Stavroulakis and Papadimitriou
Journal of Shipping and Trade (2022) 7:14
https://doi.org/10.1186/s41072-022-00116-7

Journal of Shipping and Trade

ORIGINAL ARTICLE **Open Access**

Total cost of ownership in shipping: a framework for sustainability

Peter J. Stavroulakis[1,2*] and Stratos Papadimitriou[1]

*Correspondence: pjstav@gmail.com

[1] Department of Maritime Studies, University of Piraeus, Piraeus, Greece
[2] Department of Management and International Business, School of Business and Economics, The American College of Greece, Ag. Paraskevi, Greece

Abstract

Purpose: Shipping is pivotal for global commerce, yet its externalities are not yet fully set into context, especially with reference to environmental impact. Shipping is a practise developed from the dawn of history. Its manifestation requires the introduction of relevant supporting industries as well, such as port, cargo, and logistics operations. The holistic shipping system has been growing with its main parameter pertaining to accounting cost minimisation. Yet, the shipping ecosystem has been able to exacerbate environmental, social, and health costs that in the end may prove that shipping, in the way that it is conducted, may not be as profitable as it may seem.

Method: This paper introduces a framework for the total cost of ownership in shipping, which includes a holistic approach as to the true costs associated with shipping practises. Through a structured literature review the relevant costs are identified and assessed, providing a complete framework as to the actual cost of shipping.

Findings: Shipping may appear to be profitable in some cases, but the bulk of its profit is based on practises that incur a plethora of costs that are externalised. This paper provides a clearer understanding of the total cost of shipping and the subsequent need of a paradigm shift, so that shipping may be able to portray its potential with reference to societal and environmental benefits.

Conclusion: Through frameworks such as the one presented in this work, activities and practises may be assessed as to their true impact and footprint and claim sustainability through a solid prism of holistic analysis and true profit for humanity, rather than focusing on accounting cost and turning a blind eye at other social, environmental, and health costs.

Keywords: Shipping cost, Total cost, Environment, Social cost, Health cost

Introduction

Economic development is practically impossible without contribution of the transportation sector. Mobility is vital as it is paramount. Exchanges from all over the word occur daily while maritime transport is a pillar for international trade, responsible for transporting approximately 90% of total tonnage. At the same time, there are numerus consequences not directly assessed and linked to transportation, such as climate change, water pollution, energy shortages, land take, and other environmental concerns. At first glance, those problems might seem tough to identify, but refer to an indicative plethora of external costs caused from transportation, shipping included (Hoffmann et al. 2017).

Degraded air, water, and soil quality leading to higher mortality of humans and animals are an occurring outcome of pollution from direct and indirect shipping activities. International shipping is practically governed under varying regulatory systems according to corresponding countries authorities' competence and willingness, as centralized and coordinated through international law and the IMO. Policy makers have to be informed on a regular basis about the health externalities of shipping to coordinate policies and measures in the right direction. The problem is that shipping pertains to an example of an 'out of sight, out of mind' eventuality, especially with its environmental impact. Since the vessel is faraway, at least farther away than the car, truck, or train, humans tend to not think of its externalities; the notion seems to be that even if a vessel pollutes, it's far away, and since the ocean is endlessly capable of absorbing all kinds of pollution, humanity is safe. Erroneous reasoning, to say the least. The latter makes it increasingly cumbersome to provide consensus in the importance of health measures in shipping, especially if these are going to raise costs (Matekenya and Ncwadi 2022).

The shipping industry, being responsible for less than 3% of total CO_2 emissions (but far more responsible with reference to other pollutants such as Nitrogen and Sulphur oxides), suggests that the whole economy should opt for sustainability and emission reduction for efforts to be recognized and their impact to be seen. International shipping emissions might increase despite hard efforts, so it is of great importance for action to be taken immediately (cf. Casaca and Loja 2021, 2019; Vierth and Johansson 2020). A single line haul is divided into four stages, including free sailing, manoeuvring, anchoring, and berthing, yet most emissions occur during free sailing and the least during manoeuvring. As many types of emissions, CO_2 emissions are a direct product varying by fuel consumed, type of engine technology, and ship regulations followed (Gerakoudi-Ventouri 2022; Carlan et al. 2019). Reducing these emissions might seem like an easy plan but monetary terms including external costs might be a burden (Czermański et al. 2020; Ben-Hakoun et al. 2016).

SOx and NOx as precursor emissions contribute to the formation of PM2.5, particles that are extremely harmful for human (and environmental/ecosystemic) health, causing respiratory and cardiovascular diseases, and contributing to total mortality. Premature deaths have been estimated by the Global Exposure Mortality Model (Lastname et al. 2018) model, based on cohort studies of outdoor global pollution. Receiving and analysing ship emissions (Frouws 2016), at a global level, also have been improved due to the AIS (automatic identification system) which provides real-time data. The Med Atlantic Ecobonus (MAE) Action includes a helpful tool and calculator for estimating the external cost of shipping and comparing results to the road transport sector for specific distances and cargo carried.

