Dissertation
Department of Business Administration

The Sustainability and Competitiveness of European Short-Sea Shipping

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To my parents, Nazir and Naeema,
and my siblings, Tanveer, Adnan, and Uzma

Abstract

Several factors could improve the environmental performance of European short-sea shipping (SSS) and enhance its competitiveness, and in this thesis, some of those factors are explored. The purpose of this thesis is to both explore factors with the potential to improve the environmental sustainability of European SSS and analyse the industry's competitiveness. Its findings are drawn from four studies that involved accessing multiple sources of data that includes a systematic literature review, interviews and a survey of SSS companies operating in Europe. As a whole, the thesis provides an overview on the various types of factors, especially slow steaming, collaboration and green innovations that can impact the environmental sustainability and competitiveness of SSS in Europe.

The findings indicate that for the roll on, roll off (RoRo) and roll on, roll off cargo and passenger transport (RoPax) sectors of SSS, bunker prices, rigorous competition and, above all, different service quality requirements in terms of total transit time, frequency, reliability and the convenience of departure and arrival times significantly restrict slow steaming's potential implementation. Beyond that, a 0.1% sulphur regulation enacted in 2015 has not triggered slow steaming in the RoRo and RoPax sectors to a great degree. One reason is that during the implementation of measures to meet the 0.1% regulation, a drop in bunker prices caused by lower crude oil prices made slow steaming economically unattractive in those sectors. Another reason is that the increased costs of using marine gas oil are partially transferred to customers and partly borne by the shipowners.

The findings additionally suggest that collaboration between shippers and SSS operators significantly improves the environmental and economic performance of SSS. SSS operators and large shippers in Europe should thus seek opportunities for strategic collaboration and shared planning with other agents in their transport chains. Strategic collaboration among cargo owners, ship operators and forwarding agents can especially enhance the efficiency of systems, shorten lead times, reduce emissions, lower costs per unit of output and, in turn, generate mutual benefits for all stakeholders involved.

Last, the findings also reveal that green innovations, including ones related to energy-efficiency, have a substantial impact on the economic and environmental performance of European SSS firms. Accordingly, managers at SSS firms can enhance the environmental and economic performance of their companies by dedicating resources to developing green and energy-efficient technological solutions. At the same time, they should not wait for regulations to begin developing green innovations but take a proactive approach to pursuing such innovations, which can benefit the performance of their companies.

Keywords: Short-sea shipping, environmental sustainability, competitiveness, improvement factors, slow steaming, collaboration, innovation

List of Appended Papers

This thesis is based on research conducted for the four following papers:

Paper 1: Raza, Z., Svanberg, M., Wiegmans, B., 2019. Modal shift from road haulage to short sea shipping: A systematic literature review and research directions. *Transport Reviews*, 40(3), 382–406. https://doi.org/10.1080/01441647.2020.1714789

Paper 2: Raza, Z., Woxenius, J., Finnsgård, C., 2019. Slow steaming as part of SECA compliance strategies among RoRo and RoPax shipping companies. *Sustainability*, 11(5), 1–19. https://doi.org/10.3390/su11051435

Paper 3: Christodoulou, A., Raza, Z., Woxenius, J., 2019. The integration of RoRo shipping in sustainable intermodal transport chains: The case of a North European RoRo service. *Sustainability*, 11(8), 1–17. https://doi.org/10.3390/su11082422

Paper 4: Raza, Z., 2019. The effect of Regulation-Driven Green Innovations on Environmentaland Economic performance of Short Sea Shipping in Europe. Resubmitted for consideration for publication in the special issue on "Improving the Environmental Performance of Shipping and Ports" of *Transportation Research Part D: Transport and Environment*.

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Zeeshan Raza

Göteborg, March 2020

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1 Introduction

This chapter provides the background to the thesis, the motivation for the research conducted and an introduction to the research field. The purpose, research questions and scope of the thesis are also provided.

Maritime transport is an integral part of global transport systems. In Europe in particular, maritime transport, including both deep-sea shipping and short-sea shipping (SSS), has been a major facilitator of economic development and prosperity for centuries. In contrast to deep-sea shipping, which is intercontinental and conducted across oceans, SSS is the maritime transport of goods over relatively short distances (Van den Bos and Wiegmans, 2018).

In Europe, SSS companies compete not only within the SSS industry but also with alternative modes of freight transport, especially road and rail. Sambracos and Maniati (2012) as well as Woxenius (2012) have suggested that competition among different modes of freight transport in Europe is influenced by various factors, including service quality, operational costs, new legislation (e.g. sulphur emission control areas, SECAs) and infrastructural developments (e.g. the construction of the Fehmarn Belt tunnel). Figure 2 depicts the market shares of different transport modes in the EU-28. As shown, from 2012 to 2017 the relative share of road transport increased by 1.6 percentage points, the share of air transport remained unchanged, and the shares of rail, inland waterways and maritime transport decreased by 0.8, 0.5 and 0.3 percentage points, respectively.

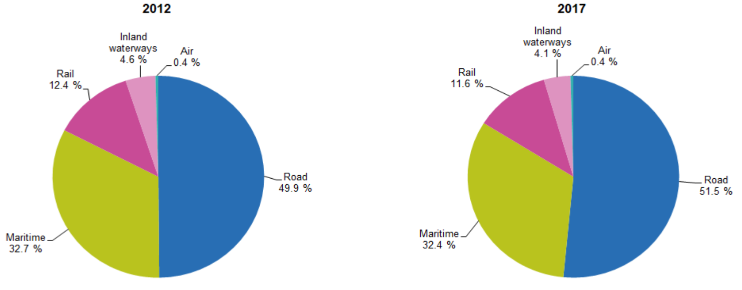

Figure 1. Modal split of freight transport in the EU-28 by percent share in tonne-km (European Commission, 2018)

Compared to rail transport and SSS, road haulage poses major challenges in the EU. Chang et al. (2010) have observed that although the environmental sustainability of road haulage has improved in recent years, other socio-economic problems representing negative externalities—for instance, highway congestion, longer wait times, traffic accidents, noise, surface use and damage to infrastructure caused by road haulage—still need to be addressed. Therefore, to overcome some of the negative externalities caused by road transport, various policies have been promulgated by the European Commission (EC) to increase the competitiveness and use of SSS. In particular, an EC white paper on the topic issued in 2011 advised that 30% of road freight transport longer than 300 km should shift to alternative modes of transport (e.g. waterborne and rail) by 2030 and that more than 50% of such transport should do so by 2050. However, despite major efforts made by the EU, particularly policies promoting modal shifts and even SSS, the results of shifts from road to sea freight transport remain disappointing. In fact, statistics from the European Comission (2018) show that road haulage has continued to capture more than 50% of the total freight market in Europe.

At the same time, although SSS provides an alternative to road haulage, primarily due to its role in alleviating road congestion and emissions from longer-distance cargo transport, environmental problems caused by shipping operations have raised justifiable concerns. Hjelle (2014) has suggested that the environmental impacts of shipping emissions can be categorised as occurring on local, regional and global scales. On a global scale, the issue of global warming caused by emissions from shipping activities has received the most attention on the political agenda. On a regional (e.g. international) level, by contrast, the chief concern centres on emissions of sulphur dioxide (SOx) and nitrogen oxides (NOx), which can cause acidification, damage crops and buildings and threaten human and animal health. In addition, Yap and Lam (2013) have pointed out that maritime transport can cause water pollution in different regions due to oil spills in water, the inappropriate disposal of chemicals and wastes and the discharging of ballast water, all of which are detrimental to aquatic ecosystems and fishery resources. Beyond that, Corbett et al. (2007) have asserted that the principal negative effects of shipping on the local scale relate to poor air quality caused by shipping emissions of NOx, SOx, hydrocarbons, non-methane volatile organic compounds and particles.

Global and regional legislators alike have recognised the need to reduce the emissions produced by maritime activities. Particularly for the EU market, the European Comission´s (2011) white paper on transport suggests that the EU's CO_2 emissions from maritime transport should be reduced by at least 40% of 2005 levels by 2050 and, if achievable, by 50%. Accordingly, the EC has crafted regulations and directives to reduce pollution and regulate the management of waste from the maritime industry. In addition to EU regulations, Europe's SSS industry is subject to the regulations of the International Maritime Organization (IMO). Indeed, European SSS is governed by the same regulations as deep-sea shipping that does not compete with road transport and only marginally competes with rail transport.

Porter (1991) has argued that regulations trigger short-term reactions to long-term proactive strategies and force firms to revise their production practices and reorganise their activities in order to survive amid fierce competition. According to an analysis by Drewry Shipping Consultants, a switchover to high-priced low-sulphur fuel oil to comply with the IMO's 2020 global sulphur regulation is expected to impose an additional $11 billion fuel cost to the shipping industry (Kalogeras, 2019). Having reviewed market reports on the topic, King (2019) has suggested that to cope with the regulations, save on operating costs and maintain their competitiveness, shipping companies have tended to adopt a combination of measures, including slow steaming, service integration, the off-hiring of chartered vessels, alliances with other companies and the use of innovative low-sulphur fuels or scrubbers, if not both. Unlike in deep-sea shipping industry, however, the application of some of those measures (e.g. slow steaming) in the SSS industry might negatively affect its competitiveness with road haulage by increasing total lead times. Notteboom (2011) has added that though regulations aim to improve the environmental performance of shipping, the cost of complying with such regulations compromises the ability of SSS to compete with road haulage. Regulations also increase operating costs for SSS firms, which can end in higher prices for SSS services and eventually cause modal back shift to road haulage—a shift that could increase not only emissions but also congestion and accidents. Thus, regulations can be or become counterproductive to EU policies related to promoting SSS for environmental reasons.

The challenges posed by environmental regulations and competitiveness, coupled with the importance of the SSS industry to intra-European trade, underscore the significance of exploring factors that could improve the environmental sustainability and competitiveness of SSS. Thus, in the wake of environmental regulations and intensified efforts by the EU to promote SSS, this thesis investigates how certain factors, including both drivers and barriers, as well as measures such as slow steaming, collaboration and environmental innovations affect SSS firms' environmental and competitive performance.

1.1 Purpose and research questions

The purpose of this thesis is to both explore factors with the potential to improve the environmental sustainability of European SSS and analyse the industry's competitiveness. To fulfil that purpose, four research questions (RQ) were specified, as discussed in what follows.

RQ1: What factors influence the environmental sustainability and competitiveness of SSS?

RQ1 is devoted to identifying factors that may affect the environmental sustainability and competitiveness of European SSS. Research by Cullinane and Cullinane (2013), Styhre (2010), Woxenius (2012) and Zis and Psaraftis (2018) has highlighted several such factors, typically classified as drivers, barriers and measures. Beyond that, measures can be divided into three categories: technical, policy-related and operational or logistical. Of those types of measures, the technical ones include, for example, efficient propellers and rudders, enhanced waste heat recovery systems, improved hull design and performance, antifouling hull coatings, hull cleaning, the use of solar or wind power and the use of scrubbers and alternative fuels. By contrast, the policy-related measures include, for instance, the internalisation of external costs, reduced taxes for the shipping industry, the use of Ecobonus and the promotion of innovations in SSS. Last, the operational or logistical measures include, for example, slow steaming, improved routing and scheduling, enhanced fleet management, the increased utilisation of ship capacity, improved turnaround times at ports, real-time information about port congestion and collaboration among transport chain agents. To all of that, however, Cullinane and Cullinane (2013) have added that the voluntary use of technical and operational measures may not generate the major environmental improvements needed to clean up the shipping industry and that additional types of mitigatory measures (e.g. regulations) are therefore needed to reduce the industry's emissions.

