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# Short Sea Shipping in the Age of Sustainability, Autonomous Navigation and Digitalization

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**Abstract:** This paper presents the comprehensive state-of-the-art on the challenges that short sea shipping currently faces across the world. The concept and its relationship with coastal shipping are introduced, followed by a review of the EU policies for short sea shipping and its practical impacts in modal split. A survey of the literature on the strong and weak points of this form of transportation is carried out, aimed at explaining the difficulties in achieving relevant modal shifts from road to sea. The experience with short sea shipping across the world is described and discussed, providing a global perspective. The paper then discusses the main challenges and opportunities in this field, namely decarbonisation, autonomous navigation, and digitalization. Conclusions are drawn on the possible impact of these game changing developments in this segment of the shipping industry.

**Keywords:** short sea shipping; sustainability; autonomous navigation; digitalization; intermodal transportation; logistics

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## 1. Introduction

Short sea shipping (SSS) is a concept created in the European Union (EU) in the late XX century, building upon the traditional concept of cabotage, but expanding it to an EU scale and adding maritime connections to countries across seas surrounding Europe. In spite of being a European concept, the fact is that it applies very well to other areas of the world, often under other designations such as coastal shipping or international cabotage. In Asia, for example, it is well known that coastal shipping has developed substantially both in the Far East and in Southern Asia [1]. In Europe, the development of SSS has been less intense, especially when measured against that of road transportation, probably because the land transport infrastructure across the continent is extensive and competitive. Recent events such as the pandemic and the Russia–Ukraine war have not favoured SSS either, especially in the passenger segment [2]. Finally, the need for near-shore production identified in recent years and, thus, to streamline supply chains may well promote some additional development in SSS in the EU over coming years in detriment of deep-sea shipping (DSS).

The competition of SSS with road has been especially difficult as road transport has benefited from lower labour costs due to the influx of eastern European drivers. It also takes advantage of much-improved road transport infrastructure and even benefits from the faster adoption of green technologies, increases in fuel efficiency, and less polluting fuels (lower sulphur content). Maritime transport remains the greener option, carrying between 80% and 90% of the world's freight while emitting only 3% of the world's greenhouse gases [3,4], but recent studies indicate that SSS, in particular, may be losing part of its green advantage, leading to the necessity of applying stricter emissions regulations for SSS to maintain its green image [1,5,6].

Traditionally, SSS has had the disadvantage of being only a connection between ports, rather than a full door-to-door transport operation, putting it at a disadvantage in comparison to road haulage. This is the reason that revision of the combined transport EU directive is much needed [7], as it promotes the development of intermodal and multimodal transport. This recent development comes in the wake of the reaffirmed commitment of the EU to greener modes of transportation, as expressed in the "European Green Deal" communication [8] which pointed to the need to reduce transport greenhouse gas emissions (GHG) emissions by 90% by 2050 to achieve climate neutrality. It has also set an objective for a substantial part of the 75% of inland freight carried today by road to be shifted onto rail and inland waterways. Later, the "Sustainable and Smart Mobility Strategy" established more detailed and comprehensive objectives so that transport by inland waterways and short sea shipping would increase by 25% by 2030 and by 50% by 2050 as compared to the 2015 levels [9].

In order to materialize this shift towards SSS, which is primarily aimed at reducing transport emissions, it is necessary that shipping keeps pace with road transport technology improvements. Electrical batteries are one possible solution as ships engaged in SSS typically operate on short routes near the coastline, making it easier to adopt such propulsion solution, as revealed by a recent China-built 700 TEU (twenty-foot equivalent unit) container vessel [10]. Alternative greener fuels suitable for internal combustion engines may also be adopted, but at the moment there is a scarcity of such fuels in the market and this constitutes a barrier to their widespread adoption. In this context, the inclusion of SSS in the emission trading scheme (ETS) [11], a typical market-based measure (MBM), will come as an additional burden as alternative fuels are not readily available, leading to extra costs and potentially promoting a reverse modal shift to road transport.

The International Maritime Organization (IMO) has privileged goal-based measures (GBMs) such as the application of carbon intensity indicators (CII) [12,13]. These will heavily impact the short sea fleet because they are based on ship operations and SSS is characterized by short routes and comparatively long port times, reducing the ship's ratings. The effectiveness of MBMs vis a vis GBMs has recently been compared and discussed in [14]. Additionally, the intention of the EU to remove the tax exemption on marine fuels by adapting the EU energy taxation directive in 2023 will increase voyage costs [15].

In spite of these difficulties, the fact remains that SSS could have a determinant role in reducing transport industry externalities. It is well known that transport activities impose costs on society and the environment that are not fully taken into consideration in the decision-making process of transport users. Apart from the impact of air pollutants and GHG, which have been tackled over the years by policies and regulations at the EU and international level, other costs, such as congestion, accidents or noise costs, collectively known as external costs of transportation, are only now starting to be addressed. Intense research in the EU has allowed for the development of a comprehensive handbook for the calculation of these external costs [16]. On the other hand, transport demand is set to triple in the next 30 years [17]. This increase in transport volume will also result in an increase in congestion costs by about 50% in 2050, as well as an increase in the costs of accidents and noise [18]. SSS has here a significant advantage, as its average external costs per cargo unit and km are lower than those of other modes of transportation and, in particular, those of road transport, making the modal shift from to sea more appealing [19].

Finally, it should be mentioned that SSS may be beneficial in terms of fostering the development of countries outside of the developed world but still located in its immediate periphery, thus positively contributing to a number of the United Nations sustainable development goals [20], namely 1, 8, 10, 12 and 13, basically covering sustainable and balanced economic development aspects. These positive contributions are obtained in comparison with deep-sea shipping and land modes of transportation (particularly road), but it must be recognized that SSS will still have some negative impact on sustainable development goal 14 (impacts on oceans, seas, and marine resources). Nevertheless, the trade-off appears to be clearly positive for SSS.

The structure of the remaining part of this paper is as follows. Section 2 presents the methodology used in this work. In Section 3, the genesis of the concept and a review of short sea shipping (SSS) policies in the EU is presented. Section 4 presents the actual situation regarding SSS in the EU and reviews the reasons for its lack of progress in this region. Building upon the findings of these two sections, Section 5 considers the situation of SSS elsewhere across the world and compares the findings with those of the EU. The final sections provide insight on the impact that contemporary challenges may have on the development of SSS: Section 6 looks at the challenges presented by decarbonisation, while Section 7 examines the impact of autonomous navigation in SSS. Section 8 discusses the impact of digitalization on the future of SSS and its integration in supply chains. Section 9 wraps up the main findings of this paper and presents conclusions and avenues for further research.

## 2. Methodology

### *2.1. Search Methods*

This section explains the research methodology used for this literature review, aimed at identifying research opportunities that could benefit this field of knowledge [21]. The first step was to identify relevant papers in the existing literature and this was conducted by performing a search in databases such as Web of Science and Scopus. To perform this search, keywords related to the topics reviewed in this paper were identified, and the search was performed in two databases, Web of Science and Scopus, and was divided into three stages. The search was performed in the "topic" field for Web of Science and in the "title, abstract, keywords" for Scopus. The first stage of the research identified papers related with the keywords "Short Sea Shipping" and as seen in Table 1, and 1866 were identified in Web of Science and 1000 for Scopus. In the second stage of research, additional keywords were added to SSS in order to identify the papers that were relevant to this study. Finally, in the third stage, the search was even more refined to identify additional papers that could be interesting to the review from a regional point of view. In the end, 66 papers were read and used for information that benefited this work. Table 1 displays the number of results obtained for each keyword in each database.

**Table 1.** Keywords used in search along with number of results.

| Keywords | Database | Stages of Research | Number of Results |
|---|---|---|---|
| Short Sea Shipping | Web of Science | 1 | 1866 |
| | Scopus | | 1000 |
| Short Sea Shipping EU | Web of Science | 2 | 145 |
| | Scopus | | 80 |
| Short Sea Shipping Automation | Web of Science | 2 | 21 |
| | Scopus | | 28 |
| Short Sea Shipping Decarbonization | Web of Science | 2 | 18 |
| | Scopus | | 15 |
| Short Sea Shipping Digitalization | Web of Science | 2 | 5 |
| | Scopus | | 6 |
| Short Sea Shipping America | Web of Science | 3 | 52 |
| | Scopus | | 39 |
| Short Sea Shipping EU Policies | Web of Science | 3 | 20 |
| | Scopus | | 28 |
| Short Sea Shipping Asia | Web of Science | 3 | 85 |
| | Scopus | | 54 |
| Short Sea Shipping Africa | Web of Science | 3 | 45 |
| | Scopus | | 20 |

### 2.2. Number of Publications per Journal

Table 2 displays the number of papers that appeared in scientific journals. In total, 52 of the 66 reviewed papers belonged to journals. Analysing Table 2, it is possible to see that *Maritime Policy & Management* published 18% of the papers reviewed. *Maritime Economics & Logistics* published 8% of the papers, while *Journal of Marine Science and Engineering*, accounted for 10%.

