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Sustainability, externalities and ocean grabbing: Pressing challenges for maritime transport

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ABSTRACT

Due to the strategic role of the maritime sector in the world economy, attention should be paid to the changing context in which its activity is carried out. Global shocks, such as COVID-19, or those more specific, such as Brexit, the recent armed conflicts in Ukraine or the Middle East, the growing insecurity in the Red Sea, or extreme natural phenomena resulting from climate change, add to new trends related to the transition towards environmental concerns, the technological revolution, financial swings, trade wars, changes in consumer behaviour or migration processes. All of this, in a simultaneous and interconnected way, is altering economic patterns and consequently having an impact on logistics and maritime transport. New circumstances pose new challenges, and the success of strategies designed to meet them requires a correct diagnosis of the problems to be solved. This work aims to contribute to the analysis of what, in the opinion of the authors, are three major challenges for maritime transport which, moreover, transcend the sector itself: the sustainability of the economic growth model, the privatisation of the use of maritime resources and the absence of a clear alternative fuel to deal with the decarbonisation of the fleet. The identification of these three major challenges resulted from an exhaustive review of the literature, which shifted away from the focus on maritime transport itself to the evolution of its economic, social and environmental context.

1. Introduction

Waterborne navigation has always played an important role in human life, so much so that even the remains of the earliest civilizations discovered on the shores of Mesopotamia and the Mediterranean reveal the existence of commercial relations [8].

If during the Renaissance took place the great voyages that changed the world as it was known until then, in the nineteenth century, with the industrial revolution and the incorporation of the steam engine into maritime transport, the voyage time between continents was shortened. The improvements experienced since then in maritime transport, particularly during the twenty-first century, have led to the consolidation of the phenomenon of globalisation, and henceforth maritime trade has soared to successive all-time highs[1] (broken only by the 2008 crisis and the pandemic, in 2020). However, it should be noted that in recent years a significant sequence of events has been detected that have had an impact on the global, international and regional supply chain. Sanchez and Tomassian [64] review events linked to financial crises (e.g., the ".com" crisis at the beginning of the millennium, the crisis of 2008–2009), extreme natural events (Katrina, the Panama Canal draught), cyber security (Wannacry/Petya ransomware), geopolitics/strategic/security (9/11, Ukraine-Russia, Red Sea and Middle East conflicts, commercial wars), health (COVID-19) or high-impact national events (Brexit). All of these have had major consequences in the way of a shock for logistics and maritime transport, but they have also left their mark on trends that are consolidated over time and that should be borne in mind. It is precisely on these trends that this paper focuses attention.

The literature linked to the maritime sector from the field of Economics traditionally revolved around three issues: navigation, ports and logistics [28,70]. According to authors such as Stopford [69], Cullinane [18] or Ma [45], it can be deduced that, until now, attention was mainly focused on the analysis of the market and its cycles, the fleet and the regulation of navigation, competition and the concentration of agents, as well as investment in infrastructure and its governance, or maritime

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[1] The volume of goods transported by sea has increased by more than 150 % since the 90 s; it currently accounts for around 80 % of world trade [73].

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trade and the articulation of its routes. All these issues are linked to the specific problems of the sector, concerned with its efficiency and its impact on competitiveness [14]. However, the world is more complex in the current days, and concerns need to be addressed from a global and interdisciplinary perspective since maritime transport is part of a broader chain: that of supply. It therefore leaves it subject to pressures of all kinds that occur all over the world. New challenges emerge, the implications of which transcend the very sector, and whose relevance requires immediate attention.

It is evident that the nature of the object of study has significantly increased in complexity.[2] In the first two decades of this century, there has been a shift from interest in regional integration and the consolidation of inland port areas, given their effect on the competitiveness of flows, to even proposing degrowth as a necessary strategy to redirect economic activity towards sustainable development; from the concern about alliances between the main operators, due to their impact on competition in shipping and, consequently, on world trade, to observe how a grabbing of the seas is taking place; from the convenience of renewing the fleet to adapt it to more sustainable environmental standards, to the need to replace fossil fuels as soon as possible with others that contribute to tackling global warming.