Several studies have investigated the potential and even implementation of the mentioned measures. However, amid recent environmental regulations and EU policies aimed at improving the environmental sustainability of European SSS and its competitiveness with unimodal road haulage, it remains essential to pinpoint the drivers and barriers affecting the realisation of those goals and to explore in greater depth some of those technical, operational and policy measures, especially slow steaming, collaboration, innovations and regulations. Furthermore, given the importance of SSS to EU trade, its slow growth compared to road haulage despite various EU policies to promote SSS requires identifying types of drivers and barriers that influence its competitiveness. Although numerous scientific studies have either descriptively or empirically addressed factors related to improving the sustainability and competitiveness of SSS, those studies were conducted in different geographical contexts with different methods and produced dissimilar results, at least to a certain extent. Therefore, to lay a foundation for the thesis, a systematic literature review was conducted, the findings of which helped to answer RQ1.

RQ2: How does slow steaming impact the competitiveness of short-sea RoRo shipping?

Slow steaming, or reducing the speed of ships, is a common practice in deep-sea shipping. Following the IMO's stipulation of a 0.1% sulphur limit in fuel in 2015, it was predicted that SSS companies would act to reduce their bunker costs by adopting slow steaming. However, for European SSS, adopting slow steaming may not be as attractive as it is for deep-sea shipping. In particular, roll on, roll off cargo transport (RoRo) and roll on, roll off cargo and passenger transport (RoPax) sectors of SSS are vulnerable to intense competition from alternative modes of moving freight, including road and rail transport. Among authors who have examined slow steaming in the context of sulphur regulations, Zis and Psaraftis (2018) used route-specific data from 2014 and 2015 about RoRo and RoPax services to quantitatively measure slow steaming's potential as an operational measure that shipping companies could implement to reduce operating costs in SECAs. In the same vein, Santos and Guedes Soares (2017) formed a method of determining the optimum ship speed for RoRo ship operations in SECAs. Johnson and Styhre (2015) suggested that reduced waiting times in port could not only support slow steaming but also reduce the additional cost effects of sulfur regulation on dry bulk shipping in the North and Baltic Seas. However, knowledge about the adoption of slow steaming by RoRo and RoPax shipping companies as a consequence of the 0.1% sulphur regulation of 2015 remains insufficient. Similarly limited is knowledge about the impact of slow steaming on the competitiveness of short-sea RoRo and RoPax in terms of service quality. RQ2 is designed to shed light on all of those issues.

RQ3: How does collaboration between shippers and short-sea RoRo firms impact the environmental and competitive performance of SSS?

In previous research, SSS and its integration have primarily been addressed from the perspective of ship operators, whereas the role of shippers in enhancing the integration of SSS into intermodal transport chains has attracted little attention. In view of that discrepancy, Saldanha et al. (2016) have even asserted that shippers cannot play any significant role in improving the competitiveness of SSS "as a spin-off from serving their own needs". By contrast, Styhre (2009) along with Paixao and Marlow (2005) have argued that large shippers, which control significant volumes of cargo, can ensure the high frequency of transport services and the improved use of capacity, both of which can eventually reduce emissions, lower the per-unit costs of transport services and, in turn, improve competitiveness. According to Stank et al. (2001), although gaining competitive advantage often also involves establishing the building block of cost-effectiveness, business success derived from a cost orientation is usually short-term at best. After all, the managerial tools and techniques used to achieve lower costs are typically easy to imitate, which means that firm-by-firm differences in performance gained from such initiatives are difficult to sustain. The same authors additionally explain that a firm may outperform competitors only if it can establish a preservable difference for itself. Owing to those dynamics, customising logistics services may present opportunities for shippers to become an integral part of their customers' business as a form of collaboration. According to Gray (1991), *collaboration* refers to a process of decision-making among interdependent parties that involves the joint ownership of decisions and collective responsibility for outcomes. Somewhat differently, Schrage (1990) has defined *collaboration* as "an affective, volitional, mutual shared process where two or more departments work together, have mutual understanding, have a common vision, share resources, and achieve collective goals". From either perspective, collaboration can help firms to tailor service offerings to meet the specific demands of customers by identifying their long-term requirements, expectations and preferences. Along with collaboration, information sharing focuses more resources, both human and financial, on business operations, which allows more informed decision-making, reduces risks and can result in mutual benefits that improve service performance. López-Navarro (2013) has verified that shared planning and joint decision-making among shippers and carriers positively affect the performance of both types of firms. In the same vein, Fugate et al. (2009) have emphasised that long-term, mutually beneficial relationships among shippers and carriers can boost the performance of both stakeholders by improving load factors and reducing the costs of fuel and labour. RQ3 seeks to clarify the importance of collaboration and shippers themselves in improving the competitiveness of European SSS.

RQ4: How do green innovations impact the environmental sustainability and competitiveness of SSS?

Europe's SSS industry tends to regard regulations as an additional cost burden that negatively affects the industry's competitiveness. A contrary view proclaims, however, that regulations stimulate innovations that, in turn, improve the environmental and economic performance of firms. Addressing the IMO's environmental regulations in particular, several researchers have focused on options for technical compliance and the cost of compliance for individual vessels and trade routes (Acciaro, 2014; Brynolf et al., 2014). Added to that, several other researchers—for example, Lindstad et al. (2017) Schinas and Stefanakos (2012) and Zis and Psaraftis (2017)—have reported that, for SSS companies, complying with environmental regulations requires additional investments and energy use, both of which increase operating costs, encourage a modal backshift to road transport and, in turn, detrimentally affect the economic and environmental performance of companies. Nevertheless, scholars have generally overlooked the importance of environmental innovations that have emerged in response to regulations. Encouraged by regulatory pressure, shipping companies adopt various green technological and process innovations and practices, including slow steaming, optimised route planning, hull coating, improved engine design and the use of scrubbers and innovative fuels, as Chen et al. (2018), Lindstad et al. (2016) and Woxenius (2012) have demonstrated. Despite their contributions, however, additional research remains necessary in order to elucidate how regulations impact the adoption of innovations as well as the environmental and economic performance of companies in Europe's SSS industry. That same need justifies RQ4.

1.2 Scope

This thesis focuses on the European SSS industry in the context of environmental regulations, especially European policy that promotes SSS and factors for improving the environmental and competitive performance of SSS. To explore the potential for such factors to that end, the thesis takes the perspective of SSS firms, which are directly influenced by shipping-related regulations and EU policies. Along with that perspective, the role of shippers is also included to highlight different perspectives.

Although several measures may have the potential to improve the competitiveness and environmental performance of SSS, three such measures—slow steaming, collaboration and green innovations—deserve more attention in the context of current environmental regulations and EU policies promoting SSS. Accordingly, those three measures are explored in depth in this thesis. At the same time, cost–benefit analyses of those measures in terms of environmental and competitive performance are excluded, due to considerable variation across trade corridors and the characteristics of vessels.

1.3 Appended papers and the outline of the thesis

This thesis is a compilation of four papers, each of which addresses at least one of the four mentioned research questions in light of research conducted during 2015–2019. Paper 1, based on a systematic literature review of 58 research articles, addresses factors that drive or hinder the environmental sustainability and competitiveness of SSS and, as a consequence, the modal shift to SSS. The paper also provides directions for future research on that topic. By contrast, Paper 2 examines how RoRo and RoPax SSS firms have reacted to slow steaming as a cost-saving measure in the context of sulphur regulations in the North and Baltic Seas. It additionally investigates the impact of slow steaming on competitiveness in RoRo and RoPax sectors. Next, Paper 3 is devoted to illustrating, with reference to an in-depth case study, the impact of cooperation between a shipper and carrier on the environmental sustainability and competitiveness of an associated SSS company. Last, drawing from the results of a survey questionnaire, Paper 4 focuses on how environmental regulations have impacted the adoption of green innovations and, in turn, how those innovations have affected the environmental and economic performance of the SSS industry in Europe.

Figure 3 depicts the relationships between the research questions and the papers. In short, all four papers address RQ1, whereas Papers 2, 3 and 4 respectively address RQ2, RQ3 and RQ4.

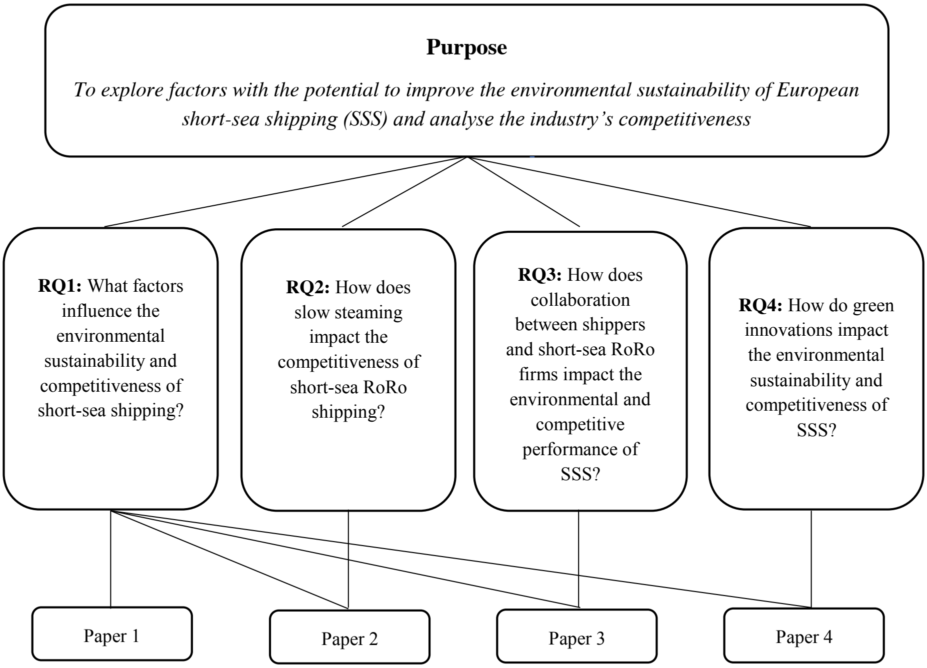

Figure 2. Relationships between the research questions (RQ) and papers of the thesis

Three of the papers were presented at international conferences, which facilitated the development of a network of experienced researchers who offered feedback on initial versions of the papers. In turn, the process of preparing articles in collaboration with other researchers helped to improve the quality of the research presented herein. Initial versions of Papers 1–3, following their presentation at international conferences, have been published in peer-reviewed journals. Meanwhile, Paper 4 was initially reviewed for its target journal, and a revised version of the paper has been resubmitted with changes made according to the reviewers' comments. Table 1 provides an overview of the papers, the research design and the research strategies applied in this thesis.

Table 1. Overview of research questions, papers, and methods used in the research for the thesis

Research questions (RQ)	RQ1: What factors influence the environmental sustainability and competitiveness of short-sea shipping (SSS)?	RQ2: How does slow steaming impact the competitiveness of short-sea RoRo shipping?	RQ3: How does collaboration between shippers and short-sea RoRo firms impact the environmental and competitive performance of SSS?	RQ4: How do green innovations impact the environmental sustainability and competitiveness of SSS?
Paper titles	Paper 1: "Modal Shift from Road Haulage to Short Sea Shipping: A Systematic Literature Review and Research Directions"	Paper 2: "Slow Steaming as Part of SECA Compliance Strategies among RoRo and RoPax Shipping Companies"	Paper 3: "The Integration of RoRo Shipping in Sustainable Intermodal Transport Chains: The Case of a North European RoRo Service"	Paper 4: "An Analysis of Environmental Regulations, Green Innovations and Performance of Short-Sea Shipping"
Journal	*Transport Reviews*	*Sustainability*	*Sustainability*	*Transportation Research Part D*
Status	Published online	Published	Published	Revised and resubmitted
First-version conference presentation	GOL 2018	IAME 2017	IAME 2018	
Methodology	Mixed methods			
Reasoning	Inductive	Inductive	Inductive	Deductive
Approach	Qualitative	Qualitative	Qualitative	Quantitative
Research design	Systematic literature review	Case study	Case study	Survey
Key data sources	Literature	Literature and interviews	Literature and interviews	Literature and questionnaire
Participants	N/A	Representatives of SSS companies	Representatives of SSS companies and shippers	Representatives of SSS companies

All articles except article 4 were written in collaboration with other researchers, whose roles and responsibilities in each paper are delineated in Table 2.

