicone-based antifouling paint but not also retrofit the ship with SCR. One solution could therefore be to separate the discount for the different abatement strategies or at least base it on the different environmental impact categories. This would also make the discount easier to evaluate since it would be possible to link investment or use of abatement measures to the discounts. Another approach could be to offer the discount in incremental steps, even though this type of policy design would be more imprecise than to categorize the discount.

Updating the scoring systems (ESI/CSI) to better match abatement costs or environmental damage costs is another potential route to encouraging ship owners to invest and improve environmental outcomes. The result of this study indicates that antifouling paint seems to be a low-hanging fruit in this context. The potential environmental savings of silicone-based coatings are vast since the usage of copper-based antifouling coatings alone on commercial shipping stands for 33% of the total input of Cu to the Baltic Sea [48]. If silicone-based coatings would receive a higher weight in the CSI index, the investment would probably be more appealing for ship owners, not only in terms of economic incentive but also communication; there are indications that information asymmetry and biases [27], could be root causes of ship owners not investing in silicone-coating, which makes spreading information important.

To make the incentives more decisive for ship owners, more ports need to adopt some type of incentive. Also, the incentives need to address matching and relevant environmental impact categories. For the global shipping, Christodoulou et al. [8] for example identified 249 incentives (like the discounts) of various types and Sköld [37] found nine different index/incentive systems (like for example CSI/ESI). The port and fairway discounts in Sweden are only partly designed to match other incentives, and the interrelatedness to other policy instruments could be improved. Without a more collective effort to design a supporting scheme, for example initiated by IMO or EU, there is a risk that the discount will be too low for ship owners to make any investment. This is also what Mjelde et al. [29] and Vaishnav et al. [45] suggested when they analyzed the potential discount for cruise ships in ports and the socio-economic benefit of the OPS in the US.

Typically, ships that already have SCR or OPS would benefit from a policy instrument that continuously refunds money based on use, like the current discounts. However, the current structure of the rebate could change with short notice, which makes this type of rebate a source of uncertainty for new capital investments. Retrofit investments in OPS, battery and SCR are unlikely under current regulations because of both the costs and the uncertainties in the rebate schemes. Ships that haven't installed OPS, battery and SCR would therefore instead benefit from some type of direct financial support or change in regulatory framework like a public procurement initiative or the NO_X-fund in Norway [2,36]. This is especially true if the goal is to introduce alternative fuels or batteries, where the costs seem to be of a different magnitude than the discounts [7,24,44].

5. Conclusion

The study examines how ports and fairways in Sweden use environmental discounts on their tariffs to mitigate the environmental impact of shipping. It evaluates the economic benefits of these discounts by comparing the potential annual benefits for different types of ships with the annualized costs of retrofitting four selected abatement technologies expected to reduce emissions that are particularly relevant to the Baltic Sea. The main conclusion is that the discounts do not seem to be a decisive factor for ship-owners when deciding whether to invest in the selected abatement technologies. For most ship categories investigated, the annual benefit of the discounts is smaller than the overall annualized cost of installing the selected technologies. Furthermore, the uncertainties associated with these investments are large, both in terms of cost and benefits. It is also worth noting that the potential economic benefits of the discount on port fees are small relative to the cost. However, under certain conditions, the discount on fairway fees could be relevant.

In the case of ships frequently arriving at Swedish fairways, the economic benefit of the discount can be significant when a ship moves from class C to class B. In such situations, it may be theoretically advantageous to invest in OPS or repaint the ship with silicone paint. However, these types of investments are uncertain and depend on factors such as energy prices and knowledge gaps rather than the discounts evaluated in this study. One way to increase the attractiveness of these technologies and raise awareness would be to assign them a higher score in the CSI. Another way would be to redesign the fairway discount itself, such as by making the economic benefits more gradual and separating the discount for different abatement strategies or environmental impact categories. The costs of installing and operating SCR are not covered by the benefit of the fairway fee when the ship moves from class C to class B, which makes the decision to install and operate an SCR on an old ship unlikely without additional incentives.