These topics, directly linked to market failures,[3] are the central point of this work. As a result of an exhaustive review of the literature, three major challenges have been identified which, although they go beyond the field of maritime transport, have an undeniable direct impact on it. As far as the authors are aware, the influence of changing economic, social and environmental conditions on maritime transport has not been analysed in a comprehensive manner, although Haralambides and Gujar [30] had already pointed out that changes in deglobalisation, climate change and technological disruption have an impact on supply chains. This paper provides an individual analysis of each of the challenges identified by the authors, laid out as follows: Section 2 highlights the relocation and some strategies proposed to deal with the negative externalities derived from an unsustainable economic growth model. Extreme natural phenomena related to climate change and the threats they pose to the planet and its inhabitants make it necessary to rethink the model of economic growth. This will necessarily affect maritime transport, since changes in production and consumption patterns alter trade flows. Section 3 addresses the issue of ocean grabbing, which results from the public/communal nature of marine resources. Globalisation has been seen to accelerate interdependence, but it has not succeeded in consolidating into strong multilateral organisations, nor has it prevented the shift of power to non-state actors due to the high intensity of technological innovation processes and the continued growth in connectivity. As a result, the process of privatisation of marine resources is intensifying. Section 4 details the great challenge of replacing fossil fuels by more sustainable alternatives, capable of contributing to curbing global warming while being technically and economically viable. The impact of maritime transport emissions on the environment has led to the International Maritime Organization (IMO) to intervene through regulation in the marine oil refining industry, the volume of emissions from vessels and the type of fuel used. Liquefied natural gas and biofuel were identified as the best alternatives to reduce emissions. However, recent research casts doubt on this. A summary of their main contributions is outlined in this section. Lastly, Section 5 contains the main conclusions derived from the analysis of the literature and a process of reflection by the authors of this work.

[2] See Zhang et al. [86] for a review of the most recurrent themes in the recent literature on resilience in maritime transport networks.

[3] In a previous analysis of the main challenges to the governance of the sector, Monios and Wilmsmeier [51] also observed market failures. In this case, linked to its structure (oligopoly) and the emission of greenhouse gases (negative externality).

2. Sustainability of the growth model

The Club of Rome[4] laid the foundations for the study of ecosystem degradation due to economic growth. Thirty years on, the global ecological footprint data has exceeded the recommended levels of sustainability by 20 %. From the 1990 s onwards, sustainability ratios became increasingly relevant regarding the different predictive scenarios of industrial activity, giving rise to a debate about the factors that enhance the risks of climate change, and the strategies needed to deal with them.

For some authors, the natural limits of growth were exceeded, leading us to the "overshoot" phase,[5] an idea that was echoed after the Rio Summit in 1992. Some contemporary currents of thought criticise the traditional approach to development, which focuses on economic growth. These include the so-called "welfare economy", the "green economy" or the "theory of degrowth". They stress the need to recognise the limits of the planet and argue that the focus of political and economic action should be on human well-being and environmental sustainability. In this line of thought, the *theory of degrowth* stands out, based on the interconnection of economic and ecological systems, with the affirmation that the maximisation of growth is planned in disregard of its effects on the environment, and it is opposed to the idea that growth in Gross Domestic Product is an indicator of well-being. This leads to the necessity to address economic policy in terms of human well-being and environmental sustainability[6]: it advocates putting an end to the current model of production and consumption to restore the basic balances of the planet; reducing and redirecting growth to prioritise the sustainability of economic development and reduce inequalities [21].[7]

Today, we are witnessing a deregulated globalisation, where economic protectionism and ideological exclusionary extremes have their place, which makes the world tense and subject to intense vulnerabilities. The economic theories mentioned above, although they have not permeated society, add to the trend that began in the last decade, and accentuated after the COVID-19 pandemic, to transform the global value chains to partially reverse the processes of productive relocation introduced since the 90 s. The collapse of international trade observed following the start of the pandemic, together with the rising geopolitical tensions, and the environmental need to bring production and consumer centres closer together, is giving rise to a second industrial relocation. Large companies are now basing their strategies on three new concepts: reshoring (recovering relocated factories); nearshoring (reducing the concentration of risks outside the region); and friendshoring (relocation to allied countries).

In brief, whether it is due to an awareness of the need to shift towards a more sustainable economic model, or due to the convenience of relocating production centres, changes in international trade relations can be expected. In some cases, due to a potential destruction of trade (for example, due to the fall in exports from Southeast Asia to the West, both due to the increase in the standard of living in this area and the reduction in consumption in the most developed countries); in others, derived from the feasible creation of new flows (strengthening South-South trade). The balance between the two contrasting changes will have far-reaching consequences for international trade flows in the medium term, both on the demand side (more volatile and containing the growth of flows) and on the supply side (with frictions arising from

[4] The Limits to Growth [47].

[5] See Monios and Wilmsmeier [50] to delve deeper into the concepts of collapsology and deep adaptation.

[6] For instance, Raworth [60] observes that there is interdependence between the health of society and that of the planet.