Table 2. Authors of each paper in the thesis and their responsibilities

Paper	First author	Other authors and affiliations	Responsibilities of authors
Paper 1	Raza	Svanberg (SSPA AB, Sweden) Wiegmans (Delft University of Technology, the Netherlands)	All authors designed and planned the paper. Raza collected and analysed the data as well as drafted the manuscript except for Section 3.2.2, which was written by Svanberg; and Svanberg and Wiegmans supervised and improved the manuscript by editing it and providing suggestions in response to the reviewers' comments.
Paper 2	Raza	Woxenius (University of Gothenburg, Sweden) Finnsgård (SSPA, Sweden)	All authors planned the study as well as prepared and participated in interviews. Raza performed the literature review, conducted several interviews and drafted the manuscript, as well as improved the manuscript by responding to comments from reviewers; Woxenius reviewed, edited and supervised the manuscript; and Finnsgård reviewed and edited the manuscript conducted several interviews. Raza improved the manuscript by responding to the review comments.
Paper 3	Christodoulou	Raza and Woxenius (All authors are affiliated to University of Gothenburg)	All authors planned the study and participated in the interviews. Christodoulou drafted the manuscript. Raza provided literature reviews and contributed to the overall suggestions. Woxenius reviewed, edited and supervised the manuscript.
Paper 4	Raza		Sole author

A brief overview of the different chapters of this thesis is provided as follows:

Chapter 1 *Introduction* provides a background and introduction to the research field. The definitions of the key concepts, research problem, purpose, research questions, and scope are provided in this chapter.

Chapter 2 “Methodology”, presents the research methods, the data collection process and the means of ensuring the quality of the research. The chapter also describes the methodology of the individual papers and the interrelationships among them.

Chapter 3, “Frame of Reference”, reviews literature relevant to the topic and, as such, forms the foundation of the thesis.

Chapter 4, “Findings”, provides an analysis of factors related to the environmental sustainability and competitiveness of European SSS. The chapter additionally presents the results of the four papers in relation to the four RQs in this thesis.

Last, Chapter 5, “Discussion and Conclusion”, elaborates upon the key measures that influence the environmental sustainability and competitiveness of European SSS companies. The chapter also articulates the key theoretical and managerial implications of the results and synthesises the findings that help to fulfil the purpose of the thesis.

2 Methodology

This chapter describes the research design of this thesis. The methods that were used to answer the four research questions are outlined, after which the processes of collecting data, analysing the data and ensuring the quality of the research are explained.

2.1 Research design

According to Bryman and Bell (2007), a *research design* can be defined as a plan or framework for the collection and analysis of data intended to answer proposed research questions. Following a mixed-methods approach, the research for this thesis relied on both qualitative and quantitative methods. To answer each research question, a particular methodological choice was made based on the nature of the research question, as detailed in this section.

To explore factors with the potential to improve the environmental performance and competitiveness of SSS, techniques mixing both quantitative and qualitative research methods were deployed. Such an approach is known as *mixed-methods research*, which Creswell and Plano (2007) along with Johnson and Onwuegbuzie (2004) have defined as a type of research in which qualitative and quantitative approaches are integrated within a single study or a set of closely related studies designed to solve an overall problem. Writing about qualitative research, on the one hand, Kothari (2004) has posited that using qualitative approaches can provide a profound understanding of a complex phenomenon and produce new knowledge useful for solving problems related to the phenomenon and for generating new theories. Regarding quantitative research, on the other hand, Denzin and Lincoln (2005) have highlighted that using quantitative approaches can provide statistical data, for example, useful for establishing relationships between constructs and testing theories.

The exploratory nature of the research for this thesis called for the use of a mixed-methods research design, and ultimately, the integration of qualitative and quantitative approaches in the research indeed afforded a thorough understanding of factors affecting the sustainability of SSS. Among other outcomes, using qualitative research methods to answer RQ1, RQ2 and RQ3 provided insights into the quantitative methods deployed to answer RQ1. In the following subsections, the research design and methods employed are explained in detail.

2.1.1 Research Question 1: Design of Paper 1

RQ1 was designed to determine factors affecting the environmental sustainability and competitiveness of SSS. To that end, it was important to access secondary data from the body of knowledge in scientific literature addressing types of factors that affect the sustainability of SSS and, in turn, modal shift from road haulage to SSS. Thus, a systematic literature review was conducted to gather evidence useful for answering RQ1.

Systematic literature reviews facilitate the comprehensive mapping, consolidation and evaluation of literature about a specific field of knowledge, as well as allow identifying gaps in such knowledge that should be filled as a means to further develop the field. In terms of their structure, Van Wee and Banister (2016) have argued that systematic literature reviews have to involve a methodical, scientific process of searching for literature to review and of assessing the information retrieved. On top of that, the process should be easy for other researchers to understand and replicate.

For this thesis, the systematic literature review used to answer RQ1 was designed to provide an overview of the drivers, barriers and measures that influence the environmental sustainability and competitiveness of SSS. A structured process was followed to search for scientific literature in two databases—Web of Knowledge and Scopus—that have been endorsed as good sources of peer-reviewed articles concerning the social sciences, including business, logistics and supply chain management. To achieve broad coverage of all relevant articles and reduce the risk of overlooking any important ones, the search was performed in the "topic" and "title, abstract, keywords" fields of both databases. Because various terms are used to capture the topic of modal shift in scientific literature, a fairly wide range of search terms were applied to locate relevant articles. To further reduce the risk of overlooking important articles for the review, a forward and backward snowballing approach recommended by Van Wee and Banister (2016) was deployed as well. Ultimately, 58 papers were selected for the systematic literature review and categorised by the types of factors affecting SSS that they address. Beyond the scope of the review, the factors and measures identified were later used to guide the development of RQ2, RQ3 and RQ4. The review's output thus contributed to the thesis in three ways: by explaining how other researchers have explored the topic of modal shift from road haulage to SSS, by describing the drivers, barriers and measures that influence SSS and by identifying directions for future research.

2.1.2 Research Question 2: Design of Paper 2

Addressed in Paper 2, RQ2 was designed to gauge the reactions of European SSS firms to the practice of slow steaming as a consequence of sulphur regulations in the North and Baltic Seas and to determine slow steaming's impact on the competitiveness of SSS. To answer RQ2, it was important to acquire an in-depth understanding of context-specific factors that influence the adoption of slow steaming in SSS and how it influences the competitiveness of SSS. To explore that complex problem, a multiple-case study was determined to be the most appropriate research method for the study conducted in Paper 2.

Thomas (2015) has described a *case study* as the analysis of a phenomenon, which can be a person, process, event, decision, period, project, policy, company or system. According to Yin (2009), a phenomenon should be studied both in depth and within its real-life context, and added to that, Eisenhardt (1989) has argued that such an in-depth understanding can shed valuable light on the complex interrelations occurring in a specific context. In Paper 2, the specific context was the relationship between slow steaming and the competitiveness of SSS companies.

To explain the shift from a "what" question for RQ1 to a "how" question for RQ2, Yin (2009) has argued that research questions to be addressed by the case-study approach should be phrased as "how" or "why" questions and may thus be exploratory in nature. Along similar lines, Eisenhardt (1989) had suggested the case study is indeed an appropriate method for exploratory investigations into topics about which little is known and for which new perspectives are needed. Slow steaming is not only such a topic but also a complex one, for its adoption depends on various factors and, in some cases, can affect the competitiveness of SSS companies. Beyond that, because the perspective of SSS companies on adopting slow steaming and its impact on their competitiveness remains unknown, case studies are entirely appropriate to explore the phenomenon and capture the viewpoints of actors involved. As part of the methodological choice of a case study to answer RQ2, semi-structured interviews were also conducted to collect data for the research presented in Paper 2.

2.1.3 Research Question 3: Design of Paper 3

Addressed in Paper 3, RQ3 was designed to explore collaboration between shippers and shipping companies, because such collaboration may contribute to the environmental sustainability and competitiveness of SSS. As in Paper 2, that same contemporary phenomenon, which should not be examined outside its context, was thought to be better investigated in a case study (Voss et al., 2002). In Paper 3, to understand the phenomenon of how shipper–carrier collaboration affects the environmental sustainability and competitiveness of a European SSS company, an in-depth, single-case study was conducted that revealed the primary drivers (i.e. enablers) of SSS competitiveness within intermodal transport from the perspective of a large shipper. Also as in Paper 2, as part of the case study to answer RQ3, semi-structured interviews were also conducted to collect data for the research presented in Paper 3.

2.1.4 Research Question 4: Design of Paper 4

Last, addressed in Paper 4, RQ4 was designed to probe the impact of green innovations on the environmental sustainability and competitiveness of SSS. To answer the question, a cross-sectional quantitative research design, also referred to as “survey research”, was adopted for the research in Paper 4. According to Bryman and Bell (2007), survey research necessarily comprises a cross-sectional design, because the quantitative data are collected predominantly by questionnaire at a single point in time, all in connection with two or more variables examined for patterns of associated based upon the data collected. As Yin (2009) has explained, survey methods are advantageous when the research objective is to describe the incidence or prevalence of a phenomenon or to predict certain outcomes.

Regarding the connection between theory and research, quantitative approach follows a deductive approach that focuses on testing the theories, whereas qualitative research follows an inductive approach that emphasises the generation of theory and knowledge (Bryman & Bell, 2007). In light of that difference, a quantitative and deductive approach was pursued in the research for Paper 4, for which three hypotheses, each with two parts, were developed and tested with reference to data collected with a survey questionnaire.

2.2 Data collection methods

Following Marshall and Rossman’s (2006) suggestion that methods of data collection should accommodate the study’s purpose, the data collection methods in the research for the thesis were selected with respect to the nature of the problem being addressed and the types of research questions being asked, as described in what follows.

2.2.1 Literature review

A literature review was the starting point of data collection for the thesis and the appended papers, as well as the chief source of data for answering RQ1 in Paper 1. According to Webster and Watson (2002, p. 13):

> *"A review of prior, relevant literature is an essential feature of any academic research project. An effective review creates a firm foundation for advancing knowledge. It facilitates theory development, closes areas where a plethora of research exists, and uncovers where research is needed"*

The literature review covered a variety of areas related to the research questions, including modal shift in freight transport, competitiveness, environmental sustainability, slow steaming, the integration of SSS into intermodal transport, environmental regulations for shipping, green innovations and business performance. Web of Knowledge, Scopus and Google Scholar were accessed to search for relevant scientific literature for this thesis, and a snowballing approach was employed in that process. Conference proceedings, dissertations, EU project documentation and market reports were also used as sources of literature. Material published online (e.g. annual reports of companies in the case studies) also proved useful in supporting the research findings.

2.2.2 Interviews

Bryman and Bell (2007) have ranked interviews among the most frequently used methods of data collection in qualitative research. In this thesis, Papers 2 and 3 indeed relied on interviews as a primary source of data, which were conducted as follows. First, with reference to the literature review and the research questions, an interview guide containing semi-structured questions was prepared. Second, the interview guide was sent to interviewees well before the interviews in order to let them collect their thoughts in response to the interview questions. Third, semi-structured in-person and telephone interviews were conducted, some of which were audio-taped with the permission of the interviewees, and fourth, the interviews were transcribed. Last, the interview data were analysed to generate findings, which were sent to the interviewees as a form of quality and factual check.

For the selection of interviewees, Denscombe (2010) has recommended choosing interviewees based on their knowledge and experience in relation to the phenomenon being studied. For Paper 2, managers from 11 European SSS firms from RoRo and RoPax sectors participated in semi-structured face-to-face and telephone interviews. By comparison, for Paper 3, a total of six semi-structured interviews were conducted, namely with five interviewees representing the shipper or a forwarder and another interviewee representing an SSS company. Details regarding the interview questions, characteristics of the interviewees and their respective companies appear in Papers 2 and 3.