The current study only assesses the impact of retrofitting on existing ships, but the cost of abatement may be lower for new ships, meaning that the discounts could potentially be more influential when ship owners invest in new ships. Additionally, this study only focuses on the policy instruments in Sweden, while most ships that arrive at Swedish ports operate in international traffic, suggesting that ship owners may receive different economic benefits in other countries. If all ports globally applied discounts this could potentially make a difference. Future studies should therefore expand their scope to include other policy instruments and a wider geographic coverage to evaluate the overall economic benefits for ship owners and if possible, with more detailed data sets, including data on individual ships instead of model ships. These other policy instruments could include discounts or other economic incentives in other countries, such as the NO_X fund or public procurements in Norway. Lastly, incentives from the consumer-side could also be relevant since the transport cost for certain goods could be minor compared to the overall cost of certain goods. The transport buyers' perspective should therefore be further investigated.

Funding

This study was funded by the Swedish Transport Administration (Trafikverket) (grant agreement TRV 2021/12071 and TRV 2017/97891) and the Swedish Foundation for Strategic Research (grant agreement FID20-0014).

CRediT authorship contribution statement

Rasmus Parsmo: Data curation, Formal analysis, Investigation, Writing – original draft, Visualization, Methodology. **Erik Fridell:** Conceptualization, Methodology, Supervision, Writing – review & editing, Funding acquisition. **Maarten Verdaasdon:** Resources, Writing – review & editing. **Erik Ytreberg:** Conceptualization, Methodology, Supervision, Writing – review & editing, Funding acquisition.

Data Availability

Most data is in supplementary material A & B. Some average data are from databases which are not public.

Appendix A. Supporting information

Supplementary data associated with this article can be found in the online version at doi:10.1016/j.marpol.2023.105950.

