



Decarbonization of Maritime Transport: Analysis of External Costs

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For centuries Europe's transport has been a catalyst for economic development. At present, it facilitates exchange among European Union (EU) Member States and much of the rest of the world. Maritime transport forms the main axis of international exchange, carrying ~90% of total traded tonnage. In doing so, it bears responsibility for 2.5% of worldwide greenhouse gas emissions. The efforts to reduce negative environmental impact of transport activity is centered on better modal integration of the common transport system, sustainability, green technologies in the transport sector, resource efficiency, and carbon emissions reduction. The International Maritime Organization has tasked its members to achieve a 70% reduction in CO₂ emissions by 2050 or, if possible, to eliminate them altogether. From a business end, it is possible to apply a variety of technologies to ensure zero-emissions or, at the least, a dramatic reduction of emissions in the shipping sector. The aim of this paper is to evaluate the strategic approach to the decarbonization process based on EU strategic documents and low-emission and zero-emission technologies, used and developed, in maritime transport. An estimation of external costs incurred by maritime transport will allow for the assessment of benefits resulting from the application of technologies and alternative fuels proposed in the solutions. On the basis of the obtained results from the external cost valuation it will be possible to estimate the potential for decarbonization in maritime transport.

Keywords: shipping and the environment, emission reductions, cost valuation, external costs theory, IMO, EU

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INTRODUCTION

A certain number of important environmental precedents have been recorded over the last two decades; unfortunately, the vast majority of them are far from positive (Hebbert and Jankovic, 2013; Dewan et al., 2018; Rony et al., 2019). In 2016, according to the World Economic Forum (WEF), it was the first year in which an environmental danger, specifically the failure to mitigate and adapt to climate change, ranked above weapons of mass destruction, water shortage, and energy resource prices (WEF, 2018). As can be seen, environmental concerns have been a priority for the WEF in recent years (Obersteiner et al., 2018; Simpson and Jewitt, 2019). Because of this, state parties to the Paris Agreement committed to reducing their greenhouse gas (GHG) emissions, with the aim of limiting global warming to well-below 2°C above pre-industrial levels, and to pursue efforts to keeping the increase down to 1.5°C (Karmalkar and Bradley, 2017; Nikulin et al., 2018). Despite international shipping being excluded from the Paris Agreement, the International Maritime Organization (IMO) is developing its own strategy to reduce ship-derived GHGs. The IMO argues a need for common activities and efforts to mitigate environmental burdens, as set out by its MEPC.304(72) Resolution, 13 April 2018, three sustainability-oriented goals for the entire

maritime shipping industry: (1) reduce carbon compound (i.e., oxides and dioxides) emissions from new ships through the implementation of successive phases of the Energy Efficiency Design Index (EEDI), (2) reduce carbon compound emissions in shipping by at least 40% by 2030, with efforts to achieve 70% reduction by 2050 (i.e., from the baseline year of 2008), and (3) reduce GHG emissions in maritime shipping by at least 50% by 2050 with simultaneous action aimed at their complete elimination (Psaraftis, 2019). Lastly, an additional goal is to move toward zero-emissivity in maritime shipping (Psaraftis, 2016). The IMO has also decided that in order to support the drive toward emission targets, the energy efficiency of ships should increase by 40% by 2030 (i.e., compared to 2008 levels) and by 50–70% by 2050.