The EEDI (Energy Efficiency Design Index) and EEOI (Energy Efficiency Operational Indicator) are used as a benchmark for emissions of a particular ship (Pruyn 2020). Due to the growth in total nautical miles covered, there is concern regarding the future environmental impact of maritime transport. External costs could be considered as the difference between social costs and private costs. External costs translate to costs arising when activities of one group which cannot be fully compensated, impact another group.

Different cost categories are accident costs, air pollution costs, climate change, noise costs, congestion, and habitat damage.

Emission-limiting tactics include exhaust gas treatment, cleaner fuels such as LNG (liquefied natural gas) and MGO (marine gasoil) (Sideri et al. 2021), efuels, and zero-emission systems (Sideri et al. 2021; Wik and Niemi 2016). Shipping is a huge industry, and such a sector needs constantly evolving regulation (and paperwork). Although it might seem simple and of little value, digitalizing documents can save time, money, and the environment, by reducing GHG (greenhouse gas) emissions by minimizing the use of basic material resources. Having a digital file cloud allows access from all over the world, in no time and (almost) zero emissivity. It is worth to mention the importance of ship digital twins, a revolutionary addition to shipbuilding.

The importance of shipping for the world economy cannot be overstressed. Yet, with the current approach of cost externalization, shipping is not sustainable, as it tacitly requests from society and the environment to bear a huge chunk of its cost. If the sector is to investigate topics of sustainability, a baseline of total cost of ownership must be laid. This paper assists towards this direction, and this exactly is its contribution, as it analyses different costs that are externalised in the shipping sector, along with solutions for the mitigation of externalization of costs. As the standard for many years has been the pursuit of accounting cost minimization, frameworks such as the one included in this work can pave the way towards sustainable solutions in shipping.

The feasibility of documenting the externalized costs and creating a total cost framework pertains to the research question of this work. The novelty of the research is that it is inclusive, in the manner that it pertains to a framework encompassing all the major externalized costs for shipping that need be addressed should the industry venture towards sustainability. The methodology refers to a structured literature review and the paper is organized as follows. After the present section, the types of externalized costs are analysed, along with proposals for mitigation. The paper closes with a conclusions section.

Methodology

The methodology of the work pertains to a structured literature review. Papers relevant to shipping externalities and costs were reviewed, to extract the major elements of cost externalization in shipping. From these, a structured framework based on the sustainability pillars of accounting cost, environmental cost, and ethical cost were attained. The aim of the methodology is to depart from a separation of internal and external costs in shipping, to a holistic framework where all costs are to be internalized (Fig. 1).

Shipping costs and externalities

Preliminary costs and shipbuilding

Building a ship from scratch requires a huge amount of capital related to design, materials, equipment, and construction (Fig. 2, https://commons.wikimedia.org/wiki/File:Shipbuilding.png). This amount of capital is indeed substantial and pertains to a main barrier to entry in the shipping industry. This barrier does not allow shipping to be concerned as a market with perfect competition.

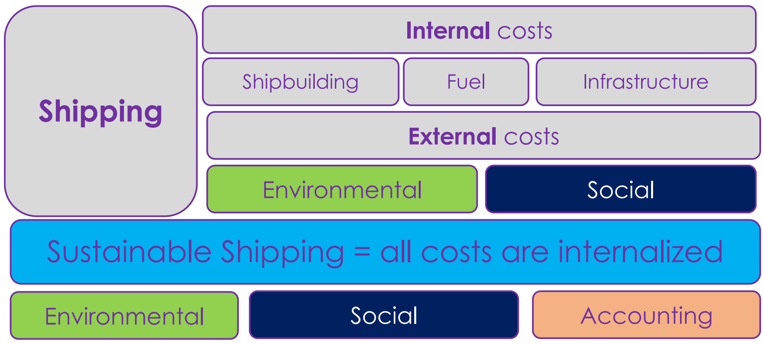

Fig. 1 The aim of the methodology (source: authors, costs are indicative—not to scale)

Fig. 2 Shipbuilding, Gloucester Harbor, 1873 (source: Wikimedia Commons, the image belongs to the public domain)

Shipyards offer attractive projects and decrease labour and material costs so that final construction costs are lower and more appealing to potential customers and of course shipowners and investors need to know the estimated vessel's cost before placing an order. The steel, other materials, engines, power generator, core equipment and labour hours are the main costs involved when building a new ship. Total cost can be changed due to variations during the preliminary design phase according to requirements. Concept design costs are the priority to a potential shipowner (Fig. 3, https://commons.wikimedia.org/wiki/File:CFD_Analysis_of_Aquarius_Eco_Ship.jpg).