[7] At the extreme, Saito [62] points out that the current capitalist model is unsustainable, and that the alternatives known as green capitalism or environmental Keynesianism are insufficient to achieve a more balanced relationship with nature.

trade wars and changes in trade patterns) [74,84]. In addition, recent events such as the Houthi attacks in the Red Sea confirm the misalignment of global value chains due to changes and diversions in trade flows. Following Monios and Wilmsmeier [51]: "*global supply chains will be less reliable, slower and more expensive*."

This evolution of trade flows will necessarily have an impact on maritime and port activities. We can give three such examples. The first, arising from changes in production systems and supply chains as reported by UNCTAD [75], affects the configuration of maritime routes. This is in addition to the growing weight of regionalisation, which is enhancing intra-regional movements in the Asian context compared with more traditional movements of the major east-west routes (in the case of the Cape of Good Hope associated with the blockade of the Suez Canal by the accident of the Ever Given, and more recently by the insecurity of traffic due to attacks from the Yemeni border), or even the emergence of new routes through the Arctic. The third example is observed from the port performance indices. According to the World Bank Group [82], new port areas are emerging in the world's top-10 (2023) in terms of efficiency: Yangshan (China); Salalah (Oman); Cartagena (Colombia); Tangiers-Med (Morocco); Tanjung Pelepas (Malaysia); Chiwan (China); Cai Mep (Vietnam); Guangzhou (China); Yokohama (Japan) and Algeciras (Spain). The disparity in relation to ports with higher traffic volumes and those with greater maritime connectivity is striking. And, at the same time, it allows to perceive new functional spaces that contribute to define a new cartography (connectivity/trade routes) and, with this, new balances of power.

As a result of all the aforementioned, new forms of multilateral governance are emerging that help shift power to the large financial, technological and industrial corporations. In other words, globalisation accelerated interdependence but did not prevent the shift of power to non-state actors. A clear example of this, with important consequences for the sector, is the second challenge to which this work refers: ocean grabbing.

3. Ocean grabbing

The commitment to a blue economy[8] can be seen as a means towards sustainable economic growth. The ocean is a source of wealth, and its commercial use is accelerating, but the dynamics inherent in this process can also generate significant negative externalities. That is, today there are new impulses, new industries and, also, new risks. Campling and Colás [13] point out that capitalism is giving rise to re-territorialisation processes in order to commodify nature and marine resources, imposing its own exploitation and appropriation formulas. In addition, technology is accelerating the processes of common resource appropriation by modifying relationships at sea, altering perceptions of risk and vulnerability [52]. In line with the work of Pauly [55], the development of capitalism is moving from the exploitation of traditional productive resources to the extension towards spaces with little commodification and unexploited natural resources; that is, the oceans. However, global supply chains are more efficient, the fewer the barriers to shipping they have to face. For this reason, Adam Smith advocated international laws that recognise freedom of navigation, protection of fishing and the preservation of commercial monopolies [30]. And for this reason, and in order to prevent waste and the deterioration of ecosystems, it is necessary to establish roadmaps and international agreements [17].

The development of the blue economy gives rise to a debate due to its practical application and its governance, complex and uncertain, which implies the need to respond to whether the proposed activities are assimilable for society as a whole, as well as who they benefit [12,16,48,56,65,68,78]. In the analyses carried out by UNCTAD [76] and the World Bank's PROBLUE programme [81], principles such as the equitable distribution of resources seem to have been diluted in favour of the inclusion approach (invitation to participate in coastal countries). In other words, the existing historical power relations are maintained, but new interrelations have been established that require complex governance [12]. The world economy is shifting from the hegemony of cooperative liberal institutionalism based on rules, to a new scenario of bilateral international relations based on the balance of powers.

At this point the link between two different phenomena is highlighted: industrialisation and the rise of the privatisation of ocean resources. The combination of increased global demand, technological progress and the decrease in land-based sources of resources makes the extraction of ocean materials of economic interest [39]. Hence, many companies are trying to anticipate and position themselves.

The growing presence of transnational companies linked to ocean activities implies the use of ocean resources and assets, and reinterprets the power relations between the companies themselves, the States and society as a whole, in line with theses as diverse as those subscribed to by the followers of the *theory of dependency*, those arguing for the deterioration of the real terms of trade, the followers of unequal exchange and monopoly capital, or those subscribing to the *theory of resource grabbing* [16].