2.2.3 Questionnaire

For Paper 4, a quantitative survey questionnaire was conducted in a large sample of individuals associated with European SSS companies. Compared to interviews, survey questionnaires pose advantages in terms of cost and time required, for they facilitate the collection of large amounts of data in short amounts of time. To enhance their effectiveness, Ronald et al. (2005) have suggested using simple designs for questionnaires so that respondents can easily understand them. For Paper 4, items to evaluate the impact of regulations and green innovations on the environmental and economic performance of SSS companies were adapted from published studies and responded to on a 5-point scale.

To gauge the content validity of the initial questionnaire, an online pilot test with five experienced SSS practitioners and five academics was conducted, as suggested by Malhotra and Grover (1998). Based on feedback received from the pilot survey, the observed variables were refined, deleted or added to ensure that the items were understandable and relevant to practices, as Hensley (1999) has advised.

The selected sample for the study comprised European companies in the SSS industry. To improve the generalisability of the study and the proposed model, the sample encompassed a variety of sectors in the SSS industry: RoRo, RoPax, container, bulk, multipurpose and general cargo. The target group for the survey was managers or their equivalents at SSS companies who were considered to be knowledgeable in how green innovations and regulations affect their firms' economic and environmental performance. The units of analysis were individual companies, whereas the units of data collection were individual managers.

An online survey, distributed with a cover letter explaining the purpose of the survey and assuring the anonymity of respondents, was developed at www.qualtrics.com, and weblinks to the survey were sent via email to managers at 493 companies. Although online surveys are cheaper and less time-consuming than mail surveys, the pilot test revealed the technical challenges related to online questionnaires, for some of the test's participants were unable to receive emails containing a weblink to the survey due to security risks. To overcome that setback, the University of Gothenburg's email system was used instead of Qualtrics. Ultimately, 101 usable responses were returned, for an overall response rate of 20.32%. The size of companies in the sample was diverse, ranging from smaller to Europe's largest SSS companies with significant market shares (e.g. CMA CGM, DFDS, Eimskip, Frontline, Grimaldi Group, Golden Ocean Group, Maersk, Samskip, Stena Line, Unifeeder and Wilson). Details about the items in the questionnaire, the characteristics of the survey respondents and their respective companies appear in Paper 4.

2.3 Data analysis

According to Maxwell (2013), there are multiple ways to analyse collected data. For qualitative data analysis geared towards understanding a complex phenomenon, describing the problem, categorising the data into themes and identifying interrelations between variables or key concepts are recommended steps (Maxwell, 2013), and that process was indeed followed for data analysis in Papers 1–3. NVivo software was used in analyzing the interview transcripts, categorising the content into themes and concepts and processing the literature review for Papers 1–3, which helped to identify relevant and important concepts. To generate findings, the process followed in NVivo was an iterative one that involved moving back and forth between reading, analysing and interpreting the collected data.

Regarding the quantitative analysis performed for Paper 4, to test the hypotheses and analyse the collected survey data, the structural equation modelling (SEM) technique suggested by Anderson and Gerbing (1988) was employed. According to Bentler (2011), *SEM* is a statistical method of representing causal processes involving observations on multiple variables. According to Golob (2003), SEM can accommodate multiple endogenous and exogenous variables, as well as latent (i.e. unobserved) variables specified as linear combinations (i.e. weighted averages) of the observed variables. In general, the models used in SEM can be divided into two types: measurement models and structural equation models. Whereas measurement models identify the relationships between observed and unobserved variables as a means to evaluate the reliability and validity of the models, structural equation models are used to test hypotheses.

All analyses were performed in the Statistical Package for the Social Sciences version 25.0 for Windows and AMOS 25. Details about the analysis of the collected data appear in each paper.

2.4 Research quality

To assess the quality of research, different criteria have been suggested for qualitative versus quantitative research. Nevertheless, tests for validity and reliability are commonly applied across both types of research (Bryman and Bell, 2007). To gauge the quality of the research presented herein, tests for construct validity, internal validity, external validity and reliability were conducted, as suggested by Yin (2009), Creswell and Plano (2007) and Johnson and Onwuegbuzie (2004).

2.4.1 Construct validity

Validity of a research study can be assessed by testing construct validiy, internal validity and external validity (Huck, 2007). According to Yin (2009), *construct validity* deals with establishing the correct operational measures for the concepts being studied. To ensure construct validity, Yin (2009) and Voss et al. (2002) have suggested three strategies: consulting multiple sources of evidence during data collection, establishing a chain of evidence and using member checks (i.e. informant feedback). In the research for this thesis, these strategies were used in multiple ways. For instance, data triangulation was used for information obtained from the literature, from interviews with different shippers and SSS company representatives, from surveys and from company reports. Beyond that, a mixed-methods approach was deployed to answer the research questions, meaning that both qualitative and quantitative techniques were applied.

Maintaining a chain of evidence should enable readers to trace the entire research process, from developing research questions to interpreting the implications of findings, and vice versa

(Yin, 2009). For this thesis, a chain of evidence was established for both individual papers and the thesis as a whole. For example, the selection of interviewees for Papers 2 and 3 has been justified, and interview questionnaires and the coding tree for Paper 2 have been provided.

As another measure to ensure construct validity, a member check, representing the informant feedback approach, was used. During interviews, interviewees' responses were restated to them, sometimes in paraphrased wordings, which helped to establish construct validity. Added to that, before the interviews, the interviewees received the interview guide and were briefed about the type of research being conducted and the nature of the questions being asked. For quantitative studies construct validty can be assessed by testing convergent and discriminant validity (Huck, 2007). Convergent validity and discriminant validity of the constructs both of which are considered to be subtypes of construct validity, were assessed in Paper 4. Details about the results of tests for convergent and discriminant validity appear in Paper 4.

2.4.2 Internal validity

According to Yin (2009) and Reichardt (2015), *internal validity* supports the causal relationships that researchers use to explain why certain events lead to other events. Because internal validity is primarily a concern for causal and explanatory studies (Yin, 2009), it applies only to Paper 4, the research for which involved SEM.

To ensure the internal validity in Paper 4, four measures were taken. First, the validity of the survey questionnaire was measured based on a pilot test administered with five experienced managers of SSS and five scholars. Based on feedback received from the pilot survey, the items included in the survey were refined, deleted or added to ensure that they were understandable and relevant to practices. Second, three or more observed variables were used to represent each latent construct (i.e. unobserved variable) used in the structural model. Third, an SEM technique was used to measure the relationships between the latent constructs and to test the research hypotheses. Fourth and last, the model resulting from SEM was measured in the widely used Statistical Package for the Social Sciences and in AMOS 25.

2.4.3 External validity

External validity refers to the degree to which findings can be generalised (Bryman and Bell, 2007) beyond a case study or the specific context of a study. In Paper 2, a case study was conducted in order to analyse how slow steaming affects the competitiveness of European SSS in the era of sulphur regulations. The study was conducted in a European context, in which regulations for the SSS industry, the business environment and the nature of competition with alternative modes of transport may differ from those in other regions of the world. Therefore, the findings presented in Paper 2 and referred to in this thesis may not be generalisable beyond RoRo and RoPax sectors of the SSS industry in the European context.

The results of Paper 3 are based on a specific case of collaboration between a shipper (i.e. Stora Enso) and an SSS company (i.e. Swedish Orient Line, SOL). The findings of the paper may be generalisable to other industries and countries that have access to sea transport, share similar route characteristics and have large volumes of cargo that need to be transported. However, generalisation to other industries and contexts should be made with caution.

Last, the empirical findings of Paper 4 are based on a survey of European SSS operators. The types and stringency of regulations, as well as aspects of business competition, may differ in other regions of the world. Those factors should be considered before making any generalisations from the findings of the study.

2.4.4 Reliability

Reliability describes the extent to which the process of a research study is consistent and can be repeated for the same results (Voss et al., 2002). Ensuring a reduced risk of bias and error in a study, reliability can be achieved by documenting the procedures followed in conducting a research study. For this thesis, the research questions, interview guides, survey items, procedure for the systematic literature review and units of analysis were all documented in the respective papers. For the quantitative study in Paper 4, composite reliability and average variance extracted (AVE) estimates were used to validate the reliability of each construct through confirmatory factor analysis in SEM. Aside from that, the Cronbach's alpha for five latent constructs were calculated to test the reliability of the questionnaire. More details about the reliability of the research can be found in the appended papers.

Apart from the mentioned criteria, reviewers' comments on the papers also contributed to enhancing the quality of the research. All papers were peer-reviewed by two to four anonymous reviewers, and previous versions of papers 1, 2, and 3 were also presented at international conferences. Overall, the feedback from the reviewers was positive. Papers 1–3 have been published, whereas Paper 4 has been revised based on the reviewers' comments and resubmitted for publication. Table 3 provides an overview of the strategies proposed by Yin (2009) and the tactics deployed in the thesis to ensure the quality of the research.

Table 3. Summary of tests conducted to ensure the quality of the research for the thesis

Test	Strategies proposed by Yin (2009)	Strategies used in the thesis
Construct validity Focuses on establishing the correct operational measures for the concepts being studied	▪ Using multiple sources of evidence ▪ Establishing a chain of evidence ▪ Conducting member checks (i.e. for informant feedback)	▪ Triangulating sources (i.e. literature, company reports, interviews and a survey) ▪ Documenting a chain of evidence ▪ Sending the interview guide to interviewees in advance and asking follow-up questions
Internal validity Focuses on establishing causal relationships	▪ Using pattern matching ▪ Addressing rival explanations ▪ Using logic models	▪ Interpreting concepts and patterns against rival explanations ▪ Testing causal relationships in a structural equation model
External validity Focuses on establishing generalisability	▪ Using theory ▪ Using replication logic	▪ Using theory-based frameworks ▪ Using a multiple-case study approach ▪ Basing interpretations on instances of diverse properties (e.g. sector and firm size)
Reliability Focuses on whether operations of a research process can be repeated for the same results	▪ Developing a case-study protocol ▪ Developing a case-study database	▪ Documenting the research process, including: ◦ Research questions ◦ Units of analysis ◦ Interview guides and survey questions ◦ Characteristics of interviewees and survey respondents ◦ Selection of interviewees and survey participants ◦ Interview recordings and transcripts ◦ The coding tree (i.e. in Paper 2) ◦ Analytical approaches

3 Frame of Reference

This chapter is dedicated to providing a deeper understanding of the different concepts and topics examined in this thesis. The chapter overviews different sectors of the SSS industry, environmental challenges faced by the industry, environmental regulations, the current policy framework for SSS in Europe and factors that influence the competitiveness and environmental sustainability of SSS.

3.1 Definition of *short-sea shipping*

Trade between neighbouring countries using maritime transport can be traced back to the beginning of recorded trade. However, European Commission first time used the term *short-sea shipping* in a white paper on transport policy in 1992 (EC, 1992). Seven years later, the European Comission (1999, p. 2) officially defined *short-sea shipping* as:

> *"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"*

The Eurpoean Comission (1999, p. 2) further specified its definition of *short-sea shipping*:

> *"Short sea shipping includes domestic and international maritime transport, including feeder services, along the coast and to and from islands, rivers and lakes. The concept of short sea shipping also extends to maritime transport between the Member States of the [European] Union and Norway and Iceland and other States on the Baltic Sea, the Black Sea and the Mediterranean Sea"*

Paixao and Marlow (2002) have added that the term *short-sea shipping* is defined differently depending on the context in which it appears and the types of vessel and cargo being considered. In the literature, other terms such as *coasting trade*, *coastal shipping* and *regional shipping* are sometimes synonymously used for *short-sea shipping*.

3.2 Sectors of the short-sea shipping industry

According to Fusco (2016), the SSS industry can be divided into sectors based on the type of cargo being shipped. After all, the nature of the cargo determines the type of vessel required to ship it: vessels for bulk (i.e. dry or liquid), container ships, general cargo vessels and roll on, roll off (RoRo) and roll on, roll off passenger (RoPax) ships. Whereas bulk shipping usually serves one customer, liner shipping serves several customers and operates on fixed routes and schedules.