**Table 2.** Number of papers by journal.

| Journal | Number of Papers |
|---|---|
| International Journal of Maritime Affairs and Fisheries | 1 |
| Transportation Research Part D: Transport and Environment | 3 |
| Journal of Cleaner Production | 1 |
| Maritime Policy & Management | 9 |
| Journal of Transport Geography | 2 |
| Transport Reviews | 3 |
| Marine Policy | 1 |
| Maritime Economics & Logistics | 4 |
| Ocean Yearbook | 1 |
| Sustainability | 2 |
| Maritime Transport Research | 2 |
| Maritime Business Review | 1 |
| Journal of Marine Science and Engineering | 5 |
| Journal of Shipping and Transport Logistics | 1 |
| Transportation Research Record | 1 |
| Ocean Engineering | 2 |
| Research in Transportation Business & Management | 2 |
| WMU Journal of Maritime Affairs | 1 |
| Carbon Management | 1 |
| Transportation Research Part A: Policy and Practice | 1 |
| Transportation Research Part C: Emerging Technologies | 1 |
| Journal of Physics | 3 |
| Transportation Research Procedia | 1 |
| Journal of Shipping and Trade | 2 |
| International Journal of Information Management Data Insights | 1 |

### 2.3. Year of Publication of the Papers

The year of publication is of major importance in research, particularly when analysing topics such as automation, digitalization, environmental sustainability, or government policies, which are of significant relevance to the development of shipping in today's world. As seen in Figure 1, which displays the years of publication for the papers analysed in this work, 74% of the papers were published after 2015, and more than 41% were published after 2020.

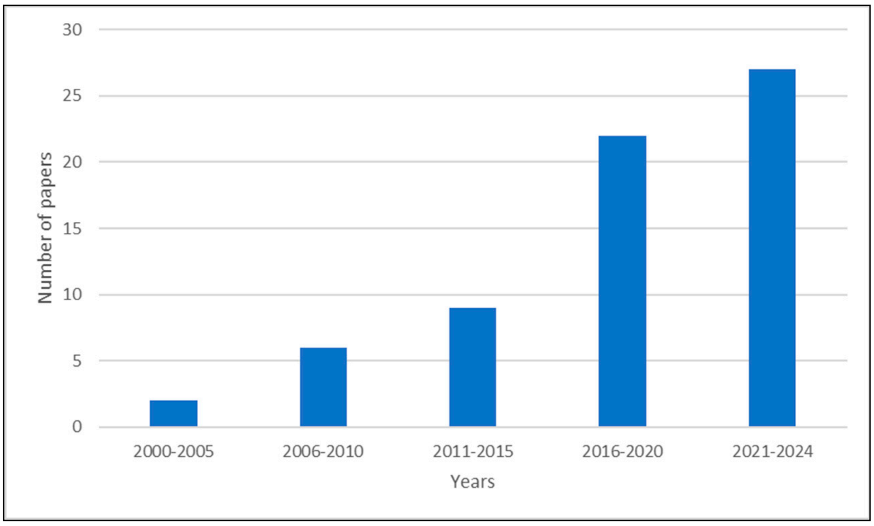


**Figure 1.** Number of papers per year.

### *2.4. Description of Papers Analysed*

Table 3 provides an overview of all the papers analysed in this study, dividing them by year of publication; topic of paper; author; and type of research, which was divided into three categories: Literature Review, Case Study, and Survey. Analysing Table 3, it can be seen that 48% of the papers were literature reviews varying with different topics and regions of study. Case studies also accounted for 48% of papers analysed, and 4% of the papers seen were surveys.

**Table 3.** Authors, year of publication, type of research, and topic of papers.

| Author | Year of Publication | Type of Research | Topic of Paper |
|---|---|---|---|
| Hilmola [2] | 2022 | Literature Review | Ropax SSS and COVID-19 Pandemic |
| Raza et al. [21] | 2020 | Literature Review | Modal Shift to SSS |
| Aperte and Baird [22] | 2012 | Literature Review | MoS Policies in the EU |
| Baird [23] | 2007 | Literature Review | Economics of MoS |
| Baindur and Viegas [24] | 2011 | Literature Review | Challenges to MoS |
| Douet and Cappuccilli [25] | 2011 | Literature Review | A review of EU SSS policies |
| Takman & Gonzalez-Aregall [26] | 2023 | Literature Review | A review of EU freight policies |
| Paixão and Marlow [27] | 2002 | Literature Review | Strengths and Weaknesses of SSS |
| Paixão and Marlow [28] | 2007 | Literature Review | TEN-T impact on SSS |
| Medda and Trujillo [29] | 2010 | Literature Review | SSS determinants |
| Suárez-Alemán [30] | 2016 | Literature Review | SSS in today's Europe |
| Psaraftis and Zis [31] | 2020 | Literature Review | EU policies for SSS |
| Brooks and Frost [32] | 2004 | Literature Review | SSS in Canada |
| Mustafa et al. [33] | 2010 | Literature Review | SSS in Canada- Regulatory Issues |
| Brooks and Trifts [34] | 2008 | Literature Review | SSS in North America |
| Brooks et al. [35] | 2014 | Literature Review | SSS in South America |
| Konstantinus et al. [36] | 2019 | Literature Review | SSS in SADC: Barriers |
| Park et al. [37] | 2021 | Literature Review | SSS in Northeast Asia |
| Arof and Zakaria [38] | 2020 | Literature Review | SSS in Southeast Asia |

**Table 3.** *Cont.*

| Author | Year of Publication | Type of Research | Topic of Paper |
|---|---|---|---|
| Brooks et al. [39] | 2012 | Literature Review | SSS in Australia |
| Bendall and Brooks [40] | 2011 | Literature Review | SSS in Australia |
| Tadros et al. [41] | 2023 | Literature Review | Green Shipping |
| Psaraftis [42] | 2012 | Literature Review | MBMs for GHG emissions |
| Ghaderi [43] | 2019 | Literature Review | Automation in SSS |
| Murray et al. [44] | 2022 | Literature Review | Artificial Intelligence in Shipping |
| Ziajka-Poznańska and Montewka [45] | 2021 | Literature Review | Cost and Benefits of Autonomous Shipping |
| Santos and Guedes Soares [46] | 2020 | Literature Review | SSS in the era of information technology |
| Bavassano et al. [47] | 2020 | Literature Review | Blockchain in Shipping |
| Gerakoudi-Ventouri [48] | 2022 | Literature Review | Blockchain in Shipping |
| Svindland [5] | 2018 | Case Study | Environmental Effects of ECAs |
| Hjelle and Fridell [6] | 2012 | Case Study | SSS environmental viability |
| Marrero and Martínez-López [14] | 2023 | Case Study | Decarbonization of SSS |
| Ramalho and Santos [19] | 2021 | Case Study | External Costs in SSS |
| Orive et al. [49] | 2022 | Case Study | Motorways of the Sea |
| Santos et al. [50] | 2022 | Case Study | SSS and TEN-T |
| Ramalho et al. [51] | 2020 | Case Study | External Costs in SSS |
| Martínez-López and González [52] | 2020 | Case Study | Optimization of intermodal transport Routes in Chile |
| Martínez-López and González [53] | 2021 | Case Study | SSS in East Africa |
| Konstantinus et al. [54] | 2020 | Case Study | SSS in SADC |
| Zheng et al. [55] | 2021 | Case Study | SSS in Northeast Asia Routes |
| Zis and Psaraftis [56] | 2017 | Case Study | Sulphur limits impact on SSS |
| Zis and Psaraftis [57] | 2018 | Case Study | Measures to mitigate environmental legislations |
| Zis and Psaraftis [58] | 2021 | Case Study | Short term measures impact on decarbonizing shipping |
| Zis et al. [59] | 2020 | Case Study | Decarbonization of maritime transport |
| Ramalho and Santos [60] | 2021 | Case Study | GHG emissions in intermodal transport chains |
| Gilbert et al. [61] | 2015 | Case Study | Technologies for Sustainable shipping |
| Zis [62] | 2019 | Case Study | Cold Ironing impacts |
| Faber et al. [63] | 2022 | Case Study | Possibilities to evade EU ETS |
| Lagouvardou and Psaraftis [64] | 2022 | Case Study | Implications of EU ETS |
| Raza [65] | 2020 | Case Study | Effects of green regulations on SSS |
| Ghandriz et al. [66] | 2020 | Case Study | Automation in Land Transport |
| Nordahl et al. [67] | 2022 | Case Study | Autonomous ship concept |
| Santos and Guedes Soares [68] | 2018 | Case Study | Economic feasibility of autonomous ship |
| Dantas and Theotokatos [69] | 2023 | Case Study | Assessment of an SSS autonomous vessel |
| Nguyen et al. [70] | 2022 | Case Study | Autonomous vessels in liner shipping |
| Akbar et al. [71] | 2020 | Case Study | Autonomous vessel in SSS |

**Table 3.** *Cont.*

| Author | Year of Publication | Type of Research | Topic of Paper |
|---|---|---|---|
| Psaraftis and Zis [72] | 2023 | Case Study | Autonomous shipping and AEGIS project |
| Tangstad et al. [73] | 2023 | Case Study | Autonomous SSS feeder service |
| Krause et al. [74] | 2022 | Case Study | Green Intermodal system with autonomous SSS |
| Kanellopoulos et al. [75] | 2023 | Case Study | Automated operations- MOSES project |
| Kostovasili et al. [76] | 2022 | Case Study | Future of SSS |
| Kaklis et al. [77] | 2023 | Case Study | Digital Twin Vessels |
| Perakis and Deniss [78] | 2008 | Survey | SSS in USA |
| Konstantinus [79]. | 2021 | Survey | SSS in SADC |

## 3. European Union Policies for Short Sea Shipping

Coastal navigation has been present in every part of the world for millennia [80], and its contemporary challenges have been recently reviewed [81]. The terminology related to different variants of coastal shipping is complex and requires a few notes. It is first useful to indicate that in 1992 the European Council published [82] a definition of maritime cabotage which reads as "*a maritime transport service within a Member State normally provided for remuneration, including: (a) mainland cabotage: the carriage of passengers or goods by sea between ports situated on the mainland or the main territory of one and the same Member State without calls at islands; (b) off-shore supply services: the carriage of passengers or goods by sea between any port in a Member State and installations or structures situated on the continental shelf of that Member State; (c) island cabotage: the carriage of passengers or goods by sea between ports situated on the mainland and on one or more of the islands of one and the same Member State, ports situated on the islands of one and the same Member State (Ceuta and Melilla shall be treated in the same way as island ports)*".