The consolidation of a small number of transnational companies, with activities related to the ocean economy is striking, and the globalisation process has contributed to increasing their economic power. They stand out for their scope [77], operate under business conglomerates, and are highly intertwined with global supply chains, facilitating high capitalisation and monopolisation of markets. It means the following: i) the majority of the revenue extracted from the use of the world's oceans is concentrated among 100 transnational corporations; ii) these companies currently generate more than $1 trillion in revenue; and iii) if they were a country, said country would constitute the 16th largest economy in the world. In addition, as can be seen in Table 1, (i) 60 are listed on the stock exchange; ii) there is a clear predominance of North American companies (12 % of the total), followed by those from Saudi Arabia and China (8 % each), Norway (7 %), France (6 %), the United Kingdom (5 %) and South Korea, Brazil, Iran, the Netherlands and Mexico (4 % each); (iii) they have a clear sectoral specialisation in favour of oil and gas extraction (47 companies), shipbuilding (14) and container shipping (11); iv) those linked to cruise tourism (4) account for 93 % of the sector's turnover), while in the fishing sector it is atomised (the 9 largest companies only represent 15 % of turnover).

Österblom et al. [54] define these companies as a "super-entity" of the global economy. These groups handle ocean resources, from the exploration of the seabed for minerals to installing wind turbines, cruising and laying undersea cables.[9] As Jouffray et al. [39] state, human societies have utilised ocean resources for thousands of years, still this implies a turning point in their use regarding: i) food (fisheries, aquaculture or nutritional aspects); (ii) materials (extraction of basic resources, such as hydrocarbons and minerals or genetic material); and (iii) space (cables, pipelines, tourism, border territories, renewable energies or military activities). This is known as the *blue acceleration fever*: the ocean may be vast, but it is not unlimited.

Bennet et al. [9] and Arias Schreiber et al. [4] warn against the relativisation of the risks of an unequal distribution of benefits and potential social damage arising from the exploitation of marine resources, and stress that future development of the oceans, seas and coastal communities advocated by the Blue Economy may entail material risk. While the blue acceleration limits the advance of marine-fisheries

[8] The blue economy proposes to promote economic growth based on the sustainable use of marine resources.

[9] There are more than 1.3 million kilometres of submarine telecommunication cables and more than 100,000 km of pipelines for transporting gas, oil or water. Likewise, the growing demand for drinking water and irrigation means that there are more than 16,000 desalination plants that transform 65 million cubic meters of seawater per day. There are also 9000 offshore oil and gas platforms.

Table 1
Weight of the top 100 transnational companies related to the ocean economy according to activity in their sector (2018).

	Companies' relevance	Number of societies	Turnover (million $)	Main Companies
Cruises	93 %	4	547,000	Carnival; Royal Caribbean; Norwegian Cruise Line; MSC Cruise
Container companies	85 %	11	156,000	A.P. Möller-Maersk; MSC; CMA/CGM; COSCO; Hapag-Lloyd; ONE; Evergreen; Yang Ming; Pacific International Line; Hyundai Merchant Marine; ZIM
Port activities	82 %	5	38,000	D.P. World; Shanghai Inter. Port Group; PSA; A.P.M. Terminal; Hutchinson Holding
Shipbuilding and repairment	67 %	14	118,000	Hyundai; Daewoo Sh; China State Sh; General Dynamics; Huntington; China Sh.; Fiacantieri; Samsung; BAE Systems; Sembcorp; Imabai Sh.; Yangszijiang Sh.; etc.
Oil and gas extraction	51 %	47	830,000	Aramco; Petrobas; National Iranian Oil Co; PEMEX; Exxon Mobil; Royal Dutch Shell; Equinor; TOTAL; BP; Qatar Petroleum; Chevron; China National Offshore Oil Co; Abu Dhabi Ntal Oil; Petoro; ENI; Petronas; Nigerian Petroleum; State Oil Azerbaijan; Sonangol; Conoco Phillips; Var Energy; etc.
Offshore wind energy	48 %	1	37,000	Orsted
Maritime Equipment	18 %	9	354,000	Hyundai Engineering; Technip FMC; Saipem; Wartsila; Subsea; Hitachi Zusen; DEME; Royal Boskadis; Aker Solutions.
Fishing	15 %	9	276,000	Maruha Nichiro; Nippon Suisan Kaisha; Dongwon; MOWI; THAI Union Group; Mitsubishi; OUG Holding; Austevoll Seafood; Trident Seafood

Source: Authors' elaboration based on Virdin et al# [77].

interventions which are socially and ecologically fairer in terms of access, use and management of resources, the promotion of certain productive activities can increase social-economic inequalities between coastal communities.

Despite these risks, the prospect of commercial exploitation of the seabed is leading many countries to claim maritime rights of national sovereignty over ocean space, and each claim contributes to the reduction of the area designated as the common heritage of mankind. It is important to note that the highly geo-political ocean space is controlled by various maritime jurisdictions in which States assert their influence. Reclaiming the ocean means entering a new framework of relations of power and sovereignty [42,66]. Following González-Laxe [25], it could be said that a genuine "race for the sea" has been launched, along with a dynamic of ocean grabbing and territorialisation.