Maritime shipping is currently responsible for <3% of total manmade CO₂ emissions. Forecasting predicts that by 2050 this proportion will grow from 50 to 250% with the business-as-usual model (i.e., with no action taken). The Kyoto Protocol climate target, set a worldwide cap of 1.5–2.0°C on global warming (UNFCCC, 1997, 2008), calling for a reduction in CO₂ emissions by 50–85% for the whole economy. Currently available technologies allow reductions of up to 75% (Bouman et al., 2017). **Supplementary Table 1** presents data on CO₂ emissions from maritime shipping in the period from 2007 to 2015 and its share in overall emission levels. It can be deduced that total shipping CO₂ emissions, after a downturn between 2008 and 2010, increased from 910 million tons to 932 million tons (i.e., +2.4%) from 2013 to 2015. It is still below the 2008 peak, but according to forecasts international shipping emissions may increase, exceeding the 2007 level. In 2015, global shipping accounted for approximately 2.6% of global CO₂ emissions. The majority (i.e., 87%) of shipping CO₂ emissions is attributable to international shipping activity (Jalkanen et al., 2016; Johansson et al., 2017; Russo et al., 2020). Domestic shipping accounted for about 9% of total shipping CO₂ emissions and fishing accounted for ~4% in 2015. Examining the ship fleet structure, it can be observed that 55% of that figure (i.e., over a half) was generated by container ships, bulk carriers, and oil tankers. It is well-known that the level of ship emissions depends on such factors as fuel consumption, engineering design as well as engine operation and maintenance. Also, in the case of individual ship designs and fuels, the amount of emissions depends on the way in which the engines are operated (EDGAR, 2017). Therefore, a single voyage is divided into four stages according to vessel operation modes, namely: free sailing, maneuvering, anchoring, and berthing. According the International Council on Clean Transportation report, free sailing accounts for the most CO₂ emissions across all ship classes, while maneuvering accounts for the least (Jiang et al., 2012; Olmer et al., 2017). The IMO has tasked its members to reduce CO₂ emissions to 70% by 2050 or, if possible, to completely eliminate them. This means that ship-owning enterprises will have to immediately act to reduce ship-derived CO₂ emissions, while also striving to eliminate emissions. Hence, there arises a question as to the maritime shipping sector's potential for reducing CO₂ emissions, both in quantitative and monetary terms [i.e., reducing external costs (Antheaume, 2004; Wang et al., 2017)]. As such, this paper aims

at evaluating approaches of the decarbonization process based on European Union (EU) strategic documents and low-emission and zero-emission technologies, used and developed, in maritime transport in the context of CO₂ emission reduction.

METHOD

To achieve the shipping sector's potential for decarbonization, it is necessary to calculate the external costs of CO₂ reductions. Full cost accounting in terms of external costs theory is applied (Antheaume, 2004; Mizutani et al., 2011; Frischmann and Marciano, 2015; Wang et al., 2017). For this purpose, tabularized datasets have been put together to show basic quantitative and qualitative data on global shipping [i.e., fleet size, deadweight tonnage (DWT) (**Supplementary Table 2**), gross registered tonnage, main engine power output, and power generator output for commercial vessels (**Supplementary Table 3**)]. The resulting figures are then compared with average fuel consumption data at main engine load where maximum continuous rating (MCR) = 0.85. To simplify matters, average figures for speed and corresponding fuel consumption correspond with engine type. Consideration has been given to three principal marine fuels, including: heavy fuel oil (HFO), marine gas oil (MGO), and liquefied natural gas (LNG) (Elgohary et al., 2015; Thomson et al., 2015; Hansson et al., 2019).

The resulting data have been inputted into an external cost calculator developed in the “Ecobonus” project (MAE, 2018). The calculator is used to estimate the external costs of maritime shipping compared to transport by road at specified distances per cargo unit expressed in linear meters. For the purpose of this research, this parameter has been cross-referenced to deadweight tonnage. The input data in the calculator included variable voyage speed, non-linear function of fuel consumption relative to speed, normative CO₂ emission indexes for selected fuel types, normative external costs in maritime shipping (i.e., € 187.00/t-CO₂), and normative external costs in transport by road (i.e., 0.10 €/vkm noise, 0.21 €/vkm accidents, and 0.19 €/vkm congestion). CO₂ emission costs have been calculated for different variants at the variable average speed of shipping traffic, starting from 15 kn through 17, 19, and 21 kn as the most representative velocities for present-day maritime shipping. The authors believe the calculator has a serious flaw whereby it adopts an excessive fuel consumption index for 217 g/kWh energy efficiency. To correct for this unrealistic rate, the value has been replaced by 180 g/kWh (i.e., 17% lower). The original figure overstated the external costs as a result of overestimated fuel consumption. Another defect is in its limited list of fuel types to choose from.