Subsequently, in 1999 [83] the European Commission (EC) approved a communication entitled "The Development of Short Sea Shipping in Europe". This document presented a definition of short sea shipping as the "*movement of cargo and passengers by sea between ports situated in geographical Europe or between those ports and ports situated in non-European countries having a coastline on the enclosed seas bordering Europe*". This definition basically broadens the old concept of cabotage (which has existed for centuries) to the EU level, while also adding maritime connections to ports in countries across the enclosed seas bordering Europe (Mediterranean, North, Baltic, and Black Seas).

These communications laid the foundation for different EU-funded support programs aimed at bolstering the development of SSS and addressing related challenges within the maritime sector. One example of these programs was the Motorways of the Sea (MoS) initiative, a flagship EU program, aiming to enhance maritime connections by establishing efficient and environmentally friendly shipping routes. According to [84], the concept was introduced with the 2001 Transport White Paper [85]. The creation of "Motorways of the Sea" was suggested by the EC as a true competitive alternative to land transport, and are defined as "*maritime connection between two ports interconnected with the Trans-European Networks and intermodal corridors, where cargo is rapidly handled through port optimization, avoiding congestion areas and geographical barriers*".

Additionally, it was stated that financing for the development of the MoS should be provided and that they should be included in the trans-European network (TEN-T). In 2011, ref. [18] stressed again the importance of the MoS, and in 2013 the new TEN-T regulations reinvented the MoS as a maritime element of the TEN-T that would help create a barrier-free European maritime environment [86]. Developing the MoS initiative is still of major importance [49]. In these regulations, it is defined that the MoS shall include maritime links between the Union's core network ports and other maritime ports within the comprehensive network. In addition, logistical infrastructures that are a part of port operations shall be included in the MoS.

A review of the MoS policies being applied in Europe is given in [22], leading to the conclusion that the EU has been enforcing regulations and recommendations for SSS and the MoS with limited success. The main reason for the lack of success seen is linked to the lack of funds, especially when compared to the subsidies being given to other alternative modes of transportation. One different approach to the type of politics being enforced would be a shift towards the incorporation of external costs for road transport and other modes of transportation, promoting a modal shift to SSS. In [23], similar conclusions are drawn, with the main conclusions being the fact that the seaway has a history of receiving less support than other transportation infrastructure, possibly as a result of policymakers' incorrect belief that the seaway functions as a freeway and is thus not entitled to public funding in the same manner as roads and railroads, but in order to even out the playing field between the different transportation modes, more funds should be allocated towards maritime transportation. The critical success factors for the implementation of MoS are favourable market conditions and a supportive public policy that takes into account the local market and regulatory environment, which are essential for the long-term viability of the MoS projects [24].

In addition to the MoS program, the EU has for many years subsidized several actions aimed specifically at supporting the SSS. The first action of this type was the PACT (1997–2001) program, which was the first of its kind. It had a budget of EUR 51 million and financed 167 projects of combined transports, more particularly feasibility and operating projects; however, only 51% of the projects were completed [25]. This was followed by the Marco Polo I Program, which was implemented between 2003 and 2006 [87], and was, in turn, succeeded by the Marco Polo II Program [88], between 2007 and 2013, and by the Connecting Europe Facility (CEF). These programs have provided financial support to SSS projects, encouraging the adoption of innovative technologies and promoting a modal shift from road to sea transport in an effort to decrease traffic on the roads, enhance intermodality, and improve the community's freight transport system's environmental performance, all of which contribute to a more effective and sustainable transportation system. The majority of projects were evaluated and compensated based on measurable outcomes, like the real achievement of a modal shift and the avoidance of freight traffic in the European transportation network.

A review of the effectiveness of the Marco Polo programs on reducing road traffic is provided in the report of the European Court of Auditors (ECA) [89]. The programs were determined to be ineffective as the targets set were only reached to a very limited degree, the modal shift away from road transportation was very small, and, in addition, there was a lack of data to analyse the benefits of decreasing the environmental impact when it came to improving congestion and road safety. Another criticism of the programs was the selection process, which selected projects based on their performance and resulted in an absence of initiatives that were sufficiently relevant given the state of the market at the time. It was also mentioned in the ECA report that the EC did not perform valid market research to analyse the potential success of intended projects, and there was a lack of corrective actions to improve the effectiveness of the programs. However, with a total budget of EUR 435 million, it was estimated that the environmental benefits of Marco Polo II were around EUR 3 for every euro spent and lead to the elimination of 3.5 billion tonnes of $CO_2$ emissions [90].

In [91], the EC presented an outlook on the results of the Marco Polo program: for the first program it was stated that the program achieved 46% of the overall modal shift target, and for the second program, it was reported that in late 2012, by the end of the program, only 19.5 of the expected 87.7 btkm (billion tonne kilometres) had been achieved. When it comes to the environmental benefits of the first program, it is indicated that for each euro invested, the actions of the projects generated around EUR 13 in environmental benefits.

There it is highlighted that the achievement of the programs' objectives was affected by the economic crisis existent at the time; nonetheless, the Marco Polo initiatives represented good examples of efficient use of EU funds. Therefore, it is clear that the performance of the Marco Polo programs vary depending on the focus of the evaluations [26].

With the conclusion of the Marco Polo programs, the CEF 2021–2027 program is nowadays funding projects related to sustainable and multimodal mobility, including SSS, and this program aims at promoting growth, jobs, and competitiveness through infrastructure investment at the European level. This program sums a total budget of EUR 33.71 billion [92] and hopes to contribute to the development of the existing TEN-T network. When it comes to SSS, the main goals are to create new links or upgrade the existing ones, develop actions to facilitate SSS in addition to harmonizing the existing Maritime National Singe Windows, and to create a European Maritime Single Window environment. The CEF will also continue to develop the MoS program with four pillars in mind. Firstly, sustainability, reducing all kind of emissions is essential for SSS to keep its image of a green alternative to road transport, and this will be achieved by developing alternatives to non-fossil fuels, green onshore power supply, and using eco-incentives. Secondly, implementing digital tools in SSS operations including data sharing. Thirdly, improving the connectivity to the rest of the TEN-T network. Lastly, ensuring the SSS market has the capacity to withstand the evermore common shocking events in the world, such as the COVID-19 pandemic and ongoing wars. These measures are expected to require a budget of almost EUR 10 billion [93].

Another initiative which studied a new approach to funding projects involved with SSS was the Med-Atlantic Ecobonus, which presents a new effective and sustainable incentive scheme aimed at supporting intermodal freight transportation. This initiative was based on its predecessor named Ecobonus, which was launched by the Italian government in 2007 and operated by reimbursing the external costs saved by using sea routes instead of road transported to road haulage firms [94]. This project then led the Spanish Government to apply for an exemption of state-aid rules in regard to certain SSS routes [95], which intend to promote the use of maritime freight transport to discourage long-distance truck trips in order to facilitate the modal shift of freight transportation from road to sea. For this purpose, a positive incentive to the end users is granted based on the external costs that they contributed to saving by using maritime transport instead of a road-only transport, as calculated using the EU handbook [16]. This program will have a budget of EUR 60 million and will run until mid-2026.

Overall, the EU has demonstrated a steadfast commitment on promoting SSS as an environmentally sustainable and efficient mode of transportation. According to estimates, by 2050, SSS will play a significant part in helping the EU achieve its transportation goals of reducing greenhouse gas emissions from transportation by 60% in 2030 and switching to other modes of transportation besides road freight for distances over 300 kilometres [96]. For this purpose, action is being taken in order to simplify the administrative processes in SSS, making it comparable with other modes in this respect. Additionally, the industry is focused on introducing new technologies to comply with the environmental regulations. To promote SSS in the EU, the European Shortsea Network (ESN) was developed with Shortsea Promotion Centres (SPC), already established in 13 EU Member States [97]. These centres were created with the goal of educating shippers on the benefits of SSS, identifying obstacles that may hamper the competitiveness of SSS and promoting alliances between operators across the transport chain to improve efficiency [98].