Coastal states must work purposefully to set the pace, goals and actors of this *blue acceleration* [39], as the process of re-territorialisation of the sea is very complex due to the fact that it brings together legal, social, environmental, technological, political, economic and cultural aspects. For this reason, authors such as Bennet, et al. [10] advise coastal states to protect themselves against the hazards of ocean grabbing. This is linked to the so-called blue justice, which advocates articulating mechanisms for protecting the interests of coastal populations [38,85], as indigenous peoples do, for example, when claiming their right to means of subsistence [9].

In short, the debate is very open and, as Barbesgaard [7] points out, under the motto of "blue growth", appropriations are produced from global policies that supposedly align the needs of the different productive agents. However, the blue economy encourages an increase in ocean development activities that are, at the same time, directed and/or driven from abroad with the risk of undermining the principle of self-determination for which many developing ocean States have been struggling. The blue economy also focuses on economic growth driven by the use of ocean resources, but not on the environmental degradation that such use can entail. This causes another negative externality: pollution from shipping and its effects on global warming. The need to tackle this problem leads us to talk about the third major challenge of maritime transport addressed in this work: finding a fuel that allows for the decarbonisation of the fleet.

4. Fleet decarbonisation

According to the World Economic Forum [83], climate change is probably the greatest challenge currently facing humankind.[10] In the specific case of the maritime sector, it is expected that the increased frequency of extreme weather events, together with the expected rise in sea levels, will have adverse and direct consequences for both port infrastructures and navigation (see, for instance, Garcia-Alonso et al. [24]).

Global warming is accelerating due to the emission of greenhouse gases and other particles that are equally harmful to the environment. One of the main emitters is the transport sector, and the maritime mode, despite being the most efficient in terms of CO2 emissions per tonne [88], generates 3 % of greenhouse gas emissions.[11] According to the International Renewable Energy Agency [37] and Balcombe et al. [6], if the emissions of the global fleet were allocated to a country, it would occupy sixth place in the ranking of CO2 emitters. This is because 99 % of active ships use petroleum-derived fuel [59], and their consumption reaches 7 % of the total [33]. In addition, a significant increase in emissions is expected over the next three decades[12] [34]. This situation has led the United Nations to declare this decade as the Ocean Decade of

[10] Over 140 million climate migrants are expected by 2050 [36].

[11] According to the International Maritime Organization [34] and the European Environment Agency [23], it is responsible for 2.9 % of CO2 emissions: 9.8 % of SOx; 14.7 % of NOx; 6.7 % of PM2.5; and 3.6 % of PM10.

[12] Improvements in energy efficiency are expected to be offset by an increase in traffic (IMO, 2021), confirming the fulfilment of the Jevons paradox [51].

Ocean Science for Sustainable Development [72].[13]

To combat the harmful effects of emissions from shipping,[14] the fleet must face the challenge of decarbonisation in accordance with the Paris Agreement and the Glasgow Climate Pact, adopting propulsion technologies with low or zero carbon emissions. However, the lack of consensus on which alternatives are the most appropriate [31], coupled with the lack of coherence of the policies designed [5], make the transition no easier. It is to be expected that the decarbonisation of the sector would not be so difficult thanks to the existence of the International Maritime Organization (IMO), an international organisation that regulates its activity. However, this has not been the case, and there are serious doubts about the fulfilment of the IMO [35] objectives: i) to reduce CO2 emissions from international shipping by at least 40 % on average by 2030 compared to 2008; (ii) reach a minimum of 5 % (10 % desirable) of energy sources/technologies that generate zero (or near) GHG emissions by 2030; and (iii) eliminate GHG emissions entirely by 2050. Several studies draw attention to the difficulties in achieving these objectives. For example, Lister et al. [44] point to delays in procedures and ratification of instruments by some Member States, as well as strong resistance from shipping companies, as causes of increasing regulatory fragmentation and lack of environmental governance. Monios and Ng [49] point to the decrease of the legitimacy of the IMO as the main governing body for the shipping sector. Others, such as Prehn [57], emphasise the lack of political consensus and the complexity of implementing the UN principles established to address climate negotiations.

Achieving the IMO objectives requires a technological revolution that entails financial incentives and regulatory reforms [46], and which is mainly aimed at replacing fossil fuels with alternative fuels,[15] such as liquefied natural gas (LNG), liquefied petroleum gas (LPG), methanol, ethanol, hydrogen, ammonia, biofuels or electricity [61]. However, the use of traditional heavy fuel oil (HFO) and marine diesel oil (MDO) is still predominant [67].