Further details may be considered later. Dimensions, size, and general parameters are given prior to more complex characteristics and requirements. Rapid and flexible adjustments are crucial regarding the early stage of shipbuilding. Typically, labour and materials costs make up for approximately 70% of total shipbuilding costs. Steel usually accounts for approximately 30% of the material costs, the same as the ship's

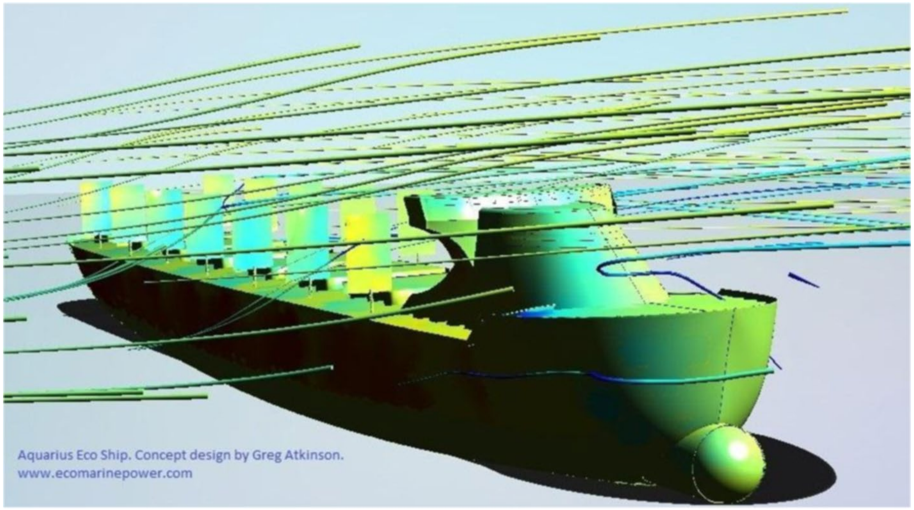

Fig. 3 Analysis of airflow around rigid sails on Aquarius Eco Ship concept design (source: Wikimedia Commons, the image is used under a CC BY-SA 4.0 license)

Fig. 4 Container vessel, Monte class, main engine (source: Wikimedia Commons, the image belongs to the public domain)

main engine (Lin and Shaw 2017) (Fig. 4, https://commons.wikimedia.org/wiki/File:Monte_HM_k130.jpg).

A quantifiable structure consisting of principal features and individual sub-items leads to an estimation based on a combination of those principal features and can be easily adjusted according to secondary features. Calculations and issues that pertain to direct costs include length, breadth, depth, design, scantling draft, displacement, maximum speed, maximum continuous rating power (MCR), revolutions per minute (RPM), thickness of the self-polish antifouling (SPAF), deckhouse height, layers of the lashing bridge, number of (e.g.) reefer containers, and number of crew. Different type of steel, according to durability, flexibility and other crucial factors is a variable when estimating material costs. Here the focus is on total cost minimisation, but the very crucial parameter of dismantling cost should not be left out. Shipbreaking had migrated to the East because of increasingly stringent regulation in the West, a situation that is exacerbating total cost of ownership, as dismantling and shipbreaking is performed under dubious, if existent, standards.

Sustainable energy systems and their costs

The usage of sustainable energy is an increasing concern, worldwide (Fig. 5, https://commons.wikimedia.org/wiki/File:What_are_the_safest_and_cleanest_sources_of_energy%3F.png). Especially for the shipping industry, shipowners deal with yearly operational cost and annual investments costs, which are modified based on fuel prices, duration, and number of calls. A Mixed Integer-linear Programming (MILP) approach is a very reliable and fast method to solve problems full of combinations to proceed in finding costs for maritime operations.

There are many examples of investment costs' analysis found on common engine energy conversion systems (Bernacki and Lis 2021). Ownership and operating costs increase with the reduction of GHG emissions (but on the other hand social and environmental costs increase with emissions). Unfortunately, the increase of costs is not linear compared to the baseline and consensus from the industry and beyond is required for sustainable priorities to be aligned.

Infrastructure investments

Improved seaport access and expansion of capacity can cause direct positive economic effects. A seaport (Fig. 6, https://commons.wikimedia.org/wiki/File:Tianjin_port.jpg) ensures seamless continuity between land and sea (Li et al. 2020). Sustainable impact due to port changes concerns external costs, energy consumption, operating costs, and transit time. Shipping operators, shipowners, and shippers benefit from reduction in transit and operational costs. Reductions in operating cost often leads to increased vessel sizes (cf. jumboisation), using economies of scale, which account for a big percentage of the total discounted economic effects (Baldi et al. 2019). Increase in vessel sizes triggers the