3.2.1 Bulk sector

In Europe, SSS is mostly used to transport liquid and dry cargo in bulk, typically in shipments from a single origin to a single destination. Posing a lower risk of damage due to the convenience of its stowage operations, bulk cargo is regularly shipped in large volumes and often in an unpackaged form. Transporting bulk cargo also requires specialised vessels, which tend to operate for tramp services or on an irregular basis. Due to economies of scale, bulk shipping has a clear competitive advantage over alternative modes of freight transport, particularly for long-distance routes (Fusco, 2016).

3.2.2 Container sector

The container shipping sector of the SSS industry is primarily engaged in transporting high-value cargo and providing connections for deep-sea container vessels employed in transoceanic trade. Container ships are more competitive for longer-distance routes but require efficient container-handling systems at the ports (Paixao & Marlow, 2002). Container shipping competes with road transport on routes where road transport is inefficient due to geography and road congestion. In the container sector, factors such as increased vessel sizes, alliances with other shipping companies and consolidated volumes have heightened the demand for larger ports and terminals. In turn, larger ports and vessels have heightened the demand for smaller feeder vessels to connect trans-shipment hubs with smaller spoke ports (Rodrigue, 2017). Thus, today's SSS container sector is a mix of SSS feeder vessels and SSS container vessels; whereas the operations and timetables of feeder vessels depend upon the deep-sea vessels that they serve, container vessels have their own fixed liner operations and schedules (Mukhtarov, 2018). In European SSS, the container sector as a whole occupies 15% of the total SSS market (European Comission, 2018).

3.2.3 RoRo sector

Of all sectors in the SSS industry, the RoRo sector is very sensitive to market changes, for RoRo shipping often competes head-to-head with road transport (Fusco, 2016). RoRo shipping is differentiated from other sectors of maritime shipping due to the far greater elasticity of demand for such transport, precisely because it faces such fierce competition from modes of land transport. According to Notteboom (2011), RoRo shipping is generally liner shipping, that offers a continuous service of transporting wheeled cargo and passengers between two ports. RoRo vessels are characterised to have loading ramps; unlike for lift on, lift off transport, or LoLo transport (e.g. container shipping), whose cargo needs to be loaded and discharged by cranes, cargo on RoRo vessels can be towed or wheeled aboard without requiring any special equipment. RoRo vessels are also used to transport semi-trailers, cars and containers on so-called "MAFIs" and cassettes and have built-in accommodations for a maximum of 12 passengers. Beyond that, RoPax ferries are used to transport passengers and their vehicles, as well as buses and trucks, following sailing schedules designed to accommodate both RoRo shippers and passengers. Together, the RoRo and RoPax sectors of the European SSS industry play a significant role in European trade and account for 14% of the total SSS market in Europe (European Comission, 2018). Figure 5 shows the market share of different sectors of Europe's SSS industry in 2015.

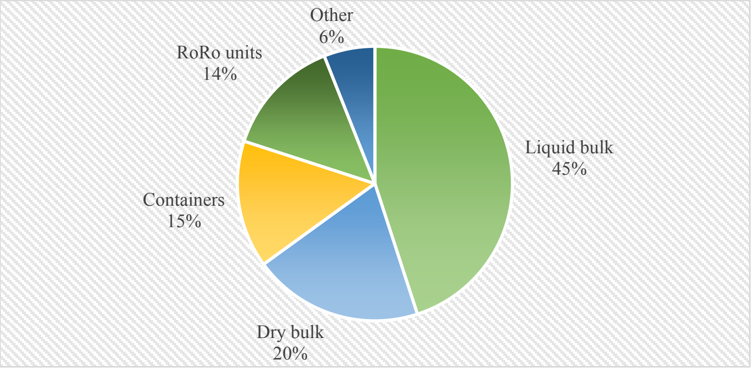

Figure 3. Short-sea shipping of goods in the European Union in 2015 by type of cargo and percentage of gross weight of goods (European Commission, 2018)

3.3 Policy for short-sea shipping in Europe

In Europe, a coastline of nearly 100,000 km dotted with hundreds of ports makes it easy to integrate maritime transport into any intermodal transport chain in Europe (Ng, 2009). Since the 1990s, to reap the benefits provided by sea transport, balance the modal split in the freight market and overcome the negative externalities (e.g. pollution, congestion and road accidents) caused by road freight transport, European authorities have devised various policies and programmes. Including the Pilot Action for Combined Transport, Marco Polo I and II, Galileo, the Trans-European Transport Network, the Ecobonus programme and Motorways of the Sea, such policies and programmes have been designed to promote different, socially preferred modes of transport (European Comission, 2003). According to EU goals underlying those policies and programmes, SSS should operate as part of intermodal transport chains or even completely substitute for road transport, depending on the shipping corridor. In support of those goals, as part of a new objective of the Combined Transport Directive, the EC's 2011 white paper proposed to shift 30% of road freight travelling more than 300 km to multimodal solutions (i.e. including rail and SSS transport) by 2030 and more than 50% by 2050 (European Comission, 2011).

Despite those various policies, programmes and targets, coupled with a budget of 895 million euros, the EU has not achieved its goals set for expanding the use and competitiveness of SSS in Europe. In fact, by market share, road haulage increased during the past decades compared to SSS. Statistics reveal that, during 2000–2009, road transport's share increased by 11.4%, whereas maritime transport's share increased by only 1.7%. Of course, within that period, the size of the EU increased from 2004 to 2007 after several eastern European nations joined, which provided relatively few new, natural opportunities for shipping. As a result of those trends, the impacts of the Marco Polo I and II programmes from 2000 to 2009 were minor at best. Critical reviews of EU policies related to SSS have been provided by Suárez-Alemán (2016) and Suárez-Alemán et al. (2015) and are discussed in greater depth in Paper 1 of the thesis.

3.4 Sustainability of short-sea shipping

In the literature, *sustainability* has been defined and interpreted to have an array of meanings. A widely used definition of the term comes from the Bruntland Report published by the World Commission on Environment and Development (WCED, 1987), which defines *sustainability* as "meeting the needs of present without compromising the ability of future generations to meet their needs". Expanding upon that definition, Elkington (1998) divided the concept of sustainability into three dimensions by introducing the so-called "triple bottom line", which emphasises that environmental, social and economic dimensions of sustainability are equally important in decision-making of companies. In the environmental dimension, for example, sustainability means maintaining or improving human welfare systems by preserving the resources of global ecosystems (e.g. water, air and energy) to ensure that such resources are not depleted but remain available for future generations (Bansal, 2002; Goodland, 1995). By contrast, the economic dimension of sustainability demands the ample production of products and services to meet the demands of consumers by generating profit. Last, to observe the social dimension of sustainability, businesses should consider the impact of their activities on the societies in which they operate.

In the past several years, the SSS industry has been pressured to improve its environmental and economic sustainability, especially its competitiveness. Generally, SSS has been regarded as a mode of transport with a lighter footprint in terms of emissions of CO_2 equivalents per tonne-km than road-based alternatives. However, the claim regarding the environmental superirioty of SSS to road haulage has been challenged for example by Svindland (2020) Vierth et al. (2018), Hjelle (2014), Hjelle and Fridell (2012), Hjelle (2011), Hjelle (2010), who in their research studies considered the realistic estimates for fuel consumption, cargo flows and load factors.

In papers on EU transport policy, a top reason for shipping cargo by SSS instead of by road transport is the former's assumedly better environmental performance. However, maritime transport is often generally considered to be an environmentally friendly mode without explicit evidence for such an assumption or only with reference to empirical data on average energy use per capacity tonne-km, such as figures determined with the IMO's Energy Efficiency Design Index (Eide et al., 2011). Nevertheless, such figures typically show that maritime shipping is indeed significantly more energy-efficient than road transport (Hjelle, 2014; IMO, 2009).

3.5 Environmental regulations for short-sea shipping

Compared to other transport industries, the maritime transport industry, given its international nature and offshore operations, has for long escaped the attention of environmental regulators. However, in response to increased environmental concerns and to control the creation of detrimental shipping pollutants both above and below the ocean's surface, various environmental regulations have been promulgated by regional and global authorities.

In the EU, the most important environmental regulations related to shipping put forward by the EC stipulate the use of double-hulled oil tankers (Regulation 417/2002/EC) in order to prevent oil pollution in the event of collisions, as well as require the provision of suitable port reception facilities for waste (Directive 2000/59/EC), the reduction of sulphur emissions (Directive 2012/33/EC) and punishment for pollution-related offences (Directive 2005/35/EC).

Moreover, the IMO, as a UN authority, has sought to regulate pollution caused by shipping with various treaties and conventions. To control marine pollution by oil, the IMO also adopted the first-ever comprehensive antipollution convention, the International Convention for the Prevention of Pollution from Ships (MARPOL), in 1973. Since then, MARPOL has been amended several times to also include requirements concerning pollution from chemicals, other harmful substances, garbage, sewage and, under Annex VI adopted in 1997, air pollution as well as NOx and SOx emissions from ships. Other international instruments in the remit of the IMO regulate oil pollution preparedness, response and co-operation (e.g. the OPRC Convention and the 2000 OPRC-HNS Protocol), harmful anti-fouling systems on ships (e.g. AFS Convention), the potentially devastating effects of the spread of harmful invasive aquatic organisms carried by ships' ballast water (e.g. BWM Convention) and the safe, environmentally sound recycling of ships (e.g. the Hong Kong Convention), to name just a few (IMO, 2019).

Key regulations proposed by the IMO in recent years have addressed the use of sulphur in fuels. Under Annex VI to MARPOL, the IMO implemented a sulfur cap that requires the vessels to use fuel with lower sulfur content (IMO, 2008). The stringent form of the regulation is implemented in specific zones known as SECAs—for instance, the Baltic Sea, the North Sea, the English Channel, the eastern and western coasts of North America and the US–Caribbean region—where stringent sulphur limits have been progressively applied. Under the sulphur regulation from 1 January 2015, for example, ships operating SECAs are required to use fuel on ships with a sulfur content no more than 0.1%. The regulation also stipulates that, beginning in 2020, the global limit of allowed sulphur content is to be 0.5%. In the wake of those sulphur regulations, researchers such as Svindland (2018), Chen et al. (2018), Lindstad and Eskeland (2016) and Holmgren et al. (2014) have analyzed the impact of SECAs on the shipping industry, from technical, operational, environmental and economic perspectives. Of the nearly 14,000 ships active in the SECAs of the North and Baltic Seas each year, approximately 2200 ships operate only in those areas, whereas 2700 others spend more than 50% of their time there (Bergqvist et al., 2015; ESN, 2013).

Sulphur regulations in Annex VI to MARPOL approve different ways of achieving the equivalent of 0.1% sulphur content in fuel. As a result, to comply with the 0.1% sulphur regulation, shipping companies have had numerous solutions at their disposal. They could, for example, use scrubbers and liquid natural gas or alternative low sulfur fuels such as marine gas oil, methanol and biofuels with a maximum sulphur content of 0.1%, (Halff et al., 2019; Lindstad & Eskeland, 2016; Svanberg et al., 2018). Although by using any of these options shipowners can comply with sulfur regulation, but each of these options comes up with different economic ramifications. The use of scrubbers and liquified natural gas demands a large initial capital investment (Abadie et al., 2017; Gu & Wallace, 2017). Notteboom (2011) has argued that though alternative fuels do not require initial investment, but their higher per ton price can make the shipping operations more expensive.

At the time of their implementation, the IMO's sulphur regulations were predicted to have negative ramifications for the SSS industry, including a potential modal backshift from sea to land. Due to the 0.1% sulphur limit active beginning in January 2015, the movement of lower-value commodities was especially expected to demonstrate a shift from sea to land transport modes (Holmgren et al., 2014). Notteboom (2011) even claimed that the switch from HFO to MGO, with MGO price at US $1000 per tonne, would raise freight rates by up to 60% and cause losses in volume exceeding 50%. All of those forecasted figures suggested that, due to the price increase, some shippers would opt to transport their goods not by boat but by truck or another mode of land transport. After all, the cost of vessel fuel accounts for nearly 50% of the total operating cost of a ship, and the price of low-sulphur MGO was 70–80% higher than that of HFO (Bengtsson et al., 2014; Notteboom, 2011).