Of the alternative fuels considered to date, LNG is the only one that has stood out[16] because it generates fewer emissions than fossil fuels,[17] is not toxic or corrosive, and does not produce odours [79]. In addition, its price is competitive, and it does not require gas cleaning systems or distillates to meet ECA requirements [1]. However, supply infrastructure is scarce, and its use entails a high initial investment [43,87]. A great deal of attention is also currently being paid to methanol, ammonia and hydrogen [3]. There is, however, no scientific consensus that any of these are preferable to conventional fuels. It is true that all of them cause fewer emissions in the operational phase, but they have significant limitations in terms of the production, distribution and supply phases.

For a fuel to be deemed an acceptable alternative, it must be evaluated from a life cycle standpoint: both the emissions in the process of production, distribution, supply and consumption, as well as its requirements for fertile land for its production, must be considered. A chronological summary of the progress in the comparison of alternative marine fuels based on this perspective can be found in Bilgili [11]. It points out that the use of LNG favours the reduction of emissions of nitrogen oxides and sulphur, but the methane leaks that it entails reduce effectiveness in the fight against global warming.[18] In this sense, methanol offers good results: potential global warming would fall by 56 %, so it is, a priori, more environmentally friendly. Nonetheless, from a life cycle perspective, LNG would be preferable. In short, the lowest energy consumption is achieved with the use of LNG (which produces zero PM2.5), and the lowest contribution to global warming is achieved by using methanol[19] obtained from biomass,[20] so both fuels are preferable to HFO. Despite this, technological and infrastructure limitations mean that the use of LNG only offers good results in short-sea transport, and climate neutrality cannot be expected with its use until the very long term. In addition, the impact on human health of LNG in the short and long term exceeds that of other alternative fuels.

Continuing with the life cycle perspective, ammonia and hydrogen are also preferable to HFO from an environmental point of view. Despite the interest in ammonia, given that its structure is carbon-free [40], hydrogen offers better results in terms of ecotoxicity, potential global warming, acidification and ozone depletion. This is because hydrogen does not produce SOx or PM during operation, although both its production and distribution generate a significant amount of GHG (higher than that generated by GMO and LNG, although not as much as ammonia[21]). Only hydrogen of nuclear, electric or renewable origin is considered preferable to GMO in this regard, although it is still more harmful in terms of GHG than LNG. On the contrary, in the operating phase, the latter is the worst of the three alternatives (in this phase, the GHG emissions of hydrogen are zero, as are its effects on acidification, eutrophication, photochemical formation of ozone and formation of local particles). Therefore, hydrogen meets the Tier III, 2020 and 2050 targets for, respectively, NOx, Sox and greenhouse gases, while LNG and MGO do not. However, hydrogen engines exhibit low volumetric efficiency and pre-ignition concerns [19].

Biofuels are preferable to hydrogen from a life cycle perspective, although they generate an amount of NOx comparable to that of HFO. Although the emissions of biofuels differ according to the raw material of origin and their generation process, they all contain carbon, as is the case with fossil fuels. Despite this, they are considered neutral in this sense when they come from plants since they photosynthesize and capture CO2 from the atmosphere [41]. Another advantage of this type of fuel is that it can be used mixed with traditional fuels with hardly any need to alter the engines and systems of the ships. This is highly relevant considering half of those which are active can continue sailing for another 15 years. As a disadvantage, it is worth noting the opportunity cost in land use [67].

Table 2 synthesises the main advantages and disadvantages of all these alternatives to traditional fuels, as identified by different authors in their most recent studies, and allows us to conclude that there is still not one which is clearly superior to the rest. From a life-cycle perspective, biogas obtained from organic waste is the best option, while methanol, biodiesel and ammonia would be the worst. However, authors

[13] According to Wang et al. [80], maritime transport is related to the fulfilment of SDG14, and indirectly to SDGs 3, SDG8 and SDG11.

[14] Port operations account for just 4 % of total shipping emissions [71].

[15] The installation of scrubbers would allow HFO to continue to be used [87]. This alternative is interesting in that the average age of almost half of the world's fleet is less than 15 years [73]. However, the high cost of installation and maintenance of the filters makes it inadvisable for ships with a useful life of less than 4 years. Likewise, emissions also depend on the route and speed of navigation, both of which are influenced by the price of emission allowances [27], and slow sailing is also being used as a strategy to reduce emissions [71], although it is clearly insufficient.

[16] Almost 3/4 of the consumption of petroleum derivatives by the current fleet corresponds to HFO; 26 % is MDO and 2 % is LNG [26].