RESULTS

Strategic Approach to Low- and Zero-Emission Technology

Basic guidelines for contemporary development of Europe's transport policy have been set out in the “Strategy for intelligent and sustainable development favoring social inclusion,” adopted

in March 2010, and the “White Paper: A Plan for establishing a harmonized European transport area—striving to achieve a competitive and energy-saving transport system” (Pawłowska, 2013; Wojewódzka-Król, 2017). Focusing primarily on the regulations and documents relating to shipping emissions, it is established, the advancement of sustainable development of maritime transport correlates with CO₂ emissions. This aspect has been dealt with in the International Convention on the Prevention of Pollution of the Sea by Ships—MARPOL 73/78. The problem of reducing ship-derived CO₂ emissions has been discussed in Appendix VI to the MARPOL Convention. As such, if the amount of CO₂ emissions is considered the direct product of fuel consumption and, by extension, the type of technology and engine used in a ship, the pertinent regulations refer to energy efficiency of ship engines (Bijlsma, 2008; Yuan et al., 2017). As of 2013 (i.e., according to Appendix VI amendment to the MARPOL Convention), it is obligatory to determine the EEDI for newly designed ships with more than 400 registered tonnage (RT) as well as any type of drive, except for LNG, and the Energy Efficiency Operational Indicator (EEOI) for ships already in service. Introduced provisions, establishing the obligation to implement the Efficiency Plan Energy Management, were established in 2011 (Kotowska, 2014). These indicators are a tool-based energy efficiency assessment of ships regardless of age and will in the long-term determine allowable fuel consumption norms, whereby the EEDI is a theoretical value reflecting future efficiency and the EEOI is a practical benchmark for CO₂ emissions measured under specific travel and service conditions for a given ship.

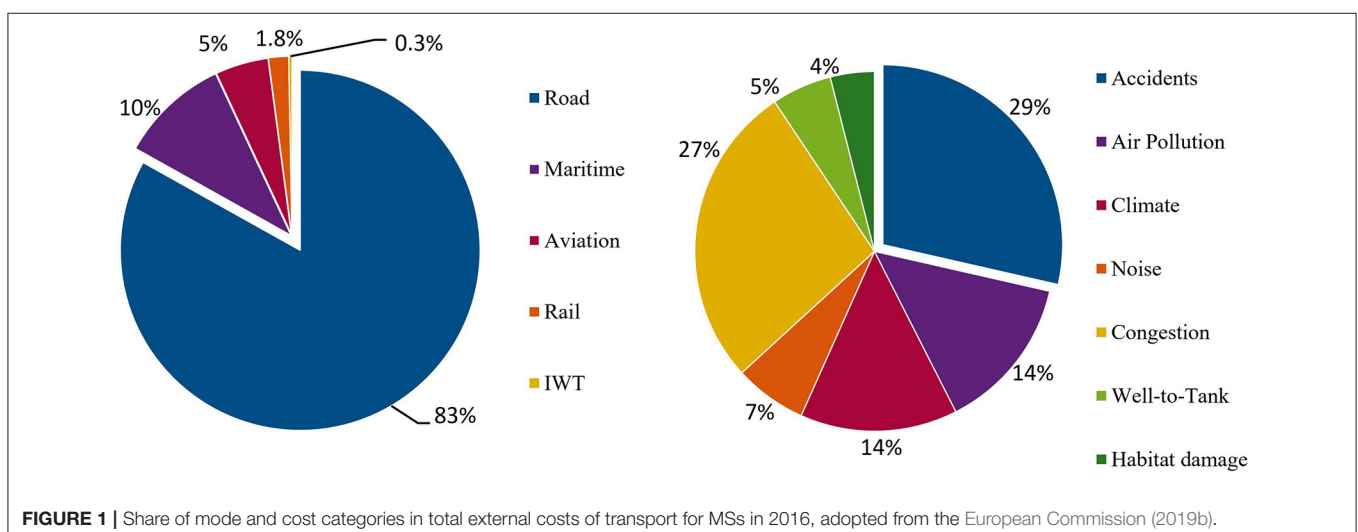
There is no agreement as to the effectiveness of the EEDI procedures. Research by Ančić and Šestan (2015) elucidate the reduction of CO₂ according to these procedures will be easier than expected, meaning that the size of the reduction may exceed forecasts. Other research, questions the potential for further reduction of CO₂ emissions, specifically in LNG-powered ships, as vessels now under construction, equipped with this drive, will be propelled by a dual fuel engine that will fully comply with the EEDI limits (Attah and Bucknall, 2015). Indeed, Shi (2016)