In addition, a recent new proposal will update the current Combined Transport Directive and will complete the Greening Freight Package in order to support activities that, when compared to road-only operations between the same starting and ending points, reduce negative externalities (these being the unintended and adverse side effects or consequences of an economic activity that affects parties who are independent of that activity [99]) by at least 40%. Nonetheless, according to the EC's commissioner for transport, road transport will continue to have an important role in the transportation market, but more sustainable modes such as SSS will assist in reducing the external costs [100].

The current energy taxation directive (ETD) provides mandatory exemption of the aviation, waterborne navigation, and fishing sectors and was adopted back in 2003 [101]. However, since its adoption, the paradigm of maritime transportation has changed, and this directive no longer maintains the proper functioning of the EU's internal market. In 2019, this directive was reviewed, see [7], and it was concluded that it was not in line with the environmental policies being applied in the EU and that it even supported the use of fossil fuels. The proposed changes to the ETD would help reducing fossil fuel consumptions by imposing greater taxes on fossil fuels and lowering them on renewable energy sources, as well as by examining the potential for tax exemptions and reductions that would invert the current lower taxation of fossil fuels. This would be achieved through the introduction of "*content based taxation, by eliminating incentives for fossil fuel use and by introducing a ranking of rates according to their environmental performance*" [7]. It is anticipated that the industry would be encouraged to cut fuel use if energy post-tax incentives for maritime fuel use were phased out. According to [102], in the particular case of the ETD, this phase out would have a duration of 10 years once it is in force [103]. However, the EU is facing difficulties in approving this directive, especially when it comes to the removal of the tax exemptions for aviation and marine fuels, which has halted negotiations.

Supporting the ETD are oil and biofuel trade associations, which believe that it will incentivise the production of green fuels [104]. Another supporter of this directive is the European Sea Ports Organisation (ESPO), which state that "*tax incentives can be an important instrument to encourage the development and use of cleaner marine fuels and discourage the use of fossil marine fuels in Europe*" [105]. However, they advise that the taxation is based on the principle that the polluter pays. Additionally, some concerns were stated by ESPO, such as the fact that it is not clear how the proposal will be enforced since vessels can perform long voyages without bunkering and can purchase fuel in ports outside of the EU.

## 4. Short Sea Shipping in the European Union: Policy Results and Challenges

The previous section has covered the development of policies of the EU for the promotion of SSS, allowing for the conclusion that a substantial amount of funding has been granted to shipping companies and ports since at least 1997. It is thus important to analyse the results of this public spending. Figure 2 shows the modal split in domestic and intra-EU27 freight transport from 1995 to 2021, as per [106]. It can be seen that the road transport share has grown over 7%, while sea transport (SSS) has declined by almost 1%. More importantly, inland waterways have declined 1%, rail lost 3.7%, and pipelines 1.7% in terms of market share quota. The conclusion is that road transportation has grown at the expense of all other modes, but the declines in rail and sea are especially noteworthy (considering also that pipeline transportation is marginal). When the period of analysis extends from 2010 to 2021, it can be seen that SSS lost 0.3% while road gained 3%, both in market share. The unavoidable conclusion is that the policies of the EU to promote a modal shift away from the road have not been very successful.

Even though SSS plays a pivotal role in the EU maritime transport strategy, contributing to sustainable and efficient freight transport, as seen above there has been a decrease in SSS market share in the past years, despite all the policies that the EU has promoted, such as the previously mentioned Marco Polo programs or the MoS initiative. The paragraphs below explore the policy results and challenges associated with SSS in the EU.

To understand what went wrong with SSS in the EU, a description of the strengths and weaknesses of this type of shipping needs to be provided. In 2002, an analysis of this topic was developed [27], and it concluded that some of the strengths of SSS consisted of an extensive coastline existent in the EU, lower freight rates for transportation, the market players possessing an extensive knowledge to operate this transport mode, lower external costs (albeit not yet included in freight rates), and a favourable common transport policy that could support underused capacity. In contrast, some of the identified weaknesses at the time were that it was a capital-intensive industry, dependent on other modes for door-to-door transportation, and required careful planning when it came to route design and port layout; additionally, it was mentioned that it was a very bureaucratic industry, especially compared with road transportation. In 2007, it was identified that SSS still suffered from weaknesses, particularly at the interface level of its operation [28]. In 2010, it was concluded that in order for SSS to be competitive with road transportation, it needed to show benefits when compared to its road alternative along with creating door-to-door maritime services [29].

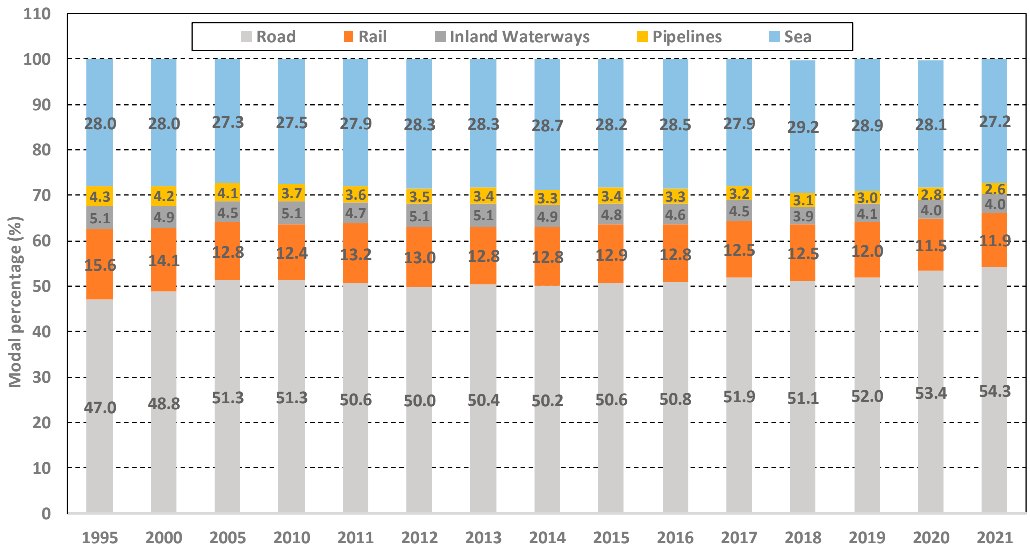


**Figure 2.** Modal split in domestic and intra-EU27 freight transport from 1995 to 2021.

An analysis of the challenges that were faced when implementing MoS was developed in [24] and provides some instruments that can assist SSS ventures and encourage the modal shift away from road transportation. These instruments were banning road transportation, particularly trucks, on weekends; increasing road tolls; applying charges based on distance travelled; and increasing wages for drivers. It was also mentioned that increasing the investment in port infrastructure to increase operations efficiency assisted SSS. In [25], a review of the SSS policies in the EU is carried out and concludes that the performance of the EU programs has been disappointing. The main reasons behind the lack of success are stated to be bureaucratic issues and legal problems along with the difficulty of SSS to compete against the *reliability and the easiness provided by truck haulage in Europe*.

A review of the role of SSS in the European Maritime Transport Policy [30] mentions that, in total, EUR 895 million have been spent on maritime SSS marketing; nonetheless, despite this outlay, the EU's initiatives have not yet accomplished their intended objectives. Additionally, it was concluded that SSS was not properly promoted, with one of the critics appointed to the EU stating the fact that port infrastructure had not seen the same kind of investment as other infrastructures, and that ports only received 5 percent of total European transport investments, whereas road transport received 60 percent. Moreover, it is mentioned that road investments were more efficient, and this is concerning since adapting port infrastructure to the SSS requirement is crucial for the efficiency of SSS. Another criticism was attributed to the Marco Polo programs, which despite supporting companies to choose SSS, did not promote efficiency in SSS activities, which is crucial to increasing the attractiveness of this type of shipping.

Some measures that could improve the competitiveness of SSS are also provided in [107]. Firstly, it is necessary to identify all barriers that prevent the development of true MoS, such as the lack of a single market, excess of bureaucracy, market access for service providers in ports, and other factors which make SSS less competitive. Secondly, it is necessary to complete the single market for shipping, tackling the constraints to goods transported by SSS between two EU ports and ensuring the goods moved by SSS have the same treatment as road alternatives. Thirdly, it is necessary to simplify procedures for regular short sea services with third countries, increasing the trade volume for SSS. Fourthly, it is necessary to ensure market access to port services and guarantee the free movement of goods; for example, setting up a common framework for Pilotage Exemption Certificates would benefit SSS since they would pay lower port fees. Finally, competition-neutral ways to financially stimulate SSS are necessary, with one option being to fund infrastructures both ashore and on vessels, which can increase the efficiency of SSS operations.

A review of the European policies for SSS is also given in [50], with the main factors that may have led to the decrease in SSS transport over the past years duly identified. One of the factors that is analysed in the review has already been mentioned above and is the failure of the port packages employed in the EU, particularly when it comes to regulating market accesses, which have created delays in ports due to regulations and may further incentivize road transport. To solve the ports problem in the EU, one possible solution could be the creation of a dedicated SSS terminal which would provide faster port operations and increase efficiency. Another factor was the entrance of new countries into the EU. Despite the fact that the decline in SSS had begun previously to the EU's enlargement, the addition of these countries created a simplification in bureaucracy for road transport, while SSS did not obtain this advantage. Moreover, some of the countries which joined offer low-wage workers, which has turned the playing-field in favour of road transportation. One other reason was the development of rail freight corridors which, despite being crucial to the efficiency of SSS operation, could shift traffic that would otherwise be moved by SSS towards rail transport. Additionally, according to [31], the development of some railway lines could be avoided with the use of well-developed TEN-T infrastructures and SSS. Additionally, the introduction of sulphur regulations by both the EU and the IMO could increase the fuel costs for SSS, which could lead to shippers turning to land-based alternatives. Decarbonizing SSS could be an opportunity to renew its fleet in the region, which could increase the competitiveness.