[17] Chu-Van et al. [15] concluded that LNG (along with biofuel) may be the solution to meet emission reduction standards. LNG is the alternative that reduces emissions to a greater extent compared to the use of HFO: CO2 by 20 %, NOx by 90 %, and SOx by 100 % [43].

[18] The use of LNG falls far short of the requirement to reduce CO2 emissions compared to HFO [32]. In addition, despite its cost advantage over other alternative fuels, its storage is complex since it requires more space and must be carried out in well insulated tanks [40].

[19] From an economic point of view, it is the most efficient option, although its use requires having the appropriate infrastructure. However, it is highly toxic and highly flammable [40].

[20] The effect on global warming of methanol from GTL and natural gas exceeds that caused by HFO.

[21] Ammonia is also more difficult to ignite than other alternative fuels and is highly toxic and corrosive.

Table 2
Advantages and disadvantages of the main alternatives to fuel oil.

Fuel	Characteristics
LNG	Pros: - Easily usable in two- and four-stroke engines - Non-toxic, non-corrosive and odour-free - Cheaper than other alternatives - Reserves available for a long period of time - Greater reduction in total emissions compared to HFO Cons: - Does not achieve the target of reducing CO2 emissions by 50 % compared to HFO - Its combustion generates significant methane leaks - Complex storage (space and isolation) - Greater volume is required to generate the same energy as traditional fuels - Positive results for short distance (technological and infrastructural constraints) - Greater impact on human health
Methanol	Pros: - Greater reduction in CO2 emissions than LNG - Effective reduction of SOx and PM emissions - Easy to use and store - Liquid at room temperature Cons - Highly toxic and flammable - From a life cycle perspective, LNG would be preferable - Greater volume required to generate the same energy as traditional fuels
Ammonia	Pros - Carbon-free - Can be stored on ships in liquid state at 20°C - Less flammable than other fuels Cons - Production and distribution generates a large amount of GHG - Difficulties for ignition - Highly toxic and corrosive - Requires greater volume to generate the same energy as traditional fuels
Biofuel	Pros - Preferable to hydrogen from a life-cycle perspective - Can be used mixed with traditional fuels with little to no need to alter the ships' engines and systems Cons - Generates an amount of NOx comparable to that of HFO - Contains carbon - Opportunity cost in land use
Hydrogen	Pros - Good results in terms of ecotoxicity, potential global warming, acidification, ozone depletion and local particle formation - Meets Tier III, 2020 and 2050 targets for, respectively, NOx, Sox and greenhouse gases Cons - Production and distribution generate a significant amount of GHG (higher than LNG) - Engines exhibit low volumetric efficiency and ignition problems

Source: Authors' elaboration based on Bilgili [11], Dere [19], Karatug et al# [40], Lee et al# [43] and Munim et al# [53].

such as Dere [19] are committed to hydrogen due to its renewable nature,[22] its combustion properties and its versatility of storage and distribution, although the high energy requirement necessary for its storage and recovery is still a problem to be solved. Therefore, we are in a transition phase in which LNG is emerging as a satisfactory alternative until 2030, but will then probably give way to hydrogen once the capacity to generate green hydrogen is satisfactory [22].

The chosen option must be economically profitable, efficient and sustainable from the point of view of supply to avoid bottlenecks in its distribution [53]. In addition, it must be linked to other strategies, such as the development of more energy-efficient ships [20], or the reduction of their size, which would encourage the reduction of emissions by avoiding to induce a reduction in tariffs to increase the cargo of their holds [29,51]. However, the fact should not be ignored that ship replacements entail an extra cost that, although initially borne by shipowners, will be passed on to consumers. Hence the need to make a good diagnosis of all the environmental and social implications.

5. Closing remarks

As part of a reflection on the pressing challenges facing the maritime transport sector, distinction needs to be made between the three types of factors that could influence its evolution [63]. These three categories are: i) global shocks; ii) events that, although more geographically localised, have an international impact and iii) widespread trends. Within the first (for example, the SARS-COV-2 pandemic or those events related to the climate change) and the second (localised problems -for instance, Brexit- or conflicts of all types, or temporary collapses of a transit area -Suez blockage by Ever Given-) are those factors that, having a significant effect on maritime traffic, involve specific disturbances. However, those included in the third category condition the evolution of the sector in the medium and long term. These include aspects as diverse and ambitious as, for example, changes aimed at modifying the economic growth model, as complex as changes in the maritime cycle or as specific as the redefinition of routes or a technological revolution of the shipping industry.