goes further by stating implementation of the EEDI alone, and consequently other ship service parameter indicators, will not suffice and make it necessary to market the practice (i.e., bring it in-line with shipping practice) and technical capacity, to a larger extent, required by the IMO resolution. The IMO’s future objectives have been specified in the published report “Initial strategy on reduction of GHG emissions from ships” (IMO, 2018). It is worth noting, the IMO Resolution MEPC.304(72), introducing the EEDI as an instrument for reducing GHG emissions in international shipping, was the first legislative act in international law following the ratification of the Kyoto Protocol (Bickel et al., 2005). Hence, it is legitimate to assume that the shipping sector is serious about sustainable development goals and willing to commit itself to reducing GHG emissions.

Estimation of External Costs in EU Transport

In the last decade, public concerns regarding the environmental impacts of maritime transport have been increasing. This is due to the fact that, despite a better environmental performance, its overall impacts will be outweighed by the expected increase in the volume of ship movements (Turvani et al., 2009). External costs of transport refer to the difference between social costs and private costs of transport. Those costs are defined as the costs which arise when the social or economic activities of one group of persons have an impact on another group and when that impact is not fully accounted, or compensated, for by the first group (Bickel et al., 2005). The reason for this is lack of market incentive for transport users to take external costs into account when making a transport decision. External costs have been a key issue in transport research since 1995. In Europe, this trend is in line with the political willingness to internalize externalities in transport pricing policies. Total external costs of transport for the EU Member States (MSs) in 2016 were estimated in the updated handbook on the external costs of transport (**Supplementary Figure 1**; European Commission, 2019a).

The total external costs for road, rail, inland waterway transport (IWT), aviation, and maritime (i.e., excluding



congestion costs as they are not calculated for all modes) amount to € 71 billion, which corresponds to 4.8% of the total gross domestic product in the MSs. For aviation and maritime transport, a detailed calculation of the external costs has only been done for a set of selected airports and sea ports. Maritime shipping (i.e., 50% allocated to origin and 50% to destination) was worth € 44 billion for all traffic to-and-from 34 selected EU ports with the indicative estimate for all traffic to-and-from all EU ports at € 98 billion. **Figure 1** illustrates the share of mode and cost categories for total external costs of transport for MSs in 2016.

Road transport is the predominant mode that incurs by far the most external costs (i.e., 83% of the total costs). Maritime

transport accounts for 10%, aviation for 5%, rail transport for 1.8%, and IWT for 0.3% of the costs. Total external transport costs can be further broken down with 69% dedicated to passenger transport and 31% to freight (i.e., including light commercial vehicles). The most important cost category is accident costs equaling 29% of the total costs, followed by congestion (i.e., 27%). Climate change and air pollution costs both contribute to 14%, noise costs to 7%, and habitat damage to 4% of the total costs. The most important cost categories for maritime transport are climate change and air pollution. Total climate costs for maritime shipping have been estimated to be € 24 billion—based on transport performance for consistency with the other transport modes and cost categories. It is worth

TABLE 1 | Specification of selected technologies and solutions exploiting the potential of ships for reducing CO₂ emissions, adopted from Czermański (2019).