References

[1] S. Andresen, E.L. Boasson, G. Hønneland, International environmental agreements: an introduction, Routledge, 2012.
[2] H. Bach, A. Bergek, Ø. Bjørgum, T. Hansen, A. Kenzhegaliyeva, M. Steend, Implementing maritime battery-electric and hydrogen solutions: a technological innovation systems analysis, Transp. Res. Part D: Transp. Environ. 87 (2020).
[3] Bahr, J. v, Å. Romson, S. Sköld, and H. Winnes. 2018. Statlig styrning av hamnavgifter för fartyg. © IVL Svenska Miljöinstitutet 2018, Stockholm.
[4] A. Bergek, S. Jacobsson, B.A. Sandén, 'Legitimation' and 'development of positive externalities': two key processes in the formation phase of technological innovation systems, Technol. Anal. Strateg. Manag. Vol. 20 (No. 5) (2008) 575–592.
[5] J. Bonilla, J. Coria, K. Mohlin, T. Sterner, Refunded emission payments and diffusion of NOx abatement technologies in Sweden, Ecol. Econ. 116 (2015) 132–145.
[6] Bosch, P., P. Coenen, E. Fridell, S. Åström, T. Palmer, and M. Holland. 2009. Cost Benefit Analysis to Support the Impact Assessment accompanying the revision of Directive 1999/32/EC on the Sulphur Content of certain Liquid Fuels. AEA Technology plc, Harwell.
[7] S. Brynolf, J. Hansson, J.E. Anderson, I.R. Skov, T.J. Wallington, M. Grahn, A. D. Korberg, E. Malmgren, M.J. Taljegard, Review of electrofuel feasibility-prospects for road, ocean, and air transport, Prog. Energy (2022).
[8] A. Christodoulou, M. Gonzalez-Aregall, T. Linde, I. Vierth, K. Cullinane, Targeting the reduction of shipping emissions to air: a global review and taxonomy of policies, incentives and measures, Marit. Bus. Rev. (2019).
[9] CSI. 2020. cleanshippingindex.com.
[10] CSI. 2022. News from Clean Shipping Index. Clean Shipping Index/IVL Swedish Environmental Research Institute, ivl.se.
[11] R. Dietz, C. Sonne, B. Jenssen, K. Das, C.A. de Wit, K. Harding, U. Siebert, M. Olsen, The Baltic Sea: an ecosystem with multiple stressors, Environ. Int. 147 (2021), 106324.
[12] ESI. 2020. General Information.
[13] European Central Bank. 2021. Euro foreign exchange reference rates.
[14] F.W. Geels, Processes and patterns in transitions and system innovations: refining the co-evolutionary multi-level perspective, Technol. Forecast. Soc. Change 72 (2005) 681–696.
[15] S. Gössling, C. Meyer-Habighorst, A. Humpe, A global review of marine air pollution policies, their scope and effectiveness, Ocean Coast. Manag. 212 (2021), 105824.
[16] Hagem, C., B. Holtsmark, and T. Sterner. 2015. Refunding emission payment. Statistisk sentralbyrå, Oslo.
[17] Helcom. 2018. State of the Baltic Sea–Second HELCOM holistic assessment 2011–2016. Pages 1–155 *in* Baltic Sea Environment Proceedings. Helcom Helsinki, Finland.
[18] L. Höglund-Isaksson, Global anthropogenic methane emissions 2005-2030: technical mitigation potentials and costs, Atmos. Chem. Phys. 12 (2012) 9079–9096.
[19] IHS. 2023. Seaweb - Maritime Portal: Ship database.in I. M. M. Trade, editor.
[20] IMO: AFS Convention. 2001. International convention on the control of harmful anti-fouling systems on ships.*in* Entry into force: 17 September 2008, AFS/CONF/26.
[21] S. Jacobsson, V. Lauber, The Politics and Policy of Energy System Transformation—Explaining the German Diffusion of Renewable Energy Technology, Elsevier Ltd, 2004.
[22] Jivén, K., A. Mellin, L. Styhre, and K. Garme. 2020. Lighthouse Reports - Fossilfri kollektivtrafik på vatten hinder och möjligheter för färjor med hög miljöprestanda - En förstudie utförd inom Trafikverkets branschprogram Hållbar sjöfart som drivs av Lighthouse. ©lighthouse.nu, Gothenburg.
[23] Johansson, M., I. Vierth, and A. Bondemark. 2020. Evaluation of the Swedish Maritime Administration's new system for fairway dues and pilot fees. A model comparison for the period 2017 to 2019. Swedish National Road and Transport Research Institute (VTI), Linköping.
[24] F.M. Kanchiralla, S. Brynolf, E. Malmgren, J. Hansson, M. Grahn, Life-cycle assessment and costing of fuels and propulsion systems in future fossil-free shipping, Environ. Sci. Technol. (2022).