Finally, one possible solution to assist in the modal shift towards SSS would be the internalization of external costs in the supply chain. The work of [51] developed a case study in which the inclusion of external costs in different intermodal routes including SSS were investigated. The results of this study support the modal shift from road transport towards SSS, concluding that for the majority of the regions studied SSS-based intermodal chains were the optimal choice, which supports the idea that the internalization of external costs for freight rates in the EU would assist in keeping SSS competitive against land-based alternatives.

## 5. Short Sea Shipping beyond Europe: A Global Perspective

While Europe has been a frontrunner in embracing and optimizing SSS as a distinct market within the shipping industry, other regions around the world have also recognized the potential of maritime transport within their domestic borders and, more broadly, in their geographical regions. In fact, frequently, the term SSS is not used in these regions of the world, but the importance of this market segment is universally accepted, with a recent International Transport Forum (ITF) study dedicated to this theme [81].

Canada and the United States (US), with their vast coastline and numerous inland waterways, are optimum regions for the implementation of SSS. Efforts to enhance the efficiency of these waterways have led to increased interest in short sea routes as a viable option for transporting goods between key ports. The primary triggers of SSS in North America include the continent's continued urbanization, growing traffic congestion, and environmental concerns [32]. In fact, in 2003, Canada and the US signed the *Memorandum of Cooperation on Sharing Short Sea Shipping Information and Experience* [108].

A survey [78] to understand the state and prospects of SSS in the early 2000's was carried out for the US. At that time, the US government was already supporting SSS as an alternative, more environmentally friendly mode of freight transportation. In this region, SSS was focused on the transportation of containerized general cargo, and in 2002 at least seven SSS operations already existed. SSS had promising prospects in the region, and the few existing operations at the time supported the adoption of this mode of transportation. However, according to [33], significant obstacles to SSS growth in the region included US and Canadian marine regulations as well as decaying port infrastructure. More specifically, US domestic shipping policy placed two regulatory obstacles to SSS, one being the requirement that all commercial cargo (international or domestic) transported by vessels using US ports had to pay a Harbour Maintenance Tax, and the other being The Jones Act, which is a cabotage regulation that limits the transportation of American goods and passengers across domestic waterways between US ports to vessels that are built, registered, and manned by Americans.

The Canadian government has recognized the potential of SSS to alleviate road congestion, reduce GHG emissions, and enhance overall transportation resilience. Initiatives such as the National Trade Corridors Fund [109] aim at investing in projects that improve the fluidity and efficiency of the country's transportation networks, including those supporting SSS. On the east coast of Canada, parts of which are highly dependent upon interprovincial, intra-regional, and international sea links, the SSS sector is quite dynamic [32]. The SSS operations in the region consist of inter-coastal feeder services to deep-sea carriers and companies operating to US. Shippers have a positive perception of SSS in the region and have stated that if available they would consider switching to SSS, with price, reliability, and transit times being the main key factors that they looked into when considering SSS [34].

In South America, SSS remains underdeveloped, largely due to a variety of factors, including the presence of bilateral trade regulations and cabotage restrictions, the fact that the conclusion rate of SSS projects is low, as well as the fact that cargo shippers have been encouraged to use long-distance road freight transport by their established view of what the maritime industry could accomplish in the region. Nonetheless, SSS has potential in the area, as shown by the region's natural surroundings and the lack of alternative rail choices for most corridors [35]. Ref. [52] presented a study on the feasibility of a MoS for Chile, and it was concluded that the region had potential for a SSS operation due to its geography.

Several African countries have been making efforts to promote and improve SSS as part of their broader strategies to enhance trade, connectivity, and sustainable transportation. According to [53], the combination of the location of East African ports with the obstacles found in the road corridors of the region, make SSS a consideration for an alternative mode of transportation. In this study, four different ports were identified as suitable locations to implement SSS. Other studies were performed on the state of SSS in the southern Africa region. The main agent pushing SSS in the region is the Southern Africa Development Community (SADC), and, given its vast geographic area along with the projected increase in freight volumes and the trade policies the SADC is pursuing, SSS has the theoretical ability to work in the region. However, there are major constraints, particularly, poor logistics performance, ports efficiency, and the high cost of freight transport [36,54,79].

Asia is also exploring SSS as a viable solution to the challenges posed by urbanization and increasing demand for goods transport. Northeast Asia (NAE) countries like China, Japan, and South Korea, with their extensive coastline, are investing in developing and optimizing SSS routes to complement existing land-based transportation. The work in [110] designed a cargo flow network model for SSS and concluded that the implementation of SSS operations in the region has potential to develop at rapid speed, particularly if the port infrastructure is improved and the vessel capacity is increased. The two main markets in the region are the Korea–China shipping market and the Korea–Japan shipping market. SSS has the ability to connect Korea to Japan and China, which are both countries with significant economic power in the world market [37]. Additionally, SSS can act as a mechanism for cooperation between countries in the region, especially between China and Korea, which have an annual dialogue to determine new shipping routes and regulations. Ref. [55] presents an analysis of the cost effectiveness of three major roll-on/roll-off (ro–ro) and lift-on/lift-off (lo–lo) SSS routes. These authors conclude that shippers in NAE are worried about the transit times and transportation costs of containerized cargo in SSS, and due to this, ro–ro transportation in the region can improve the efficiency of logistics network for the area, even if lo–lo is more effective in terms of cost when compared to ro–ro. One other interesting feature of the SSS market in the region is the fact that rail and road transportation does not occur across land borders due to the military tension in the region [37], which may act as an incentive to SSS.

The state of SSS in the Association of Southeast Asian Nations (ASEAN), more particularly in the mainland South-east Asia and archipelagic Southeast Asia, is studied in [38]. Due to the natural conditions of this region, it is stated that it is impossible to achieve the objectives of economic development without a localized version of SSS, especially in its ro-ro version. Currently, the majority of SSS operations involve the movement of cargo using feeder container vessels connecting the hub ports with other smaller ports within the region. Two successful routes are mentioned in this research are Labuan (Malaysia)–Muara (Brunei) and Muara–Labuan–Menumbok (Malaysia), their success being attributed to the high demand for transportation in these corridors.

Another region of interest for SSS is Australia, with [39,40] presenting an analysis of SSS in this region. In Australia, coastal shipping, which is defined as the maritime transport that takes place between ports on the same continent [81], is considered instead of SSS. However, it can be stated that they are similar types of shipping. It is mentioned that SSS has received a significant amount of attention from both the government and from researchers. SSS in the region is more focused on the transport of bulk cargo. In 2008, coastal shipping already represented 26% of domestic freight transportation, However, the shipping share has seen a decrease in the previous years due to the increase in cargo moved by rail or road. It was, the however, concluded in these studies that there existed a few corridors on which SSS could compete against road or rail transportation.

## 6. The Decarbonisation Challenge for Short Sea Shipping

Decarbonization of human activities has become a major goal across the world, with shipping being responsible for nearly 3% of world $CO_2$ emissions; meanwhile, at the EU level, maritime transport represents 3 to 4% of total EU emissions of $CO_2$. Although these values may be considered to be moderate, in 2012, a study [6] indicated that SSS was beginning to lose its reputation as a more environmentally friendly mode of transport. When it came to $SO_2$, $NO_X$, and PM emissions, SSS was deemed not worthy of its label as a green alternative to road transportation, and it was concluded that effective policies when it came to technological solutions and regulations needed to be developed. In 2015, the new maximum limit of fuel sulphur content for ships sailing within Emission Control Areas (ECA) was reduced to 0.1%. This newly imposed limit affected SSS, since additional capital and operational costs were created to either implement a scrubber to the vessels or by using more expensive fuels with lower sulphur content [111]. Furthermore, besides the North Sea and Baltic ECAs, a new Mediterranean ECA will come into effect in regard to the sulphur limit from 1 May 2025 [112].

The increase in the operating costs that is mentioned in [56] and was brought on by the stricter regulations could have resulted in the termination of some routes due to the loss of their economic viability, and a modal shift towards either road or rail alternatives could have happened, which is against the EU goals. In [41], a review is provided of the current regulations and existing technologies that assist the maritime industry in the process of decarbonization, covering *hull design, propulsion systems, new clean fuels and treatment systems, power systems and ship operation*. In this review, it is stated that marine diesel engines have shown progress towards decarbonization, particularly dual-fuel engines, which use a small amount of diesel to perform the ignition and then use alternative fuels as the main fuel. To support this process, alternative fuels such as biofuel and liquefied natural gas (LNG) will be crucial.