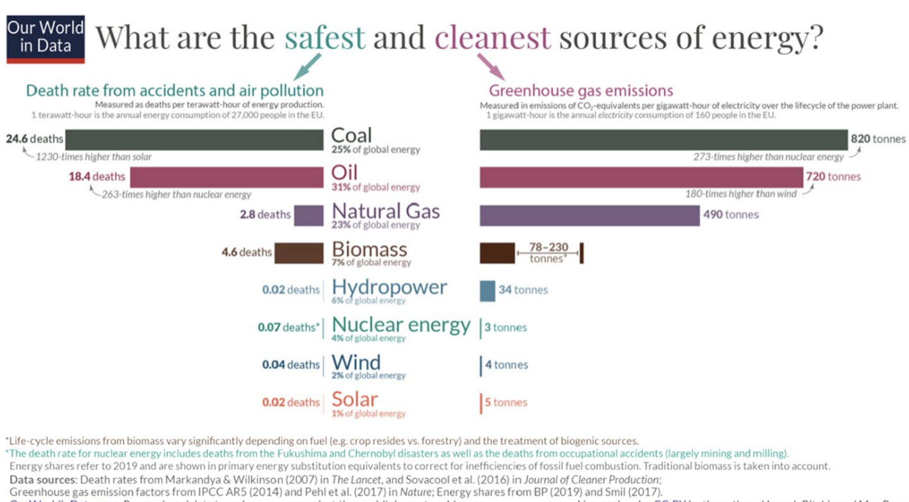

Fig. 5 The safest and cleanest sources of energy (source: Wikimedia Commons, the image is used under a CC BY-SA 4.0 license)

Fig. 6 Tianjin port (source: Wikimedia Commons, the image belongs to the public domain)

need for adjustments and port investments to accommodate new vessels. Upgrading a port's facilities is a costly project which helps keeping up with market changes.

Such an investment to a port's fixed assets provides improved quality and transport efficiency. An upgraded port has as a result shorter service times and lower cost for freight carriers and economic benefits for port operators. Total generalized transport costs are reduced, given that everything else remains unchanged, thus affecting the route decision by freight carriers in favour of the upgraded port (Alamoush et al. 2021). Indirect effects are also passed through price mechanisms on to other companies. Generalized maritime transport costs consist of shipping operating costs and transit time costs, two sectors where port investments are crucial (Brooks et al. 2022). Infrastructure improvements either reduce travel time or in-port congestion allowing larger ships, making transportation services more efficient (Alamoush et al. 2021). Again, cost minimization can be directly associated with social and environmental costs, as ports and related transportation infrastructure a priori cannot be sustainable, as for this infrastructure to materialize, an ecosystem must be destroyed. Here, concepts of mitigating externalities can be explored, along with more research to find sustainable solutions for port and transportation infrastructure to coexist with nature.

Transport costs can be separated in sub-categories. Operating costs will include administration, repairs and maintenance, staffing, stores, lubricants, and insurance. Voyage expenses will include fuel cost (Fig. 7, https://commons.wikimedia.org/wiki/File:MSC_Preziosa,_WPAhoi,_Kaiser-Wilhelm-Hafen,_Hamburg_(P1080387).jpg) and port dues and lastly, capital costs include interest and capital repayments. The daily shipping cost can be calculated with the daily operating cost, the daily voyage cost, and the daily capital cost. The bigger the vessel, the less fuel costs contribute to total voyage expenses, again, because of economies of scale. Yet, these economies tell us nothing of the social and environmental costs that are maximized when accounting cost is minimized. Worse still, these costs may be very difficult to uncover due to the scope of the shipping industry. A factory can maybe do little to cover the pollution it instigates, and a vessel is a polluting factory constantly on the move. Again a collective consensus from the industry and beyond is required to redefine what profit and cost is, as with the present context, in

Fig. 7 Bunkering for a cruise vessel (source: Wikimedia Commons the image is used under a CC BY-SA 4.0 license)

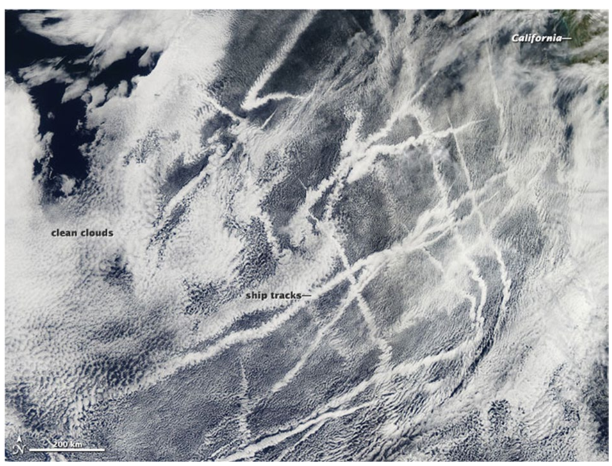

Fig. 8 Ship Tracks off the California Coast (source: Wikimedia Commons the image is used under a CC BY 2.0 license)

order to minimize the cost for a specific profit and loss account, the industry is creating an ocean of social and environmental costs.