According to Holmgren et al. (2014), a modal backshift to road would contrast the the EU policy of improving the environment, because road transport causes severe congestion and more emissions. In 2015, due to the drop in bunker prices, modal shift from SSS to road haulage did not occur. However, since 2016, bunker prices are increasing, which could cause the RoRo sector in particular to lose cargo volumes to competitive modes of land transport as asserted by Zis and Psaraftis (2017).

3.6 Competitiveness of short-sea shipping

Competitiveness is a multidimensional concept that can be used at the levels of the firm, industry and country (Murtha & Lenway, 1994). At the firm level, *competitiveness* refers to the strength or capability of an organisation in comparison with its competitors (Ajitabh & Momaya, 2004). To that, Ajitabh and Momaya (2004) have added that there are five dimensions of competitiveness: performance, quality, productivity, innovation and image: Whereas *performance* can include standard financial measures such as earnings, growth and profitability (Hamel & Prahalad, 1989), *quality* refers to the capacity of products and services to satisfy customers' expectations (Barney, 1991). Next, *productivity* captures the higher production and lower use of resources (Ajitabh & Momaya, 2004); *innovation* refers to how products, services and management processes offer creative, effective solutions (Mintzberg, 1993); and *image* can mean how well branding builds trust and reputation in companies' relationships with stakeholders (Kay, 1993).

Literature review in Paper 1 has revealed that the competitive performance of intermodal SSS versus door-to-door road haulage ranks among the most extensively studied topics in literature on the competitiveness of freight transport and has been approached in terms of three dimensions: economic performance, environmental performance and service quality. After all, to improve SSS's ability to compete with alternative transport modes (e.g. road and rail) is one of the most pressing challenges that the SSS industry faces today. According to Brooks and Frost (2004), due to its role in alleviating emissions and traffic congestion, SSS generally serves as an alternative to road haulage. Therefore, SSS operators compete not only within their sectors and the SSS industry but also in areas with alternative modes of freight transport, including pipelines, trucks and rail.

3.6.1 Economic performance

The primary objective of studies on the economic performance of SSS versus road haulage has been to assess the cost-competitiveness of prospective intermodal SSS services against road haulage. Studies by Feo et al. (2011), Garcia-Menendez and Feo-Valero (2009) and Ng (2009), for examples, have involved analysing the cost-competitiveness of SSS against road haulage for trade corridors in the Baltic, western Europe and Mediterranean regions. In a few other articles, scholars have additionally demonstrated that including external costs can affect the cost-competitiveness of SSS. For instance, Chang et al. (2010) and Suárez-Alemán et al. (2015) have estimated and compared the total costs of transport and time, including the external costs of air pollutants and greenhouse gases for road, rail, barge and SSS in South Korea and Europe. A distinct feature of their studies was that to evaluate external costs, they included not only air pollution but also other externalities such as highway congestion, noise emissions, specifics of climate change, landscape damage and traffic accidents. Altogether, those studies have shown that including external costs in cost comparisons can make SSS seem more competitive than it is in reality.

3.6.2 Environmental performance

Policymakers often cite the superior environmental performance of intermodal SSS compared with road transport to encourage a modal shift to SSS. On that topic and Svindland (2020), Hjelle (2014), Corbett et al. (2012), Hjelle and Fridell (2012), Hjelle (2011), Hjelle (2010) have evaluated the environmental performance of SSS versus road haulage in Europe and the United States in terms of CO_2, NOx and SOx emissions. They found that due to factors such as high fuel consumption and lower load factors, intermodal SSS tends to generate more emissions per tonne-km than road haulage, at least in the scenarios analysed.

3.6.3 Service quality

Service quality is considered an important part of competitiveness (Sharma, 2001). Research by both Paixao and Marlow (2005) and Yang et al. (2013) has demonstrated that high quality of the shipping services enhances the competitive performance of shipping companies. Among other factors, time is a major component of service quality, and time-related factors such as schedule reliability, sailing frequency and speed are all substantially important for shippers. Indeed, high performance in those time-related factors can considerably reduce the inventory costs, production costs and logistical costs of cargo owners (Brooks et al., 2012). Senić and Marinković (2014) have asserted that high performance in service quality improves the satisfaction of customers, who when satisfied usually continue purchasing those services and even recommend them to others.

Numerous researchers have assessed the importance of attributes of service quality considered by shippers to play an important role in their decisions about modes of transport. D’Este and Meyrick (1992), Bergantino and Bolis (2008), Puckett et al. (2011) and Brooks et al. (2012)

have all compared the importance of service quality between road haulage and SSS from the perspectives of Australian, Canadian, Italian and US forwarders and shippers. Their findings have revealed that, among other factors, certain attributes of service quality, especially shorter transit times, greater frequencies of services and reliability, are more important than the higher freight rates paid for cargo transport. In support of those findings, D'Este and Meyrick (1992) have argued that the indirect, long-term costs of failing to deliver consignments on time and intact may result in the loss of markets, market share, and customer confidence.

4 Results

This chapter answers the RQs with reference to results presented in the appended papers.

4.1 Environmental sustainability and competitiveness

This section addresses RQ1—that is, "What factors influence the environmental sustainability and competitiveness of European SSS?" Multiple factors, including drivers, barriers and measures, either directly or indirectly influence the environmental sustainability and competitiveness of SSS and are identified in Paper 1. In the context of environmental regulations and EU policies related to promoting SSS in Europe, the impact of measures such as slow steaming, collaboration and innovations on the sustainability and competitiveness of SSS has been investigated in considerable depth in Papers 2, 3 and 4, respectively, and elaborated upon in Sections 4.2, 4.3 and 4.4, also respectively.

As revealed in Paper 1, based on a review of the literature, various drivers (i.e. strengths or advantages of SSS compared with unimodal trucking and other conditions) and barriers (i.e. issues, limitations or weaknesses of SSS) influence the modal shift to SSS. Nineteen such drivers are classified into six groups (D1–D6), as shown in Table 4. In addition, 24 barriers, classified into seven groups (B1–B7), are listed in Table 5.

Table 4. Drivers of the competitiveness of short-sea shipping in Europe

Driver groups and drivers									
D1. Financial			D2. Capacity					D3. Operational	
Lower required investment in infrastructure	Cost-effectiveness	Economies of scale	Underused shipping capacity	Availability of sufficiently long sea lanes	Capacity to carry large industrial unit loads	SSS as a new alternative	Easy to expand transportation network capacity	High energy efficiency	Flexible operating hours
•									
•	•	•	•	•	•			•	•
			•						
•									
•		•					•	•	
	•					•			•
				•					
		•	•						
4	2	3	3	2	1	1	1	2	2

(Continued)

Driver groups and drivers								
D4. External					D5. Regulatory			D6. Other
Reduced air pollution	Fewer accidents	Less congestion	Fewer noise emissions	Higher safety in dangerous goods transport	Imposition of eco-taxes and carbon taxes on truck fuels	Imposition of more road tolls	Reduced hours of service by truck drivers	Alliances with trucking industry and port authorities
		•						•
•	•	•	•	•	•		•	•
•		•						
•					•	•		•
•		•	•	•				•
•		•	•					
•		•			•	•	•	•
6	1	6	3	2	3	2	2	5

Table 5. Barriers to the modal shift from road haulage to intermodal short-sea shipping

Barrier groups and barriers											
B1. Service quality					B2. Financial		B3. Technical				
Longer lead times at ports and in transit and slower speeds	Lower reliability	Lower frequency	Additional cargo-handling costs	Capital intensity of SSS industry	Additional inventory costs for shippers	High labour costs	Incompatibility of equipment and ICT systems	Complicated customs clearance rules	Absence of integrated management systems	Lack of robust strategy in SSS firms	Lack of innovation and R&D activities
•											
•	•	•	•		•		•		•	•	•
•		•		•			•		•	•	•
•			•								
•	•							•		•	•
							•				
•	•		•				•		•		
•		•			•						
	•		•			•		•			
				•			•				
•								•			
•											
9	4	3	4	2	2	1	5	3	3	3	3

(Continued)

Barrier groups and barriers											
B4. Communication				B5. Service and market				B6. Regulatory			B7. Administrative
Poor industry image	Poor marketing activities by SS firms	Weak communication by SSS firms	Insufficient information available to SSS users	Poor port–hinterland connectivity	Lack of SSS integration into door-to-door transport chain	Shortage of RoRo vessels in the spot market	Volatility of transport demand	Construction of road infrastructure for trucking	Inconsistent policies	Imposition of taxes in SSS sector	Complex documentary and administrative procedures
•	•	•	•	•	•			•			•
	•		•	•	•						
							•		•		
•											
	•		•	•					•		
•									•	•	
•				•	•						•
										•	
						•	•		•		
											•
4	3	1	3	4	3	1	2	1	4	2	3

To manage barriers related to the increased use of waterborne transport, Rogerson et al. (2019) have suggested numerous strategies, including educating stakeholders, securing volumes, conducting a proof-of-concept run and identifying business opportunities for stakeholders (e.g. ports, shippers, shipping companies, forwarders and hauliers). Added to that, Paper 1 shows that policy initiatives, both economic (e.g. internalization of external costs) and regulatory (e.g. measures to restrict or discourage road freight), and reduced taxes for the SSS industry can boost the competitiveness of SSS as a mode of transport. Other findings in the paper indicate that including external costs in cost comparisons for SSS versus road haulage can make SSS seem more competitive. Beyond that, the results of Paper 1 also suggest that environmental regulations (e.g. sulphur limits in SECAs) reduce emissions caused by shipping operations, the higher cost of complying with such regulations impairs the competitiveness of SSS versus road haulage. The paper indicates that instead of providing financial grants directly to trucking companies to increase the use of SSS on some routes, EU funding should be spent on promoting innovations in the shipping industry, which can create long-term value for the SSS industry by making it more sustainable.

Apart from policy and regulatory factors, Paper 1 also reveals that certain attributes of service quality, especially shorter transit times, more frequent services and improved reliability, are more important than the higher freight rate paid for cargo transport. The reason for that dynamic is that the indirect, long-term costs of a failure to deliver consignments on time and intact may result in the loss of markets, market share, and customers' confidence. Last, the results of Paper 1 suggest that collaboration and partnerships among SSS operators and other agents in the supply chain are essential to improving the environmental footprint and competitiveness of SSS.

4.2 Slow steaming and the competitiveness of short-sea shipping

RQ2—"How does slow steaming impact the competitiveness of short-sea RoRo shipping?"—is investigated in Paper 2. In response to environmental regulations, shipping companies have tended to use the environmentally sustainable practice of slow steaming. Considering the importance of slow steaming, Paper 2 examines how SSS firms have reacted to the practice as a cost-saving measure in the wake of sulphur regulations in the North and Baltic Seas, as well as how slow steaming has affected competitiveness in those sectors.

Overall findings suggest that by influencing entire supply chains, the use of slow steaming may adversely affect the competitiveness of RoRo or RoPax sectors of the SSS industry, along with their customers. Of course, factors such as competition within the industry and with alternative transport modes, fuel price, and different service quality requirement of customers hinder the potential application of slow steaming in RoRo and RoPax sectors.

Implementing slow steaming in the RoRo and especially the RoPax sectors is further complicated by variety in the types of customers as well as in the characteristics of routes and ships. As interviewees from the case firms clarified, slow steaming across a certain limit in the RoPax sector—a limit that varies depending on the characteristics of routes and vessels—may either prompt a loss in business volumes or require more vessels to maintain the frequency of services. However, the current market situation does not favor additional tonnage in the sector, for it appears that the market has achieved equilibrium. Added to all of that, time-related attributes of service quality, including total transit or lead time, frequency, reliability, convenience of departure and arrival times and variety in types of customers, are considerably more important for the customers of the RoRo and RoPax firms in the case study. Last, slow steaming, which works against customers' convenience, may deteriorate the service quality of RoRo and RoPax services, which may ultimately force the sector into an uncompetitive position in the market.