[25] M. Karl, J.E. Jonson, A. Uppstu, A. Aulinger, M. Prank, M. Sofiev, J.-P. Jalkanen, L. Johansson, M. Quante, V. Matthias, Effects of ship emissions on air quality in the Baltic Sea region simulated with three different chemistry transport models, Atmos. Chem. Phys. 19 (2019) 7019–7053.
[26] R.P. Keller, J.M. Drake, M.B. Drew, D.M. Lodge, Linking environmental conditions and ship movements to estimate invasive species transport across the global shipping network, Divers. Distrib. 17 (2011) 93–102.
[27] M. Lagerström, A.-L. Wrange, D.R. Oliveira, L. Granhag, A.I. Larsson, E. Ytreberg, Are silicone foul-release coatings a viable and environmentally sustainable alternative to biocidal antifouling coatings in the Baltic Sea region? Mar. Pollut. Bull. 184 (2022), 114102.
[28] T. Lindé, I. Vierth, K. Cullinane, Evaluating the effects of Sweden's environmentally differentiated fairway due. Transp. Res. Part D. 70 (2019) 77–93.
[29] A. Mjelde, Ø. Endresen, E. Bjørshol, C.W. Gierløff, E. Husby, J. Solheim, N. Mjøs, M. S. Eide, Differentiating on port fees to accelerate the green maritime transition, Mar. Pollut. Bull. 149 (2019), 110561.
[30] OECD. 2021. Consumer price indices (CPIs) - Complete database.in S. t. OECD, editor.
[31] D.R. Oliveira, M. Lagerström, L. Granhag, S. Werner, A.I. Larsson, E. Ytreberg, A novel tool for cost and emission reduction related to ship underwater hull maintenance, J. Clean. Prod. 356 (2022), 131882.
[32] Palisade. 2020. @RISK version 7.6. ©Copyright 2023 Palisade, 555 Fayetteville, Street Suite 300, Raleigh, NC 27601 USA.
[33] W. Samuelson, R. Zeckhauser, Status quo bias in decision making, J. Risk Uncertain. 1 (1988) 7–59.
[34] B.A. Sandén, K.M. Hillman, A framework for analysis of multi-mode interaction among technologies with examples from the history of alternative transport fuels in Sweden, Res. Policy 40 (2011) 403–414.
[35] Sjøfartsdirektoratet. 2011. Guideline on the NOx tax. Sjøfartsdirektoratet - Norwegian Maritime Directorate, Haugesund.
[36] Skattedirektoratet. 2016. Avgift på utslipp av NOx 2016. Særavgiftsseksjonen, Oslo, Fredrik Selmers vei 4, Helsfyr.
[37] S. Sköld, Green ports - green port dues, indices and incentive schemes for shipping, Inland Seaside Sustain. Transp. Strateg. (2019) 173–192.
[38] SMA. 2016. Farledsavgift fråga och svar (dnr 17–02807). Swedish Maritime Administration.
[39] SMA. 2017. Sjöfartsverkets författningssamling - Sjöfartsverkets föreskrifter om farledsavgifter - SJÖFS 2017:27. Swedish Maritime Administration.
[40] SOU 2007:58. Hamnstrategi – strategiska hamnnoder i det svenska godstransportsystemet. Regeringskansliets förvaltningsavdelning, 106 47 Stockholm.
[41] Stena Rederi Technical Division. 2018. ESS plug-in hybrid STENA JUTLANDICA.
[42] T. Sterner, J. Coria, Policy Instrument and Natural Resource Managment, RFF Press, New York, 2012.
[43] T. Sterner, L. Isaksson, Refunded emission payments theory, distribution of cost, and Swedish experience of NOx abatement. Ecol. Econ. 57 (2006) 93–106.
[44] B. Stolz, M. Held, G. Georges, K. Boulouchos, Techno-economic analysis of renewable fuels for ships carrying bulk cargo in Europe, Nat. Energy 7 (2022) 203–212.
[45] P. Vaishnav, P.S. Fischbeck, M.G. Morgan, J.J. Corbett, Shore power for vessels calling at US ports: benefits and costs, Environ. Sci. Technol. 50 (2016) 1102–1110.
[46] Winnes, H., E. Fridell, L. Ntziachristos, A. Grigoriadis, and J.-P. Jalkanen. 2020. Evaluation, control and Mitigation of the EnviRonmental impacts of shippinG Emissions (EMERGE) - Summary and analysis of available abatement methods for SOX, NOX and PM, together with data on emissions, waste streams, costs and applicability.
[47] E. Ytreberg, S. Åström, E. Fridell, Valuating environmental impacts from ship emissions – the marine perspective, J. Environ. Manag. 282 (2021), 111958.
[48] Ytreberg, E., K. Hansson, A.Lunde Hermansson, R. Parsmo, M. Lagerström, J.-P. Jalkanen, and I.-M. Hassellöv. 2022. Metal and PAH loads from ships and boats, relative other sources, in the Baltic Sea. available at Research Gate.
[49] Zakeri, B., I. Staffell, P. Dodds, M. Grubb, P. Ekins, J. Jääskeläinen, S. Cross, K. Helin, and G. Castagneto-Gissey. 2022. Energy Transitions in Europe–Role of Natural Gas in Electricity Prices. Available at SSRN.