The environment

Ship exhaust emissions (Fig. 8, https://commons.wikimedia.org/wiki/File:Ship_Tracks_off_the_California_Coast_-_NASA_Earth_Observatory.jpg) are a very important element of shipping externalities and costs. Emissions from every vehicle, vessel, or factory are an economic and social burden causing adverse environmental effects. For many countries, emissions play an important systemic role due to heavy ship traffic and dense port traffic (Tzannatos Ernestos 2010). Premature deaths related to shipping are most likely caused by PM emissions whereas most shipping externalities refer to global temperature rise, acidification, eutrophication, and reduced quality of life. For shipping emission externalities close to shore, one may consider the equivalent of damages imposed to rural areas.

Plastic is one of the most used materials worldwide, although destructive in terms of ecosystemic balance, as it is responsible for causing marine ecosystem degradation. Plastic debris (Fig. 9, https://commons.wikimedia.org/wiki/File:Plastic_Pollution_in_Santa_Luzia,_Cape_Verde.jpg), making up for more than 80% of marine pollution, is posing a great threat to the marine environment (Aretoulaki et al. 2021). Plastic waste usually originates from inland sources, although many ships might carry plastic parts as cargo or dump microplastics. Marine litter dumping, either deliberate or not, and accidental loss of cargo bears a potential direct cost associated to marine litter, while lost containers are a threat due to their size and ability to float. Smaller particles of litter might interfere with propellers, being responsible for engine shutdown or propeller damage and subsequent repairs, which translate into urgent expenses for the shipowner. It is of great importance that all ships follow necessary regulations regarding dumping so that socio-economic impact from plastics and waste in the oceans is minimized (Argüello 2020). Unfortunately, as mentioned above, only a small percentage of plastic originates from ships, thus limiting plastic dumping from vessels might not have direct positive results overall.

Noise is one of the external costs transportation modes must deal with. Road hauls and inland terminals are usually a noise source impacting the surrounding environment and ecosystem. More specifically, noise is considered an environmental pollutant which impairs health of residents, seafarers, and wildlife. Unfortunately, noise pollution is not yet treated as the threat it really is, although it has been recognised by the World Health Organization as a threat for health and a factor for reduction of property values. In the maritime sector, ports are rarely built near residential areas, thus have reduced consequences compared to inland modes, with reference to noise (Sun et al. 2022).

Onboard ships, the engine room is the principal noise generator. On most ships, noise levels over 100 dB(A) and even up to 110 dB(A) are present. A result of noise exposure combined with vibration and heat, is anxiety symptoms on the crew. Seafarers exposed to loud noises such as engineers in the engine room, are also at risk of hearing loss. The SOLAS convention includes additional requirements regarding noise levels on board

Fig. 9 Plastic Pollution in Santa Luzia, Cape Verde (source: Wikimedia Commons the image is used under a CC BY-SA 4.0 license)

ships. Noise is not yet perceived as an existing danger; social awareness has a long way to go until the industry fully understands noise related costs and impact. Raising awareness for noise related risks and other external costs related to ship operations is urgent (Tzannatos Ernestos 2010; Vukić et al. 2021).

Internalizing external costs

Shipping belongs to an intermodal transport network, as there are numerous two-way flows of products between ships, inland waterways, rail, track, and aviation. During decision-making there are many costs such as social and environmental which are not considered due to their unspecified nature. Congestion, accidents, and noise costs are only some of the problems slowly starting to get recognition (Dominguez-Péry et al. 2021). Keeping in mind that demand for transport is expected to grow in the following years, a corresponding increase of externalities and their costs is unavoidable.

The European Commission suggests an 25% increase of inland waterways and short sea shipping transport to minimise road transport externalities. Full impact caused by the transport sector can only be realized when we internalise all external costs. Principles such as the 'polluter pays' carbon pricing, emission trading schemes, and infrastructure charging mechanisms, can help internalising costs and accounting full costs of transportation in decision making. The Eurovignette system is an effective example of covering part of vehicles' external costs. A similar system can be used in maritime transportation to reduce external costs and overall social impact. Papers emphasizing short sea shipping and external costs are rather scarce in comparison to road or rail alternatives.

The concept of external costs was developed by Arthur Cecil Pigou, who published the book 'Economics of Welfare' in 1920, although Alfred Marshall had already proposed the same concept. After the abovementioned study, more work has been conducted in this field (cf. Stavroulakis et al. 2021a, 2021b, 2020; Koliousis et al. 2019, 2018a, 2018b, 2017; Stavroulakis and Papadimitriou 2017, 2016). Externalities in general can be either positive or negative. More specifically, regarding the transport sector, we are talking about significant negative externalities, known as external costs (Vierth and Merkel 2020; Ramalho and Santos 2021). External costs can be categorised in accidents, congestion, noise, air pollution, climate change, well-to-tank (WTT) emissions and infrastructure land take. Only variable external costs can be internalised. Ship accidents can be considered as rare events and although an accident has significant impact, it only represents a small percentage of total costs and externalities.

Congestion costs found in most transportation modes include time costs, costs related to reduced reliability and missed activities due to delays. Air pollution accounts for impact on health, especially caused by particulates, nitrogen oxides and sulphur.