From a corporate standpoint, an industrial rebuilding of shipping activity has taken place, with a more marked concentration, integration (vertical and horizontal) and expansion into other industries (energy, aviation, logistics, finance, etc.), coinciding with a period of notorious financial ups and downs. Meanwhile, two concurrent phenomena are observed. On the one hand, changes in globalisation, with a growing weight of regionalisation, associated to the relative advance of movements on the great east-west routes vs. intra-regional routes; on the other, changes in consumer behaviour, driven by both the green transition and the rise of e-commerce and greater burden-sharing. The sum of these parts leads to a major problem to be solved: the sectorial reorganisation at international level in a context of a new rebalancing in the use of maritime resources. Additionally, the green transition strategy can be considered as transversal to all these specific objectives, and for the maritime sector it implies directly the great challenge of decarbonisation.

The variety of phenomena mentioned above that alter the functioning of maritime transport and the supply chain have taken the form of health, financial, technological or cyber, geostrategic and security crises or extreme natural events and others of a national or regional political nature with high external impact. This has caused the object of analysis to become much more complex, making it essential that the theoretical and methodological approach must be integrated between several disciplines.

Changes in the growth model, as well as in the international governance of the oceans or in global trade, are issues that directly affect the maritime sector, yet they are beyond its control. However, its reconversion, and in particular the remodelling of the fleet to reduce GHG emissions and contribute to curbing global warming come within its scope.

The current IMO targets in this regard, although more ambitious than the previous ones, are not sufficient to promote innovation in alternative propulsion technologies. This poses a concern in the sense

[22] Its sustainability increases if it is obtained through water electrolysis using green energy [53].

that, as stated by Adamowicz [2], reducing GHG emissions in the field of maritime transport requires acting in three directions: technical, operational and market. The first has to do with the design of the ships and their propulsion system. The second, with the choice of routes and the navigation speed of the vessel, while the third concerns the market mechanisms that put a price on emissions. Therefore, for the IMO to be effective in its fight against climate change, it is necessary to address some main weaknesses: i) its lack of capacity to regulate new technologies; ii) uncertainty about its regulatory mandate and iii) the lack of political consensus in the negotiations [5].

Decision-making within the IMO is not an easy task. States with a large number of vessels (such as Japan, the USA, Germany, Norway or China) maintain very active positions. Shipping companies and their associations, along with classification societies, also show a great capacity for proposals and oppositions, as do companies with flags of convenience (in Liberia, Panama or the Marshall Islands), which act as lobbies highly sensitive to changes in regulations. As a result, the IMO faces significant constraints in its efforts to adopt guidelines for the decarbonisation of maritime transport. Among the main constraints observed in recent times, we highlight the divergence of interests between developed and developing countries on two issues. The first is to do with the implementation of measures to reduce emissions, because it may have a disproportionate impact on the economies of the least developed countries. This is particularly concerning for small island states, lesser developed countries or those that typically export high-value perishable products (because speed control means loss of competitiveness or markets for them and therefore a significant loss of revenue). The second divergence of interests is related to high transition costs, both in fleets and infrastructure: while more developed countries tend to favour stricter and faster measures to reduce emissions, developing countries advocate a more equitable transition. They seek protection from negative economic impacts and demand equal access to infrastructure and technologies. Consequently, in order to advance the process of the decarbonisation of maritime transport, the IMO must focus its efforts on achieving a global consensus on this issue.

In conclusion, from the study of the literature and the process of reflection carried out by the authors of this work, it can be stated that the ocean economy is growing as the commercial use of the oceans accelerates, and the pressing challenges it faces relate i) to the need to develop a more sustainable economic growth model, which will necessarily have an impact on trade and, therefore, on the maritime routes and port activity; ii) to the rise of the privatisation of ocean resources; and finally, iii) to the urgent sector decarbonisation. Only the widespread adoption of internationally agreed rules and procedures will allow to articulate a global ocean governance capable of preserving the structure and functions of the marine ecosystem [58]. As Haralambides and Gujar [30] state, addressing these challenges requires that stakeholders "work together to build a more secure and resilient global system of international (maritime) trade in general".

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CRediT authorship contribution statement

Lorena Garcia-Alonso: Writing – review & editing, Writing – original draft, Validation, Supervision, Resources, Methodology, Investigation, Conceptualization. **Fernando González-Laxe:** Writing – review & editing, Writing – original draft, Validation, Supervision, Methodology, Investigation, Conceptualization. **Ricarddo Sanchez:** Writing – review & editing, Writing – original draft, Validation, Supervision, Methodology, Investigation, Conceptualization.

Declaration of Competing Interest

Authors do not have any financial or personal relationships with other people or organizations that could inappropriately influence or bias their work. Our paper has not been published elsewhere and is not under consideration by any other journal. All the authors have approved this version of the manuscript, and are in agreement to submit it to Marine Policy. No conflict of interest is declared.

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Data availability

No data was used for the research described in the article.

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