Further the findings reveal that the 0.1% sulphur regulation has not resulted in slow steaming in the RoRo and RoPax sectors to a large degree. One explanation is that during the implementation period of the regulation, a drop in bunker oil prices caused by lower crude oil prices discouraged slow steaming in the RoRo and RoPax sectors. In turn, increased bunker prices have been passed on to customers in the form of higher bunker surcharges (i.e. increased freight rate due to increased price of fuel) and partly borne by shipowners as well.

4.3 Collaboration and the environmental sustainability and competitiveness of short-sea shipping

RQ3—"How does collaboration between shippers and short-sea RoRo companies impact the environmental and competitive performance of SSS?"—is addressed in Paper 3, which illustrates how collaboration between a shipper and a SSS company has impacted the environmental sustainability and competitiveness of the SSS company.

The paper's findings show that the shipper, Stora Enso, employs an innovative intermodal logistics system for the transport of a significant volume of its products. Instead of relying on third-party logistics providers, Stora Enso has not only designed the mentioned system but also invested in rail cars and Stora Enso cargo units (SECU) to transport its cargo from Swedish mills to the Port of Gothenburg, as well as chartered RoRo vessels to cover the long legs of the journey. SECUs are large, intermodal containers, similar to standard 40-foot containers but bigger, with dimensions of 13.8 × 3.6 × 3.6 m and a cargo capacity of 80 tonnes compared to the 26.5 tonnes of the International Organization for Standardization's containers. Because Stora Enso does not utilise all of the capacity for its own cargo aboard the chartered RoRo vessels, it formed a strategic collaboration with a RoRo shipping company, SOL, in order to sell extra freight capacity to third parties and manage the operations of its chartered vessels. As a result of that collaboration, the utilisation rate on Stora Enso's Gothenburg–Zeebrügge RoRo service route in 2017 reached 95% in both directions, although many northbound SECUs remained empty. Exceptionally rare for a RoRo service, such a high load factor was achieved when SOL sold nearly 100,000 RoRo units, mainly semi-trailers, to third parties or freight forwarders. Apart from the financial benefits of the collaboration for both Stora Enso and SOL, sustainable transport operations have also been promoted; the high utilisation rate of the service, not only in accordance with the implementation of the Ship Energy Efficiency Management Plan, implies lower greenhouse gas emissions per transport unit due to improved voyage planning. That finding indicates that by adopting a unique management approach and sustaining collaboration with SOL, Stora Enso has begun to efficiently transport its own cargo as well as lower its costs by selling excess capacity aboard its RoRo vessels to third parties, which has eventually contributed to the increased integration of RoRo into the corresponding multimodal transport chain.

4.4 Green innovations and the environmental sustainability and competitiveness of short-sea shipping

RQ4—"How do green innovations impact the environmental sustainability and competitiveness of SSS?"—is addressed in Paper 4. As explained in the paper, to reduce their environmental footprints, SSS companies in Europe are currently required to comply with increasingly strict environmental regulations enacted by the IMO, the EU and national regulatory authorities. At the same time, the need to improve environmental performance and economic performance has led Europe's SSS companies to adopt green innovations in the technology and processes that their businesses involve. The findings suggest that environmental regulations exert a positive, significant effect on the adoption of various types of green innovations in technology (e.g. optimised hulls and propellers, improved engine designs, enhanced waste heat recovery systems, hull coating, the implementation of onboard energy-efficiency systems, the use of scrubbers and ballast water treatment systems) as well as processes (e.g. slow steaming, optimal route planning and environmentally friendly waste disposal) among Europe's SSS companies. However, the level of environmental regulatory pressure and the subsequent response to such regulations may vary across SSS sectors.

As for the impact of such green technological innovations on the environmental performance of the SSS companies in the sample, the findings indicate that green innovations and practices positively and significantly influence the environmental performance of firms by allowing them to reduce their water pollution and air emissions (e.g. SOx, NOx and CO_2), as well as improve their compliance with environmental regulations. Beyond that, the results show that by engaging in green innovations, SSS companies can enhance their economic performance, because such innovations boost productivity, reduce energy consumption, lower waste treatment costs and, in turn, increase profitability. At the same time, the impact of three green innovations in processes—slow steaming, optimal route planning and environmentally friendly waste disposal—on the economic and environmental performance of SSS was positive but not significant.

5 Discussion and Conclusion

This chapter discusses the findings in relation to the purpose of the thesis and describes their contributions to the literature and their practical implications. The chapter ends by suggesting possible directions for future research.

Taken together, the results answering each research question in the previous section contribute to fulfilling the purpose of this thesis by identifying and investigating factors that can influence the environmental sustainability and competitiveness of the European SSS industry. In the past several years, Europe's SSS industry has been exposed to a plethora of environmental regulations, and the need for additional resources in order to comply with those regulations has adversely affected the competitiveness of SSS against unimodal road haulage. Furthermore, despite extensive support from the EC in promoting the use of SSS, the market share of SSS remains low.

To reduce their fuel consumption, costs and emissions, the operators of ships have a variety of technical and operational measures available to them that can positively contribute to the environmental sustainability and competitiveness of SSS. Among the technical measures are efficient propellers and rudders, enhanced waste heat recovery systems and improved hull designs (MAN, 2019; Yang, 2018), whereas the operational measures include slow steaming, improved routing and scheduling, enhanced fleet management and the increased utilisation of ship capacity (Styhre, 2010; Woxenius, 2012; Zis & Psaraftis, 2018). For any technical or operational measure to be appealing to the SSS industry, however, it first needs to be commercially attractive. For that reason, Cullinane and Cullinane (2013) have argued that the entirely optional use of technical and operational measures is not likely to engender the sort of environmentally friendly improvements needed to clean up the industry, meaning that other types of mitigatory measures (e.g. regulations) may be the last remaining recourse for reducing the externalities of SSS. To that, Paper 3 has added that encouraging the use of intermodal transport over unimodal road haulage and campaigns for behavioural change targeting all stakeholders in a given transport chain should be part of future policies, precisely because environmental sustainability depends upon not only technological innovations but behavioural changes as well. In effect, such actions may confer environmental as well as economic benefits for the SSS industry.

Due to the close relationship between a ship's fuel consumption and its total volume of emissions, the most appropriate approach to reducing emissions is to first reduce fuel consumption and thereby lower costs. Such thinking, termed the "green-gold" paradigm by McKinnon (2010), maintains that implementing measures such as slow steaming, collaboration with cargo owners and innovations may not only reduce the fuel consumption of their ships and their per-unit output costs but also improve their environmental performance. By extension, shipping companies with improved environmental performance can achieve other marketing gains, because today's manufacturing companies seek to enhance their market share by publicising their putatively "environmentally friendly" supply chains, which is another aspect of the green-gold paradigm (Cullinane and Cullinane, 2013).

All of those findings have certain implications. First, in the context of sulphur regulations in the North and Baltic Seas, Zis and Psaraftis (2018) predicted that shipping companies, particularly in the RoRo and RoPax sectors, will opt to implement slow steaming in a bid to compensate for the additional cost imposed by the regulations. The findings of this thesis, however, reveal that due to intense competition and a drop in bunker prices, SSS companies have not pursued slow steaming. On the contrary, the additional costs involved in meeting the sulphur regulations are partly passed on to the customers via increased bunker charges and partly borne by the shipowners as well. Thus, the thesis's findings are consistent with those of Adland et al. (2017), who in their empirical study using AIS data found no evidence of slow steaming in the wake of the North Sea sulphur regulations. They also discovered that vessel speed was not generally determined by fuel prices or freight rates but instead depended upon factors such as route characteristics, type of vessel, weather, market segment, market conditions and the nature of the commercial contract between the shipper and ship operator.

For RoRo and RoPax shipping companies that directly compete with road and rail transport on some routes, the use of slow steaming could even negatively affect the quality of transport services. Time-related attributes of service quality, including total transit and lead times, frequency, reliability and the convenience of departure and arrival times, were all considerably more important than the service price to the customers of the RoRo and RoPax firms in the case study. Moreover, such findings support the results of Meixell and Norbis (2008), Bergantino and Bolis (2008) and Pantouvakis (2007), whose studies demonstrated that service quality in terms of transport times, frequency, reliability and the convenience of scheduling were even more important than ticket prices or freight rates for RoPax and RoRo transport customers. Thus, implementing slow steaming on bigger vessels with more cargo onboard, as proposed by the IMO (2009), may not be practical for the RoRo and RoPax sectors of the SSS industry, for the findings of this thesis illustrate that vessel frequency is critical to customers in those sectors. To maintain a high frequency of shipping service, SSS firms would need to employ more vessels on the same routes, which is impossible due to demand and market conditions.

Second, concerning how the collaboration of a shipper and an SSS company has affected the competitiveness of SSS, the thesis's findings show that Stora Enso and SOL's collaboration has increased the use of capacity aboard their ships and, in turn, reduced the emissions and cost per unit of cargo transported. Such results corroborate what Paixao and Marlow (2005) along with Fugate et al. (2009) have emphasised: that collaboration, innovative approaches to management and long-term, mutually beneficial relationships among shippers and carriers are among the key drivers to improving the sustainability of transport companies. At the same time, the findings contrast the results of Saldanha et al.'s (2016) survey—that shippers cannot play any key role in integrating different traffic modes "as a spin-off from serving their own needs"—for the thesis's research instead revealed that large shippers are central within logistics chains. After all, by controlling large volumes of cargo, they can assist in increasing the integration of multiple modes of transport, as illustrated in the findings of the thesis. In that same context, research by Ng (2009), Paixao and Marlow (2007) has also corroborated that large volumes of cargo not only ensure a higher frequency of transport services for shippers but also increase the utilisation of capacity in the mode of transport, especially in the RoRo sector. Those authors thus concluded that both factors are fundamental to running an economically feasible RoRo service and facilitating the integration of such services into intermodal transport chains. The findings moreover show that port costs represent 60% of all shipment costs for Stora Enso, which reduces the competitiveness of SSS against road haulage. That result validates the findings of Ng et al. (2013), who observed that high cargo-handling costs in ports rank among the top barriers to furthering the integration of RoRo services into intermodal transport chains.

Last, the findings indicate that green innovations in Europe's SSS industry are driven by institutional factors such as regulations imposed by the IMO, the EU and individual countries. Such results are consistent with what Chan et al. (2016) as well as Doran and Ryan (2016) found: that coercive institutional pressure in the form of environmental regulations is the chief driver of green innovations in technology and processes. In contrast to the technological innovations, the impact of the processual innovations—the use of slow steaming, optimal route planning and environmentally friendly waste practices—on the environmental and economic performance of Europe's SSS firms was limited. As corroborated in Paper 2 of this thesis and by Chen et al. (2018), plausible explanations for that finding include substantially reduced ship bunker prices since 2014 and intense competition with alternative modes of freight transport (e.g. rail and road), which might have discouraged SSS companies, particularly ones operating RoRo and RoPax vessels, from adopting slow steaming and route optimisation to the same degree as deep-sea shipping firms.

5.1 Contributions of the research

This thesis contributes insights into some factors affecting the environmental sustainability and competitiveness of European SSS in the context of environmental regulations and EU policy promoting SSS. Realised by identifying those factors and empirically examining their impact, such insights were articulated in detailed descriptions of how slow steaming, collaboration and green innovations influence the environmental sustainability and competitiveness of SSS. Last, drivers of and barriers to the increased use of SSS and, more broadly, the modal shift to SSS have been identified. In sum, each part contributes to an overall understanding of how different factors strengthen or hinder the environmental and competitive performance of Europe's SSS industry.