Area	Measurement	Solution	CO ₂ reduction potential [%]			Investments costs [%]			CO ₂ reduction cost [USD/1t]		
			Min.	Average	Max.	Min.	Average	Max.	Min.	Average	Max.
Hull design	Vessel size	Economy of scale, improved capacity utilization	4.00	18.00	83.00	0.00	0.00	0.00	-159.00	-159.00	-159.00
	Hull shape	Dimensions and form optimization	2.00	14.50	30.00	2.50	10.00	25.00	12.00	-54.00	-36.00
	Light materials	High strength steel, composites	0.10	5.30	22.00	1.00	10.00	50.00	1036.00	86.00	131.00
	Air lubrication	Hull air cavity lubrication	1.00	5.30	15.00	5.00	7.50	10.00	744.00	31.00	-77.00
	Resistance reduction devices	Other devices/retrofit to reduce resistance	0.00	8.00	10.00	0.00	2.00	3.00	0.00	-50.00	-70.00
	Ballast water reduction	Change in design to reduce size of ballast	1.00	2.50	10.00	0.25	0.50	2.50	-106.00	-112.00	-106.00
	Hull coating	Distinct types of coating	2.00	6.00	45.00	10.00	20.00	40.00	451.00	256.00	-31.00
Power and propulsion system	Hybrid power/propulsion	Hybrid electric auxiliary power and propulsion	0.00	-2.50	-5.00	-	-	-	-	-	-
	Power system/machinery		1.00	5.80	25.00	0.50	1.00	5.00	-77.00	-118.00	-121.00
	Propulsion efficiency devices		1.00	8.00	20.00	0.50	2.50	5.00	-77.00	-98.00	-106.00
	Waste heat recovery	Recuperation	0.10	1.20	3.00	0.10	0.10	0.10	100.00	-47.00	-56.00
	On board power demand	On Board or auxiliary power demand	25.00	70.00	84.00	10.00	10.00	10.00	-88.00	-118.00	-121.00
Alternative fuels	Biofuels	Methanol, ethanol	5.00	20.00	30.00	-	30.00	-	100.00	-47.00	-56.00
	LNG	LNG	0.00	-2.00	-3.00	0.00	0.00	0.00	-	-	-
Alternative energy sources	Wind power	Kites, sails, wings	1.00	12.60	50.00	0.50	5.00	25.00	-77.00	-89.00	-77.00
	Fuel cells	H ₂	2.00	6.50	20.00	0.00	0.00	0.00	>1,000	>1,000	>1,000
	Cold ironing	Electricity from shore	3.00	5.30	10.00	0.25	0.25	0.25	-125.00	-130.00	-132.00
	Sola power	Solar panels on deck	0.20	4.00	12.00	5.00	5.00	5.00	2794.00	158.00	12.00
Operation	Speed optimization	Operational Speed, reduced speed	1.00	19.60	60.00	0.00	0.00	0.00	-160.00	-160.00	-160.00
	Capacity utilization	At vessel and fleet level (fleet management)	5.00	23.50	50.00	0.00	0.00	0.00	-159.00	-159.00	-159.00
	Voyage optimization	Advanced weather routing, route planning and voyage execution	0.10	7.30	48.00	0.00	0.00	0.00	-159.00	-159.00	-159.00
	Other operational measures	Trim/draft optimization, energy management, optimized maintenance	1.00	3.70	10.00	0.00	0.00	0.00	-159.00	-159.00	-159.00

mentioning that for climate change costs, the marginal costs are the same as the average costs. This is because the average and marginal climate emissions per km of a vehicle are equal. This implies that an additional kilogram of CO₂ emitted leads to the same social (i.e., external) costs as the average kilogram of CO₂ emitted, since the CO₂ is distributed in the whole atmosphere. This cost category contributed 0.2 €—cent/tkm, while air pollution costs amounted to 0.4 €—cent/tkm (European Court of Auditors, 2013; European Commission, 2019a).

Description of Low- to Zero-Emission Technology in Maritime Transport

Maritime transport takes advantage of a variety of optimizing, and frequently innovative, solutions aimed mainly to reduce fuel consumption by the ship engine (Rehmatulla and Smith, 2015). In that sense, the obvious direction for ship owner community efforts is consistent with the sustainable development goal relating to reduction of ship-derived emissions. The literature points out various methods of classification and analyses of areas in which emissions from ships can be reduced, using—for example—emission-reducing technology as the classifying criterion. Accordingly, Seddiek et al. (2013) have distinguished three areas for possible reductions: ship engine, fuel quality, and fuel usage. Another classification applies emissions-reducing technology as its basic criterion (Bouman et al., 2017), classing the following five stages: (1) design, (2) modernization of existing drive systems, (3) retrofitting, (4) alternative fuels, or adding alternative power sources for on-board devices, and (5) time in commercial service. The most widespread emissions-reducing technologies can be segmented into the following areas: hull design, power and propulsion system, alternative fuels, alternative energy sources, and operation (Table 1).