In order to maintain its green image, decarbonizing SSS is of major importance to the EU goals of reducing GHG emissions from transportation by 60% in 2030 [96]. However, this poses a multifaceted challenge rooted in the unique characteristics of SSS. Measures to achieve the goals can consist "*in speed reduction, change of service frequency, use of alternative fuels such as liquefied natural gas, investments in scrubber systems, and improved fleet assignment*" [57]. Some short-term solutions are provided by [58], and consist of power and speed limits imposed to vessels along with the now existing CII and operational energy efficiency ship index (EEXI) goals.

An analysis of the process of decarbonizing maritime transport is presented in [59]. It is noted that isolated measures are not enough to achieve the desired levels of emissions, and that a package of combined measures is critical to the success of this process. In [42], measures are divided into three main categories with the purpose of lowering GHG emissions: logistics-based measures, technological solutions, and MBMs. The IMO provides a list of some proposed MBMs. One proposed measure consists of the creation of an international fund for GHG emissions. Another measure defines a global reduction target for international shipping and it involves the purchase of approved emissions credits or the leveraged incentive scheme, which collects contributions based on marine bunkers. An example of this type of measure are the Emissions Trading Schemes (ETSs), which *sets a sector-wide cap on net emissions from international shipping*; from [113], the topic of ETSs will be further discussed below. When it comes to logistics measures, these can vary between speed optimization in the voyage, efficient fleet design, analysis of schedule design, and weather routing, which is the selection of optimal route configuration considering the meteorological conditions [59]. Weather routing is considered more important in deep-sea shipping as weather conditions are generally more severe and there is more flexibility when choosing an optimal route configuration. Technological measures can either consist of mechanical changes to the vessels or in the use of alternative fuels such as biogas, biofuels, or methanol. The work in [61] analyses the implementation of measures such as Flettner rotors, energy storage devices, fuel cells, cold ironing, or use of alternative fuels in a case study of an SSS vessel, where it was concluded that a reduction of more than 60% could be achieved by 2050 if these measures were put into action.

The attractiveness of different emissions compliance options in SSS is discussed in [60], such as cleaner fuels by developing a numerical model for calculating emissions in an intermodal transportation network across various modes of transportation, taking into account factors as fuel used, engine type, and design of each vessel. The results for this study confirm that road transportation has larger $CO_2$ emissions than SSS; however, SSS emissions of other pollutants are higher. Nonetheless, it is clear that the modal shift away from road transportation into SSS is much more beneficial when it comes to reducing GHG emissions, and the use of cleaner fuels and other environmentally friendly technologies could further encourage this modal shift.

Another important aspect that needs to be considered for the decarbonization of SSS is the emissions while at berth, which are very significant, particularly for SSS, since in this type of shipping, vessels spend a lot of time in port. One solution to this problem is through cold ironing, which is the process of providing shore power to cover the energy demands of ships calling at ports [62]. This can reduce the emissions of auxiliary engines at berth, leading to a global reduction in emissions, assuming that the grid powering the ships obtains power from an environmentally beneficial energy source (renewable rather than coal).

One particular MBM is the creation of ETSs, which work on a "cap and trade" principle by setting a limit on the total amount of GHG that can be emitted [114]. In 2024, the ETSs will be extended to cover $CO_2$ emissions from all large ships (of 5000 GT and above) entering EU ports, regardless of the flag they fly [115]. This measure will affect 50% of emissions from voyages starting or ending outside of the EU and 100% of emissions that occur between two EU ports and when ships are within EU ports. For every tonne of reported $CO_2$ (or $CO_2$ equivalent) emissions within the EU ETSs system, shipping companies will be required to purchase and surrender (use) EU ETSs emission permits. SSS is obviously highly penalized by this new ETSs system.

The inclusion of shipping in the ETSs has created some concerns even among EU countries, leading to seven countries (including Spain and Italy) to create a joint letter voicing their concern with the fact that the ETSs could lead to the loss of maritime trade to other regions outside of the EU [116]. The ministers of transport of these countries are concerned about the effects of the ETSs on their economy, with the main concern being the fact that vessels can avoid the ETSs by going to non-EU ports which will affect the shipping market in the region. A comprehensive study of shipping companies' options for avoiding ETSs is provided in [63]. An additional effect of ETSs that is already being seen is shipping companies planning to increase the charges for moving cargo, which will lead to customers supporting the additional costs brought on by the ETSs [117].

A study has also been developed on the implications of the ETSs on container routes existent in the EU [64]. The existing risk of policy avoidance by using trans-shipment hubs outside of the European economic area is mentioned and it is stated that this would lead to a penalization of the EU ports and a loss of revenue for the ETSs. A case study analysing the use of international hubs outside the range of the EU ETSs was then developed, and it concluded that the use of the ports outside the EU leads to an increase in the service speed to compensate for the longer distances travelled to those ports, which creates an increase in GHG emissions for the voyage going against the goal of the EU ETSs.

The ESN, representing the primary parties engaged in the intermodal maritime transport chain, has requested a revision of this directive as well as a temporary suspension of its implementation [118]. They believe that this measure will further increase the operational costs of SSS which could lead to a loss of competitiveness. Despite the commitment shown by SSS companies to reduce their emissions and improve energy efficiency in order to uphold their environmentally friendly image, there is still no optimal solution to the decarbonization of SSS, since the development of alternative green fuels is still in the early phases and their implementation in the entirety of the SSS market is not feasible. Particularly since until 2030, LNG will only cover the needs of up to 8% while fossil, biofuels, batteries, and methanol vary between 0.1% and 9% according to ESN [119]; additionally, it is mentioned that the CII compliance will particularly affect SSS since the vessels that travel shorter voyages and berth for longer time periods which will reduce the CII rating.

## 7. The Impact of Autonomous Navigation in Short Sea Shipping

### *7.1. Autonomous Navigation*

SSS has been previously recognized for its dependence on manual procedures and traditional shipping techniques, and this industry has been the target of increasingly stringent environmental regulations, as seen in the previous section, enforced by regional and global authorities such as the EU and the IMO [65]. Autonomous navigation, intelligent technologies, and digital solutions that aim to improve productivity, lower costs, and tackle environmental issues are surely able to assist SSS in entering a new era.

Firstly, the use of autonomous technologies can result in cost savings for SSS operators [43]. According to [120], automation concepts for SSS have encompassed both automated and traditional approaches utilizing ships and crewed vehicles. But over the past years, there has been a significant advancement in vehicle technologies, especially in the areas of electrical propulsion and automation, which can range from basic features like cruise control to more sophisticated ones like automated parking. When combined, these automotive technologies could enable automation in SSS. Examples of autonomous technology in SSS are autonomous vessels which can be used to navigate short sea routes without human intervention, relying on sophisticated sensors, radars, and artificial intelligence for safe and efficient transportation. Ships equipped with these technologies may lead to potential labour cost reductions along with safety improvements, especially since 75–96% of accidents on ships are caused by human error, with the higher values in this range applicable to busy shipping areas where most SSS occurs mainly due to limited crew rest time [121]. Additional technologies include automated port operation with automated cranes and other handling equipment, including also automated mooring, which increases the efficiency of SSS by reducing turnaround times, optimizing storage space, and lowering the risk of accidents. All these technologies are especially important for SSS ships, as they undertake short voyages in busy sea lanes with frequent but short port calls.

Given the fast development in the field of autonomous vessels, regulatory organizations are working to develop policies for approving autonomous ships [44]. The IMO issued MSC.1/Circ.1638 [122], containing the main results of a regulatory scoping exercise for the use of maritime autonomous surface ships (MASS). This document defines different degrees of autonomy from 1 to 4, with these degrees varying with the level of human action. In addition, several conventions such as SOLAS, COLREG, and others were reviewed. This exercise identified whether MASS could be regulated by any existing or future statutory instrument. To this purpose, a number of high-priority issues were identified, ranging from the need to develop MASS terminology and definitions, such as MASS, "master", "crew" or "responsible person", or the necessity to address the functional and operational requirements of the remote control station/centre and the possible designation of a remote operator as a seafarer. The need to analyse provisions regarding safety requirements that were previously under human control was also identified. For this purpose, the IMO suggested that the way forward may be the development of a goal-based MASS instrument.

One important topic when it comes to autonomous vessels in SSS is their comparison to autonomous vehicles performing land transportation. When analysing the paragraphs above, it is possible to identify some advantages and disadvantages of automation in SSS. Benefits of implementing automation in SSS include safety improvements by reducing the risk of human errors, which are the main cause for accidents in shipping; lower labour costs; and increased efficiency in SSS operation. Drawbacks and obstacles to the introduction of automation in SSS are the substantial initial investment since most of the technology is still being developed, job displacement, and existing regulatory challenges. When considering autonomous vehicles for land transportation some of their advantages are their user experience, efficiency, safety, mobility, productivity, energy, environment, and economy [66], along with the fact that land transportation remains faster than maritime transportation. Disadvantages to the automation in land transportation are similar to the ones for SSS and consist of the high cost of the initial investment, the lack of flexibility since it is only programmed to perform certain tasks, and legal and regulatory challenges [123,124]. Serious safety concerns arise due to the higher speed of land transportation and more intense traffic in roads, as compared to marine traffic.

When comparing automated transportation in SSS with automated transportation in land transport, it can be seen that they face similar challenges, particularly in the regulatory aspect of their implementation. Although land and sea transport are usually considered as competitors, the introduction of automation in both modes of transport will lead to an increase in the efficiency of operations and will particularly benefit intermodal transportation since it uses both modes, allowing for improvements when it comes to coordinating the different legs of the operation.