When cost of transportation includes externalities, it is easier for travellers to choose the greener, less harmful route. Paying for social costs is more likely to lead to an optimal outcome when making haul decisions. Taxes and charges are the main ways companies can fairly internalise travel externalities. Usually, the user is charged with an extra fee equal to the price of marginal external costs created by their decisions. A one hundred €/tonne of CO_2 fee is suggested by the EU handbook to polluters.

Corrective taxes, fees and regulations can internalise external maritime services costs. Taxing a service will enable decision-makers and buyers to consider the full cost and effect of their consumption movements. Sweden is an example of a country which has chosen to internalise the biggest percentage of shipping costs. Sweden's tactic is a unique regulatory system of fees based on ships' environmental performance. The European Commission has stated the need for internalization of external costs through regulations, fees, charges and taxes, also known as the 'polluter pays' principle. Taxes should include socioeconomic costs related to transport activities. Further research is needed due to uncertainty and various hypothetical circumstances found in shipping. Internalization is a complex procedure with a wide margin of error.

Aviation and the maritime sector are both international industries and face difficulties in coordinating their externalities. Most of their external costs measured are related to air pollution and GHG emissions (Willer and Johns 2021). The State of California adopted a trading scheme in 2002, triggering engine modifications to reduce harmful emissions and thus minimise external costs. Combining several countries' systems to calculate fees and charges, is a difficult and complex challenge due to differing taxing mechanisms.

Regular hauls cause damage to infrastructure, which constantly needs maintenance and re-investments. Free, public infrastructure is rarely respected due to the absence of a total cost approach and the 'curse of the commons'. Regarding Sweden's effort to contribute to greener shipping and internalization of costs, the Swedish Maritime Administration will issue SOx certificates to ships using low Sulphur fuels and have installed NOx abatement technologies. On the one hand the shipping industry's importance cannot be overstressed, but on the other, an army of very serious problems arise from the way this industry is governed, i.e., the culture of cost minimization. And the present literature review has not even gone into the matter of ethical treatment of shipping employees, where the industry also faces serious issues, albeit with its gender representation, and general HR practices. Based on the above, a total cost framework seems to surface (Fig. 10). In order for shipping to be actually profitable, all tenets of total cost have to be taken under consideration.

Conclusions

The present work summarizes many negative externalities of shipping, thus pointing the way towards the necessity of a sustainable framework that takes under consideration the total cost of ownership in shipping. The latter will include social, health, and environmental costs, which have not been taken under consideration in the past, as costs were/are traditionally externalized.

Since shipping is a pillar of global trade, hopefully its total cost will be taken under regard, as one cannot talk about sustainability in a sector that externalizes its costs. Societies are less willing to bear the cost of profiteering in distinct sectors and a paradigm shift is required as to the actual notions of cost and profit if our industries are to be sustainable and resilient (Tang and Low 2020).

This work has undertaken a literature review to extract the relevant total cost of shipping, to create a framework that can facilitate a paradigm shift towards a total

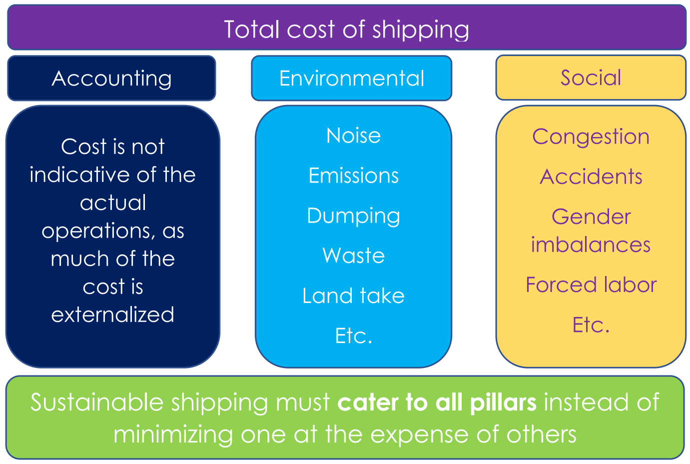

Fig. 10 The total cost framework (source: authors)

cost approach. The managerial implications of this research pertain to the fact that an inclusive inventory of costs has been relinquished, thus policy and practice can refer to this inventory if a total cost approach is required.

The limitations of this study refer to the fact that a quantitative approach is absent, although this may be included in future research. Based on the present research, a quantitative model may be formulated that takes under consideration all the relevant costs and can give solid cost figures upon a multitude of shipping scenarios.

Abbreviations

AIS	Automatic identification system
EEDI	Energy efficiency design index
EEOI	Energy efficiency operational indicator
GHG	Greenhouse gas
HR	Human resources
LNG	Liquefied natural gas
MAE	Med-Atlantic ecobonus
MCR	Maximum continuous rating
MGO	Marine gasoil
MILP	Mixed integer-linear programming
RPM	Revolutions per minute
SPAF	Self-polishing anti-fouling
WTT	Well-to-tank

Acknowledgements
The authors wish to gratefully acknowledge the contribution of the anonymous reviewers, whose comments improved the quality of the paper.