The measures that are being developed and applied to reduce ship-derived emissions primarily rely on the quality of fuel used. The resulting reductions are possible due to technical progress which is, on the one hand, elicited by ship owners themselves pushing for more fuel-efficient solutions. On the other hand, standards, and regulations in international law are becoming noticeably more restrictive, setting increasingly rigorous limits on emissions from ships during the sea voyage and port stoppage. This emission-limiting process can be divided into four stages (Table 2). Ship owners can quickly transition through these stages by, first, placing new ship-building orders and second, modernize the existing fleet. A detailed look at the process includes:

1. Exhaust gas treatment—all kinds of technologies bringing emission levels from traditional marine fuels into compliance with the applicable limits; note, these do not eliminate exhaust gases.
2. Cleaner fuels—technologies allowing for the use of cleaner fossil fuels, such as LNG and MGO, for compliance with the applicable emissions limits. LNG results in a 15% saving on CO₂ emissions, while MGO—being a more energy-rich fuel than HFO—leads to 1.3% increase in emissions.

TABLE 2 | Four stages of effective CO₂ reduction, adopted from Untiedt (2018).

Stage	Technology	CO ₂
1	Purifying Scrubber + selective catalytic reduction (SCR)	No change
2	Cleaner fuels MGO, LNG	–15%
3	E-fuels Hybrid: LNG or methanol or MGO converted to electricity	–80%
4	e/H ₂ Liquid hydrogen (LH ₂) or pure electric ship	–100%

3. E-fuels—cutting-edge technologies using fuels for on-board power generation and allowing ships to be driven by electrical energy incorporates all kinds of renewable energy sources.
4. e/H₂—one of the only two technologies nowadays (i.e., except renewable energy sources on electrically powered ships) allows for zero-emissions shipping by using renewable energy sources to generate power for hydrogen production or to charge the ship's batteries.

From these technologies, there are no currently available fossil fuel technologies complying with the requirements on pollutant emissions, including CO₂, as stipulated in the MARPOL Convention regulations. Therefore, stage one should continue to be improved via technical development and further low- to zero-emissivity technologies streamlined.

Assessment Potential of Decarbonization in Maritime Shipping

The calculation carried out produced a final estimate of external costs of CO₂ emissions as an indicator of the potential for future reductions in maritime shipping compared to the existing state. The calculations were made using the “Ecobonus” (MAE, 2018) project calculator based on figures for emission levels from road transport as an alternative to maritime transport. This calculator was designed to promote the EU's Motorways of the Sea (MoS) program. Because of this, it is necessary to consider not only the quantitative reductions of external costs expressed in USD, but also the previously calculated volumes of CO₂ emissions from the global shipping fleet. At the beginning, the primary database data from IHS (2019) were used to determine the consumption of marine fuels in the individual fleet types. This was followed by a conversion of their use to CO₂ emissions. The results are presented in Table 3.

The total emissions from the global fleet according to the existing fuel structure used in global shipping stood at 2.167 billion tons of CO₂ and—interestingly—is equal to the amount of emissions that would be obtained with the exclusive use of HFO. Therefore, the 2% contributed by LNG, which is lower on CO₂ emissions, neutralizes the 26% share produced by MGO, which has a much higher CO₂ emissivity. Assuming that the entire fleet would transition to MGO which is cleaner fuel in terms of SO_x and NO_x emissions (Seddiek and Elgohary, 2014), we would receive 2.23 billion tons of CO₂ emissions, which represents a slight increase compared to

TABLE 3 | Estimated fuel consumption and CO₂ emissions in global shipping in 2018.

Fleet group	Marine fuel use (million t)	CO ₂ emission for			Current fuel use structure [†]
		HFO	MGO	LNG	
Bulk carriers	173.0	538.7	554.6	475.8	538.7
Liquid cargo ships	224.0	697.5	718.1	616.0	697.5
General cargo and cruise ships	299.0	931.1	958.6	822.2	931.1
Total	696.0	2167.3	2231.3	1914.0	2167.3

[†] Fuel percentages sourced from Olmer et al. (2017): 72% for HFO, 26% for MGO, and 2% for LNG.

the existing circumstance. For a complete transition to LNG, the new figure for CO₂ emissions would equal 1.914 billion tons, which is just 12.7% less compared to the current HFO-based variant.