### *7.2. Autonomous Ship Concepts for Short Sea Shipping*

The world's first autonomous, zero-emission container vessel, *Yara Birkeland*, went into commercial service in the spring of 2022. The zero-emission ship will carry mineral fertilizer to the regional export port in Brevik from Yara's production facility in Porsgrunn, Norway [125]. It was supposed to gradually transition towards full autonomous sailing during the first to years of operation; however, the duration of the transition increased to two years due to regulations [126]. KONGSBERG, which was responsible for the development and delivery of all essential technologies, also mention that unmanned operations were estimated to begin in 2024. This transition will occur by training an algorithm through data collection from the voyages and, eventually, radars, sensors, and artificial intelligence cameras will help the vessel navigate by itself. Nowadays, its automated capabilities consist of auto-docking, automated mooring, and other technologies [127]. Other autonomous vessels have commenced operations such as *ZhiFei*, a container vessel in China which began testing in October 2021 and will have the ability to be either fully autonomous, remotely controlled, or to have crew on board; some research vessels and military vessels in the US; and navy vessels in the United Kingdom have also been developed. In addition, there are also new projects being developed, such as two inland container vessels in Belgium and Netherlands or a domestic autonomous container vessel in Japan [128].

The primary reason for the lack of autonomous ship building projects [67] is the immature technology and regulations, along with the low amount of reliable evidence to support the benefits of implementing autonomous technologies into shipping. To solve this problem, Key Performance Indicators (KPIs) were developed in order to allow for this assessment, and this type of work is critical to facilitate other research regarding the feasibility of introducing these technologies into SSS.

One important aspect when it comes to the implementation of automation in SSS is the economic feasibility of the investment. According to findings in [45], it is concluded that there are insufficiently accurate financial models for autonomous shipping, and that the cost estimates are highly uncertain, particularly when it comes to insurance, cyber security, and contingency operations cost, leaving only a trustworthy assessment of particular case studies.

A case study focused on an autonomous container ship for short sea trades is presented in [68], with the main objective of evaluating the economic feasibility of such a ship. In this scenario, a conventional ship and an equivalent autonomous ship under the same technic and commercial conditions are compared, with the objective of understanding how much higher the new building price and costs of the remote operations centre may be to deliver the same internal rate of return. The conclusions were that an autonomous ship could cost up to 32% more while still ensuring the same internal rate of return.

A study in [69] examines the conversion of a cargo ship used in SSS in Norwegian waters into an autonomous ship, along with the design of the crewless ships of the future. It was concluded that when compared to other shipping types, such as ocean-going vessels, MASS adoption on SSS routes with frequent port calls is anticipated to show a larger economic margin for the operators. The impact of fleet configuration is analysed [70] on the cost of liner shipping operations by examining a model in a data instance that converts conventional to autonomous vessels in a case study on the Baltic trade. The results show that the implementation of autonomous vessels brings savings when compared to traditional vessels and, in addition, the results also imply that because of its improved capacity to adapt to the asymmetry of trade, a fleet configuration that combines large and small vessels performs better, which seems to be a common configuration applied in operations when considering autonomous vessels.

An analysis of the financial ramifications of employing autonomous vessels instead of conventional ones within the future of vessels is presented in [71]. In order to achieve this, an SSS network for the shipping of containers between ports in Europe and Norway's coastline was designed using a mother and daughter route concept. Comprehensive computational trials that took into account the different existing problems led to the conclusion that the introduction of autonomous daughter vessels decreased the operational costs in addition to delivering lower fuel consumption, which benefited the environment. When also turning the mother vessel into an autonomous ship, the benefits were even greater.

### *7.3. Research Projects in Automation for Short Sea Shipping*

While the funding specifically assigned by the European Union to promote research in SSS has decreased significantly in recent years, also in line with there being less funding dedicated to promoting SSS, there are a couple of recent research projects under the EU's Horizon 2020 research and innovation program that deal with the automation and digitalization in SSS. The AEGIS project [129] was a three-year endeavour which started in June 2020 and ended in November 2023, with a total funding of EUR 7.5 M from the EU's Horizon 2020 research and innovation program. It was dedicated to developing a brand-new, environmentally friendly, dependable, adaptable, automated, and autonomous waterborne transportation system for Europe that can link both rural and urban terminals [72]. The AEGIS consortium worked to develop a new, disruptive SSS feeder-loop service based on mother and daughter ships [73]. Additionally, this project leveraged cutting-edge advancements in connected and automated transport, incorporating smaller and more adaptable vessel types, automated cargo handling, autonomous ships, standardized cargo units, and new digital technologies. A number of different user cases were developed in this project. One of them refers to a maritime transport corridor from the west coast of Norway down to the continent, for which a container vessel with 1000 TEU capacity was designed [74]. It will operate with a low autonomy level, carrying crew on board, but including automated mooring and automated cargo handling. Other vessels projects are a coastal feeder service vessel, a push boat, a barge convoy, and a self-propelled shuttle, with the latter three designed to, one day, become fully autonomous vessels while being monitored in a control centre.

Another project is called MOSES, which began in July 2020 and ended in December of 2023 [130]. This project aimed to bolster the SSS component within European supply chains. It involved addressing vulnerabilities and challenges associated with the operation of large containerships and its consequences in the feeder segment of SSS. The strategy involved a dual approach: reducing the total time to berth for TEN-T hub ports and promoting the utilization of SSS feeder services to smaller ports with limited or no infrastructure. The three main innovations developed within the MOSES project are MOSES innovative feeder vessel, followed by the MOSES AutoDock system, which is an autonomous vessel manoeuvring and docking scheme, and the MOSES Platform, which is a digital collaboration and matchmaking platform specifically designed for SSS traffic. The MOSES innovative feeder vessel equipped with a robotic container-handling system [75] will be aimed at streamlining the (un)loading processes of containerized cargo at hub ports. This innovative system not only enhances the efficiency of cargo operations at major ports but also contributes to the increased operational capacity of smaller ports.

The goal of the MOSES AutoDock system is to automate big container ships' manoeuvring and docking at deep-sea shipping ports, seeking to cut the time it takes for container ships to dock and manoeuvre in large terminals by 20% in order to lower the cost of ship handling at the port [76]. Additionally, the risks and injuries brought on by conventional line mooring techniques and manoeuvring accidents may be eliminated or significantly reduced. The MOSES Platform seeks to maximize the efficiency of SSS services by using data-driven analytics to match demand and supply. Several shippers' information will be combined by the platform, which will then make the information available to logistics service providers. It will support scenario-building capabilities and allow for varying degrees of user interaction based on the needs of the stakeholders. Additionally, it will include a dedicated module for exchanging information about empty containers. Lastly, shippers and carriers will be able to combine flows for both directions on the MOSES digital match-making platform, which will be backed by appropriate governance models, handle planned deliveries, and spot capacity [131]. The advantage of this platform for SSS when compared to the previously mentioned platforms is that it was especially designed for this type of shipping, making it even more efficient; in addition, it was developed within the scope of the EU, facilitating its application in the SSS market.

Finally, the Autonomous Shipping Initiative for European Waters (AUTOSHIP) started on July 2019 and will end in December 2024, and it aims at speeding-up the transition towards a next generation of autonomous ships in the EU [132]. The project will build and operate two distinct autonomous vessels with a focus on goods mobility in order to demonstrate their operational capabilities in scenarios involving inland waterways and SSS. The project's goals range from developing and deploying autonomous vessels to improving digital tools or devising ways to advance autonomous ships beyond the state of the art. Two different scenarios will be analysed in this project, one being an SSS fish feed carrier sailing between Skretting and Cargill and serving fish farms along the Norwegian coast. The other scenario is an inland waterways shuttle barge operating for the transportation of goods in large bags or on pallets in the Flemish region, which is centred around the important EU port of Antwerp. The project's two user cases will serve as a showcase for the full suite of technologies for autonomous operations. Along the vessel's route, functions and controls, including fully autonomous and remotely controlled sailing, will be determined.

In general, it can be seen from the user cases considered in the research projects described above that autonomous navigation is likely to mainly benefit applications typical of short sea shipping, namely those involving short freight transport routes or repetitive activities.

## 8. Digitalization: An Opportunity for Short Sea Shipping

Digitalization is also poised to have a large impact in SSS. This section will analyse this impact, examining its deep influence on maritime logistics and trade. Digitalization in SSS can range from the integration of smart ports to the adoption of digital documentation and navigation systems. In 2020, the IMO secretary general at the time stated that digitalization was the key to enabling post-COVID recovery by strengthening the resilience of the global supply chain, taking shipping into a new era [133], and considering also the significant problems faced by shipping during the pandemics. It was also found that the IMO had embraced electronic data exchange by making it mandatory under the Facilitation Convention (FAL) since April 2019 [134]. Digitalization can help improve the connectivity between SSS and multimodal inland transport [81]. The SSS market segment stands to gain a great deal from technologies brought by digitalization because they have the potential to address many of the major drawbacks of SSS that shippers have identified [46]. Two examples of digitalization in SSS consist of electronic documentation, which leads to paperless processes, and port community systems, which facilitate seamless communication and information exchange between stakeholders, reducing delays and enhancing overall efficiency in port operations.