Author contributions
PJS: Conceptualization, Data curation, Formal analysis, Investigation, Methodology, Resources, Validation, Visualization, Writing—original draft. SP: Conceptualization, Methodology, Supervision, Project administration. All authors read and approved the final manuscript.

Funding
N/A.

Availability of data and materials
Data will be made available upon request.

Declarations

Competing interests
There are no competing interests.

Received: 10 December 2021 Accepted: 14 June 2022
Published online: 24 June 2022

References
Alamoush AS, Ballini F, Ölçer AI (2021) Revisiting port sustainability as a foundation for the implementation of the United Nations Sustainable Development Goals (UN SDGs). J Ship Trade 6:19. https://doi.org/10.1186/s41072-021-00101-6
Aretoulaki E, Ponis S, Plakas G, Agalianos K (2021) Marine plastic littering: a review of socio-economic impacts. J. Sustain. Sci. Manag 16(3):277–301. https://doi.org/10.46754/JSSM.2021.04.019
Argüello G (2020) Environmentally sound management of ship wastes: challenges and opportunities for European ports. J Ship Trade 5:12. https://doi.org/10.1186/s41072-020-00068-w
Baldi F, Brynolf S, Maréchal F (2019) The cost of innovative and sustainable future ship energy systems, pp 239–250. https://www.scopus.com/inward/record.uri?eid=2-s2.0-85079635609&partnerID=40&md5=2a79b9abdc64c2e7b914cc2fd07e77ad
Ben-Hakoun E, Shechter M, Hayuth Y (2016) Economic evaluation of the environmental impact of shipping from the perspective of CO_2 emissions. J Ship Trade 1:5. https://doi.org/10.1186/s41072-016-0011-5
Bernacki D, Lis C (2021) Investigating the sustainable impact of seaport infrastructure provision on maritime component of supply chain. Energies 14(12):3519
Brooks MR, Knatz G, Pallis AA et al (2022) Transparency in port governance: setting a research agenda. J Ship Trade 7:1. https://doi.org/10.1186/s41072-021-00103-4
Burnett R et al (2018) Global estimates of mortality associated with long-term exposure to outdoor fine particulate matter. PNAS 115(38):9592–9597. https://doi.org/10.1073/pnas.1803222115
Carlan V, Naudts D, Audenaert P et al (2019) Toward implementing a fully automated truck guidance system at a seaport: identifying the roles, costs and benefits of logistics stakeholders. J Ship Trade 4:12. https://doi.org/10.1186/s41072-019-0054-5
Casaca ACP, Loja MAR (2020) 2019 World of shipping Portugal: an international research conference on maritime affairs editorial "leading the shipping industry into the future." J Ship Trade 5:27. https://doi.org/10.1186/s41072-020-00082-y
Casaca ACP, Loja MAR (2021) World of shipping portugal: an international research conference on maritime affairs editorial. J Ship Trade 6:16. https://doi.org/10.1186/s41072-021-00099-x
Czermański E, Pawłowska B, Oniszczuk-Jastrząbek A, Cirella GT (2020) Decarbonization of maritime transport: analysis of external costs. Front Energy Res 8:28. https://doi.org/10.3389/fenrg.2020.00028
Dominguez-Péry C, Vuddaraju LNR, Corbett-Etchevers I et al (2021) Reducing maritime accidents in ships by tackling human error: a bibliometric review and research agenda. J Ship Trade 6:20. https://doi.org/10.1186/s41072-021-00098-y
Frouws K (2016) Is reducing speed the right mitigating action to limit harmful emissions of seagoing RoRo cargo carriers? J Ship Trade 1:9. https://doi.org/10.1186/s41072-016-0014-2
Gerakoudi-Ventouri K (2022) Review of studies of blockchain technology effects on the shipping industry. J Ship Trade 7:2. https://doi.org/10.1186/s41072-021-00105-2
Hoffmann J, Wilmsmeier G, Lun YV (2017) Connecting the world through global shipping networks. J Ship Trade 2:2. https://doi.org/10.1186/s41072-017-0020-z
https://commons.wikimedia.org/wiki/File:CFD_Analysis_of_Aquarius_Eco_Ship.jpg
https://commons.wikimedia.org/wiki/File:Monte_HM_k130.jpg
https://commons.wikimedia.org/wiki/File:MSC_Preziosa,_WPAhoi,_Kaiser-Wilhelm-Hafen,_Hamburg_(P1080387).jpg
https://commons.wikimedia.org/wiki/File:Plastic_Pollution_in_Santa_Luzia,_Cape_Verde.jpg
https://commons.wikimedia.org/wiki/File:Ship_Tracks_off_the_California_Coast_-_NASA_Earth_Observatory.jpg
https://commons.wikimedia.org/wiki/File:Shipbuilding.png
https://commons.wikimedia.org/wiki/File:Tianjin_port.jpg
https://commons.wikimedia.org/wiki/File:What_are_the_safest_and_cleanest_sources_of_energy%3F.png
Koliousis IG, Papadimitriou S, Riza E, Stavroulakis PJ, Tsioumas V (2017) Strategy, policy, and the formulation of maritime cluster typologies. Mar Policy 86:31–38
Koliousis IG, Papadimitriou S, Stavroulakis PJ, Tsioumas V (2018a) The management of change within maritime clusters. FME Trans 46(3):360–366
Koliousis IG, Papadimitriou S, Riza E, Stavroulakis PJ, Tsioumas V (2018b) Scarcity theory and maritime clusters: from paradox to modelling. Mar Policy 93:40–46
Koliousis IG, Papadimitriou S, Riza E, Stavroulakis PJ, Tsioumas V (2019) Strategic correlations for maritime clusters. Transp Res Part A 120C:43–57
Li W, Vanelslander T, Liu W et al (2020) Co-evolution of port business ecosystem based on evolutionary game theory. J Ship Trade 5:20. https://doi.org/10.1186/s41072-020-00072-0
Lin C-K, Shaw H-J (2017) Feature-based estimation of preliminary costs in shipbuilding. Ocean Eng 144:305–319. https://doi.org/10.1016/j.oceaneng.2016.11.040
Matekenya W, Ncwadi R (2022) The impact of maritime transport financing on total trade in South Africa. J Ship Trade 7:5. https://doi.org/10.1186/s41072-022-00106-9