The calculator “Ecobonus” (MAE, 2018) compares direct road door-to-door externalities with the MoS alternative considering specific vessel technology, operating profile, port call, and port access impact. By adopting the output by the calculator for the external costs of 1 ton of CO₂ emissions (i.e., HFO = 159.10 USD; MGO = 153.44 USD, LNG = 112.40 USD; for various combinations: LNG + SCR 112.40 USD, HFO + scrubber + SCR = 162,28 USD, and MGO + SCR = 153.44 USD), it was possible to determine the total external costs of CO₂ emissions in global shipping. For HFO, these were 348.91 billion USD, for MGO 337.57 billion USD and for LNG 214.37 billion USD which represents approximately 61.4% of the same cost for HFO. Model adjustment equated to 0.96, with the model error ranging from USD 8.41 to USD 11.90 per unit of emissions. The stated values were determined for 15 kn average traffic speed. Analogous calculations were produced for higher speeds (i.e., 17, 19, and 21 kn) in order to emphasize the upward trend in the external costs of ships with no exhaust cleaning technologies—showed a fixed level.

DISCUSSION

The analyses have proven a number of important points; however, they should be interpreted with caution. First, the final external cost estimates of 1 ton of CO₂ emissions are based on a calculation of externalities in land transport as no methods for calculating emissions in maritime transport have been developed. Consequently, more experience of how external costs accumulate in maritime shipping is necessary for a more realistic estimate. Second, it is also a mistake to adopt the estimated fuel consumption structure of 2017 for 2018 data (i.e., since no current data is available). Additionally, the structure itself includes only three main types of marine fuel with the exclusion of electrical, hybrid, and methanol-powered drives. Also, future planned use of liquefied hydrogen would significantly alter the projections. As such, worldwide statistical illustrate of actual consumption of these fuels for each ship type

will need to be closely monitored and updated (i.e., as data become available).

Finally, fuel consumption data from 2018 was based only on engine power output and fuel consumption characteristics per power output at MCR = 0.85. The value of this indicator can vary depending on the global state of the economy which, in turn, determines the speed of ships (i.e., speeds are higher when demand for shipping is elevated). Despite these shortcomings, the following conclusions can be decisively formulated: (1) there are existing technically and economically viable technologies for ship drives, allowing for the reductions in emissions to generate different implementation costs to the ship owner; (2) the entire maritime sector should be steered toward a transition to cleaner fuels; (3) an intermediate stage should be a transition to LNG to generate fewer external costs, regardless of any exhaust treatment installations (i.e., to reduce NO_x emissions); (4) a theoretical assumption of the global fleet's complete transition to LNG will allow for the reduction of up to 38.5% of external costs, even though reductions in CO₂ emissions will reach only 11.7% and, best-case scenario, 15%; and (5) LNG does not ensure compliance with future CO₂ emissions limits for longer than 11 years, which calls for urgent action to develop alternative fuel technologies, especially in regards to renewable fuels. Finally, future research into the decarbonization of maritime transport will require political will, instituted at the global level. Parallel research into potential political side effects should also be carefully considered since much of the processes discussed are complex and fragmented between environmentally-friendly action and economic progress.

DATA AVAILABILITY STATEMENT

The collected data can made available from the corresponding author on reasonable request.

AUTHOR CONTRIBUTIONS

EC, BP, and AO-J contributed conception and design of the study. EC and AO-J organized the dataset and statistical analysis. EC wrote the first draft of the manuscript. EC, BP, AO-J, and GC wrote sections of the manuscript. All authors contributed to manuscript revision, read, and approved the submitted version.

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SUPPLEMENTARY MATERIAL

The Supplementary Material for this article can be found online at: <https://www.frontiersin.org/articles/10.3389/fenrg.2020.00028/full#supplementary-material>

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