Regarding electronic documentation, blockchain technology is revolutionizing the documentation and tracking of goods in SSS by creating a decentralized and secure ledger [47]. It can minimize the risk of fraud, ensure transparency in transactions, and streamline the entire supply chain process. This is very important as [107] identifies one of the main problems of SSS as being the increased bureaucratic burden when compared with road-based transport solutions. Ref. [48] mentions that although blockchain technology is still in development, it holds a great promise for solving some of the bureaucratic and transparency issues in the maritime industry.

Port community systems include, for example, Maritime Single Windows (MSW), which, according to [135], are a "facility that allows parties involved in trade and transport to lodge standardized information and documents with a single entry point to fulfil all import, export and transit related regulatory requirements". However, there were some problems in the beginning, more particularly in the EU, when it came to the EU-level harmonisation, since all the implemented national single windows are different [136]. To solve this problem, the EU issued regulation (EU) 2019/1239 [137], which establishes a European maritime single window environment starting from 2025. The IMO has also developed guidelines for setting up a maritime single window (MSW) through FAL.5/Circ.42/Rev.3, which offers guidance to public authorities or administrations responsible for developing or modifying environments for an MSW [138].

Another example of digitalization is smart containers integrated with the Internet of Things (IoT), which support enhanced decision making by various sectoral stakeholders [139]. Smart containers are similar to normal containers; however, they are equipped with sensors that are connected to a network which collects real-time data on technical parameters ranging across the temperature inside a container, hazardous atmosphere, weather conditions, or its exact location. This enables a continuous control of the inside of the container while even contributing to avoidance of the loss of containers due to extreme weather conditions or other causes. The loss of containers has increased to 3113 for the two-year period of 2020–2021 from the 779 of the previous period (2018–2019) [140]. These numbers represent a very small percentage of the total containers transported in the world, but the increase in the loss of containers is worrying, and smart containers can avoid this problem since they provide their exact location via GPS. These sensors built into the container also allow for monitoring of the progress of the containers, permitting customers or port operators to predict when ships might arrive at their destination.

According to [141], smart reefer containers allow for the near-real-time tracking of important data a such as temperature, carbon dioxide levels, and other gases, as well as GPS container position and geofencing, all of which are critical to the well-being of the cargo transported in the reefer container. In addition to that, it is also possible to set up notifications according to customers' needs during the whole transport such as off power, pull down, carbon dioxide, oxygen, and relative humidity.

Digitalization allows for the optimization of vessel performance by implementing a digital twin vessel, which [77] defines as a virtual representation of the vessel that is updated with data almost in real-time and spans its life. It uses machine learning, deductive thinking, and simulation to support decision making, sensing, and control actuation. The fact that ships engaged in SSS typically sail not far from coastlines implies that connectivity is made easier in this shipping segment, facilitating the transfer of these huge volumes of data needed to populate the condition monitoring parts of the digital twin. Ships engaged in deep-sea shipping may find it more difficult to transmit such data using satellite connections, especially in remote areas. This technology may therefore find a readier market in small-to-medium size ships engaged in SSS. Additionally, digital twin vessels allow for the understanding of how, for example, extreme weather events may impact the vessel [142].

Other examples of digitalization include cloud-based collaboration platforms enhancing collaborative information sharing and big data analytics for predictive insights allowing data-driven decision making, for example, the Cargo Stream platform, which is a shared workspace for supply chain management, with tools that make life easier for shippers, transportation companies, ocean carriers, and freight forwarders [143]. These platforms may increase the tracking and tracing of cargos along the supply chain, thus alleviating the lack of transparency that is frequently cited in shippers' complaints when discussing the possibility of using SSS more often. Additionally, these platforms may encourage the expansion of port hinterlands by providing a more accurate overview of all the transport solutions available within a wide geographical area, thus assisting in the goal of deviating a substantial part of the 75% of inland freight carried by road onto rail and inland waterways, as stated in [144].

The implementation of digitalization in shipping plays a pivotal role in mitigating the risks associated with extreme weather conditions. Through the use of advanced weather forecasting technologies, achieved with weather satellites, buoys, or computer modelling [145], along with real-time data analytics, it is possible to obtain data for current and forecasted meteorological conditions [146]. This information is crucial to the avoidance of hazardous conditions which may lead to the loss of cargo or damages to the vessel.

## 9. Conclusions

This paper first provides a review of the EU policies for SSS. In the years that followed the introduction of the SSS concept, several funding programs were developed by the EU, such as the MoS initiative, which intended to create effective and ecologically sustainable shipping routes to strengthen maritime routes around the EU. The general conclusion is that the EU has not achieved the desired success when it comes to the practical results of this program. The main reason behind the lack of success of the MoS initiative is the lack of funds employed in this initiative when compared to other alternative modes of transportation. Other EU initiatives were the PACT program along with both Marco Polo programs, which have given financial support to SSS initiatives, fostering the use of cutting-edge technology and a shift in mode from land to marine transportation in an attempt to reduce traffic on the highways. However, mixed opinions exist when reviewing the success of these programs, some indicating that the programs were ineffective while for others that these initiatives were still environmentally beneficial for the EU. Despite the discussed lack of success of these initiatives, the EU still places SSS as a crucial agent to the modal shift away from road transportation and is developing initiatives, such as the continuous support of a European Shortsea Network or the adoption of the Greening Freight Package.

An analysis of the results obtained from the above-mentioned EU policies was performed along with a description of the challenges faced in the region. The conclusion is that despite the EU efforts, road transportation is still the favoured transport alternative in the region and has shown growth in recent years. On the contrary, SSS has seen a slight decrease in its share in recent years. A description of SSS strengths and weaknesses indicates that the main reasons for the lack of success in SSS are the lack of investment in port infrastructures, particularly when it comes to the development of SSS-dedicated terminals that would boost the efficiency of operations, along with the inefficient promotion of the SSS activity. A number of measures that could assist SSS in becoming more competitive against road transportation were identified, such as a further development of a single market for shipping that would promote the movement of cargo in SSS routes and removing regulatory constraints that may delay and affect SSS operations. Lastly, one important measure to promote the modal shift away from road transport would be the internalization of external costs of transportation.

In regard to the state of SSS outside the EU, the conclusion from an analysis of the situation in North America is that both Canada and the US demonstrated interest in it as a greener alternative to road transportation, and that despite some regulatory obstacles that existed in the region, signs of some existing SSS operations were present. For Northeast Asia, it was observed that some existent SSS routes covered the three countries with major economic influence in the region, Korea, Japan and China, and that the region was investing in the development of this type of shipping. The situation of SSS is facilitated in this region due to the geography of the region with the presence of island nations. A similar situation occurs in ASEAN. Other parts of the world, such as South America or Africa, have demonstrated an interest to follow the EU example of developing SSS as an environmentally friendly alternative to road transport; however, they are still in the early development phase without many real SSS operations actually implemented.

The conclusion concerning the impact of decarbonisation (and limitation of air pollution in general) on SSS is that, in recent years, SSS has lost some of its image as a green alternative to road transport due to emissions of $SO_2$, $NO_{X,}$ and PM being comparatively higher for SSS than for land-based alternatives. This aspect, as well as the decarbonisation itself, are both crucial when it comes to maintaining the image of SSS as a more environmentally friendly alternative as well as for keeping pace with evermore restrictive regulations for maritime emissions. Different measures to assist the process of decarbonizing SSS were put forward: alternative fuels, fuel cells, improvements in operational efficiency, slow steaming, route optimization, adaptions in port infrastructure to assist vessels in reducing their emissions, and emissions trading systems.

Finally, the impact of automation and digitalization on SSS was assessed by analysing the existent and future technologies that could benefit SSS in the future. Autonomous navigation could be of advantage for SSS since it would reduce the labour costs along with increasing the safety of voyages. Autonomous technologies in SSS can consist of both of fully autonomous vessels, automation assisting a crewed vessel, and automated port operation with automated cranes and other handling equipment, including also automated mooring. All these technologies boost an operation's efficiency and can turn SSS into a more competitive alternative. The major constraints to introducing these technologies in SSS operations are, currently, costs and regulatory obstacles. Examples of existing autonomous vessels were then provided, and it was concluded that the lack of further autonomous ship projects is primarily due to a lack of confidence in novel technologies, lack of regulations, and absence of trustworthy data which can validate the advantages of integrating autonomous technologies into the shipping industry. Nonetheless, some case studies demonstrate the existing potential for the use of autonomous navigation in SSS. A number of EU research projects, such as AEGIS, MOSES, and AUTOSHIP, are indeed focused on investigating and developing new autonomous technologies and processes for digitalization in SSS.

It was also concluded that digitalization can help solve some of the problems that were identified for SSS, such as through electronic documentation in substitution of paper and port community systems which can improve the efficiency in port operations and help tackle the existing lack of investment in those infrastructures. The expansion of port single windows to also cover key stakeholders along supply chains may also increase the transparency of SSS-based transport solutions. Other innovations in this field consist of smart containers which together with the Internet of Things provide real-time tracking of the location of containers as well as valuable information on the conditions of the containers. Cloud-based collaboration platforms can also assist the EU in harmonizing requirements in the SSS market as well as the use of big data analysis to derive transport insights and allow for optimized decision making.

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