Pruyn JFJ (2020) Benchmarking bulkers delivered between 2010 and 2016, identifying the effect of the EEDI introduction. J Ship Trade 5:11. https://doi.org/10.1186/s41072-020-00063-1
Ramalho MM, Santos TA (2021) The impact of the internalization of external costs in the competitiveness of short sea shipping. J Mar Sci Eng 9(9):959. https://doi.org/10.3390/jmse9090959
Sideri O, Papoutsidakis M, Lilas T et al (2021) Green shipping onboard: acceptance, diffusion and adoption of LNG and electricity as alternative fuels in Greece. J Ship Trade 6:9. https://doi.org/10.1186/s41072-021-00089-z
Stavroulakis PJ, Papadimitriou S (2016) The strategic factors shaping competitiveness for maritime clusters. Res Transp Bus Manag 19:34–41
Stavroulakis PJ, Papadimitriou S (2017) Situation analysis forecasting: the case of European maritime clusters. Marit Policy Manag 44(06):779–789
Stavroulakis PJ, Papadimitriou S, Tsioumas V, Koliousis IG, Riza E, Kontolatou E (2020) Strategic competitiveness in maritime clusters. Case Stud Transp Policy 8(2):341–348
Stavroulakis PJ, Tzora V, Riza E, Papadimitriou S (2021a) Transportation, the pathogen vector to rule them all: Evidence from the recent coronavirus pandemic. J Transp Health 22C:101087
Stavroulakis PJ, Papadimitriou S, Tsirikou F (2021b) Perceptions of competitiveness for maritime clusters. Ocean Coast Manag 205C:105546
Sun Y, Wang Y, Xie J (2022) The co-evolution of seaports and dry ports in Shandong province in China under the Belt and Road Initiative. J Ship Trade 7:3. https://doi.org/10.1186/s41072-021-00104-3
Tang LC, Low JM (2020) Strategic intent of OBOR: enhancing energy supply resilience. J Ship Trade 5:3. https://doi.org/10.1186/s41072-020-0058-1
Tzannatos Ernestos E (2010) Ship emissions and their externalities for Greece. Atmos Environ 44(18):2194–2202. https://doi.org/10.1016/j.atmosenv.2010.03.018
Vierth I, Johansson M (2020) The impact of alternative environmentally differentiated fairway dues systems in Sweden. J Ship Trade 5:25. https://doi.org/10.1186/s41072-020-00077-9
Vierth I, Merkel A (2020) Internalization of external and infrastructure costs related to maritime transport in Sweden. Res Transp Bus Manag. https://doi.org/10.1016/j.rtbm.2020.100580
Vukić L, Mihanović V, Fredianelli L, Plazibat V (2021) Seafarers' perception and attitudes towards noise emission on board ships. Int J Environ Res Public Health 18(12):6671. https://doi.org/10.3390/ijerph18126671
Wik C, Niemi S (2016) Low emission engine technologies for future tier 3 legislations-options and case studies. J Ship Trade 1:3. https://doi.org/10.1186/s41072-016-0009-z
Willer C, Johns M (2021) Reduction of GHG emissions from ships: evaluation of inter-company R&D cooperation models in the case of Hapag-Lloyd. J Ship Trade 6:5. https://doi.org/10.1186/s41072-021-00084-4

Publisher's Note

Springer Nature remains neutral with regard to jurisdictional claims in published maps and institutional affiliations.