For SSS companies, adopting measures such as green innovations and collaborating with cargo owners can improve efficiency and, as a result, reduce energy consumption and both water and air pollution per tonne of cargo transported. Thus, such measures may also help to preserve the resources of global ecosystems—water, air and energy—for future generations and eventually contribute to the environmental dimension of sustainability. Furthermore, the measures may assist SSS companies with reducing their operating costs as well as provide ample services to cargo owners by generating profits. In that way, the thesis also contributes to the economic dimension of sustainability. Last, because nearly 19% of all deaths related to traffic accidents in Sweden in 2018 were caused by trucks (Trafikanalys, 2018), a modal shift from road transport to maritime transport could decrease the number of accidents, relieve congestion and lower CO2 emissions for each tonne-km transported (Lee et al., 2010). Less pollution, the increased availability of cost-effective transport services for cargo owners, fewer accidents and less road congestion due to a modal shift to SSS would all indirectly contribute to the social dimension of sustainability.

This thesis also contributes to theory in multiple ways. First, theoretical contributions have been made by systematically reviewing relevant literature published during the past three decades and providing avenues for future research on the topic of modal shift, especially focusing on road haulage and SSS. Beyond that, key characteristics of the literature on modal shift, including journal of publication, year of publication, methods used and geographical focus, have been identified. To extend those findings, the thesis has classified literature on modal shift according to six topics: factors influencing the competitiveness of SSS, the policy-oriented perspective, environmental legislation, the performance of SSS, port characteristics and the multi-agent perspective. Last, various types of measures and other research needs related to each of those topics that could influence the environmental and economic performance of SSS have been determined.

Second, the thesis expands the literature on slow steaming in the RoRo and RoPax sectors of the SSS industry. By incorporating the viewpoint of ship operators, the thesis provides new insights into the reactions of RoRo and RoPax operators to slow steaming in the wake of sulphur regulations. The impact of slow steaming on the competitiveness of those sectors has also been investigated in depth.

Third, the competitiveness of SSS has primarily been addressed from the ship operator's perspective, while the role of collaboration between large shippers and SSS companies has garnered little attention. This thesis contributes to the literature by investigating the impact of collaboration between Stora Enso, a major forest company in Sweden and Finland, and the shipping company SOL. The findings highlight that collaboration is an important measure for increasing the competitiveness and environmental performance of the SSS industry.

Last, past research has suggested that for SSS companies, complying with environmental regulations requires additional investments and energy use that increase operating costs, prompt modal backshift to road and, in turn, detrimentally affect the companies' economic and environmental performance. However, the role of regulations in driving green innovations in technology and processes and their impact on the performance of SSS firms have been largely overlooked by researchers. This thesis addresses that gap in the literature and contributes to current knowledge on the topic by identifying the impact of regulations on the adoption of green innovations among European SSS firms, as well as the impact of those innovations on the environmental and economic performance of the firms.

5.2 Practical implications of the findings

This thesis offers insights for managers in the SSS industry as well as for policymakers and regulators who want to increase the competitiveness of SSS and improve its environmental performance. The answer to the research questions, all directed towards factors to enhance the environmental sustainability and competitiveness of SSS, may help SSS companies to understand how different measures, including slow steaming, collaboration with shippers and green innovations, impact their environmental and competitive performance. Moreover, different measures can be applied concurrently, because they all function independently of each other.

First, from a managerial perspective, slow steaming on some routes may negatively affect the service quality of RoRo and RoPax services in terms of increased transit time. However, as the findings of this thesis indicate, managers of RoRo and RoPax companies should focus on increasing port efficiency and saving time at port to support the application of slow steaming without compromising total lead times. The firms of the case study, RoRo C and D and RoPax K, presented in Paper 2 have substantially benefitted from the strategy of slow steaming by using the time saved in port operations. To implement slow steaming, managers need to compromise with scheduling agents, however, considering the various types of customer segments. After all, there are various categories of passengers who have different needs regarding the ship speed.

Second, the thesis's findings suggest that ship operators and large shippers should seek opportunities for strategic collaboration and shared planning with other agents within transport chains. The intermodal integration of different modes of freight transport and strategic collaboration among cargo owners, ship operators and forwarding agents might enhance system efficiency, as well as reduce lead times, emissions and costs per unit of output, and thereby generate additional revenues for all stakeholders involved. Large shippers, especially in the forest industry, may reconsider their logistics and management strategies and may benefit by commencing their own unique transport networks following the lead of Stora Enso, as detailed in this thesis.

Third, the findings highlight the importance of green innovations that precipitate environmental and economic benefits in the SSS industry. At the same time, the type of green innovations being pursued is pivotal. Results from the research show that green innovations in technology, including ones related to energy efficiency, bear a strong impact on firms' economic and environmental performance. Accordingly, managers at SSS firms can enhance the environmental and economic performance of their companies by dedicating resources to developing green, energy-efficient technological solutions. At the same time, they should not wait for regulations to get motivation for developing green innovations but take a proactive approach to pursuing such innovations, which stand to benefit the performance of their companies. SSS companies should also regard environmental regulations not as threats but as opportunities. After all, because regulations direct the attention of firms to likely resource inefficiencies as well as potential technological and processual improvements in response, regulations can raise corporate awareness and create pressure to pursue innovation, which may concurrently engender environmental and economic benefits for SSS firms.

From a policy perspective, the white paper presented by EC in 2011 set a numerical target to shift cargo from road to SSS transport as part of a new objective for the Combined Transport Directive. The target was to shift 30% of road freight travelling more than 300 km to multimodal solutions (i.e. including rail and SSS transport) by 2030 and more than 50% by 2050, compared with business as usual developments. In that context, the thesis's findings, particularly those presented in Paper 1, provide important insights into drivers and barriers of modal shift to SSS, all of which can be used by policymakers as guidelines to strengthen SSS and facilitate the shift. Moreover, policymakers should consider the alternative view on the modal shift taken by Hassellöv et al. (2019), who have indicated that if the modal shift from road to sea increases the number of ships or the distance travelled by ships, then it will only place greater pressure on marine environments by increasing water and air pollution. The authors thus highlighted a policy conflict between transport objectives and several environmental objectives. They also suggested that the necessity of realising a modal shift from road to sea depends upon minimising the pressure on the marine environment, which may be possible by, for instance, avoiding shipping in environmentally sensitive marine areas, imposing stricter requirements on the performance of ships and taking measures to increase load factor and optimise vessel speed.

Currently, policymakers at the IMO, with backing from some shipping companies and non-governmental campaign groups such as Seas at Risk and Transport & Environment, are considering to impose mandatory speed limits for ships as a way to reduce harmful emissions from shipping. Regulating speeds may generate some positive outcomes if implemented in sectors such as bulk and tanker shipping and even in deep-sea shipping. However, as findings of this thesis reveal, reducing speed limits may jeopardise the competitive position of the RoRo and RoPax sectors against road and rail transport in Europe. Therefore, before devising and implementing new regulations, policymakers such as the IMO and the EC should weigh the environmental benefits possible from regulation against possible overall effects for the entire transport system.

In addition to using regulations (i.e. "sticks"), policymakers should consider providing incentives (i.e. "carrots") to SSS companies as a means to encourage desired environmental outcomes and promote innovations and collaboration. Furthermore, policymakers should draft policies in consideration of shippers' needs and encourage innovations in the sector, for such innovations may in turn reduce unnecessary costs involved (e.g. port costs) and improve the environmental sustainability of the SSS industry.

Some of the findings—for instance, about the role of collaboration and innovation in improving the environmental and competitiveness of an SSS firm—may also be relevant for policymakers and practitioners serving other industries and modes of transport. Practitioners can increase the efficiency of their processes and create more value for their customers by establishing partnerships with other stakeholders and supply chain agents as well as by investing more in innovative solutions to solve business problems. For their part, local, regional and global policymakers should allocate more resources to stimulate environmental innovations that can help to preserve natural resources and contribute to making the world more sustainable. However, generalisations of all of those results should be made with caution.

5.3 Limitations and directions for future research

There is a great potential to use this research in other parts of the world for comparison and cross-geographical and policy conclusions and knowledge. Beyond that, several areas of research identified in this thesis need more attention from scholars. In the future, researchers should use rich, real-world, numerical data such as automatic identification system (AIS) data and operational research techniques to identify the relative importance of individual drivers and barriers for a modal shift from road haulage to SSS. Because their collected data could inform policymaking for SSS, researchers should also extend their policy-related focus beyond the EU, which has long encompassed the major geopolitical scope of research on the modal shift.

Further, to moderate the adverse impact of environmental legislation on SSS, strategic solutions need to be identified as well. In evaluating the performance of SSS versus road haulage in different trade corridors, three performance-related dimensions—the economic dimension (e.g. external costs), the environmental dimension and the dimension of service quality—should be considered.

Moreover, although coercive institutional pressure in the form of environmental regulations was treated as a predictor of green innovations in the European SSS companies sampled in Paper 4 of this thesis, other institutional pressures, including coercive pressure by the customers of SSS companies, normative pressure by non-governmental institutes and mimetic pressure by competitors, can also influence the adoption of green innovations, and researchers should thus consider that alternative in their studies on the topic.

In addition, green process innovations were measured in terms of only three variables: slow steaming, optimal route planning and environmentally friendly waste disposal. However, several other types of processual innovations could exert different impacts on the performance of SSS. Future researchers should thus also consider other variables and analyse their impact on the performance of SSS.

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Paper I

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Modal shift from road haulage to short sea shipping: a systematic literature review and research directions

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Modal shift from road haulage to short sea shipping: a systematic literature review and research directions

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ABSTRACT

Modal shift from road haulage to short sea shipping (SSS) has been advocated by authorities and researchers for more than two decades. This paper provides a review of literature on modal shift and pinpoints paths for future research on topics in six categories: (1) factors influencing SSS competitiveness, (2) the policy-oriented perspective, (3) environmental legislation, (4) SSS performance, (5) port characteristics, and (6) the multi-agent perspective. In particular, we propose first, in evaluating the performance of SSS versus road haulage in different trade corridors, three performance-related dimensions – the economic dimension (e.g. external costs), the environmental dimension, and the dimension of service quality – should be considered. Second, researchers should use rich, real-world, numerical data and operational research techniques to identify the relative importance of individual drivers and barriers for a modal shift from road haulage to SSS. Third proposed direction is related to assessing which groups of actors certain policies should target. In doing so, researchers should extend their policy-related focus beyond the European Union, which has long encompassed the major geopolitical scope of research on the modal shift. Fourth, to moderate the adverse impact of environmental legislation on SSS, strategic solutions need to be identified. Fifth, we also suggest that the influence of contingencies, particularly port strikes and cyberattacks, on SSS operations and approaches for managing them should be investigated. Sixth, the economic and financial advantages of coordination and alliance for each transport chain agent need to be evaluated.

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1. Introduction

During the past few decades, along with unprecedented growth in global trade, the demand for reliable, flexible, door-to-door, and cost-efficient freight transport has accelerated across the world (Stank & Goldsby, 2000). In 2016, total goods transport

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activities in the EU-28, for instance, reached 3661 billion tonne-kilometres, and road haulage (i.e. trucking) accounted for nearly half of the total freight transport market share (EC, 2018).

However, road haulage is often characterised as causing environmental and societal problems in terms of negative externalities, including highway congestion and longer wait times, air pollution, climate change, traffic accidents, noise, infrastructure damage, and high energy consumption (Chang, Lee, Kim, & Shin, 2010). To overcome those road-related negative externalities, an instrumental measure suggested by researchers and the European Commission is a modal shift to less polluting modes, such as waterborne transport, for example short sea shipping (SSS) (Woodburn & Whiteing, 2014), especially in situations where waterborne transport is cost-efficient (McKinnon, 2008). Despite policies to promote the competitiveness or use of SSS in the EU 28, the share of road haulage in terms of total cargo volumes transported has increased from 45.3% in 1995–49.3% in 2016, whereas the share of SSS has slightly declined from 32.7% to 32.3% in those for the respective years (EC, 2018).

Since becoming a major item on the political agenda in the 1990s, the topic of modal shift has attracted considerable attention from researchers, who have mostly focused on shifting from unimodal road haulage to intermodal rail transport, as reported in the review by Bontekoning, Macharis, and Trip (2004). Other reviews have addressed topics such as modal shift from car to active transport (Scheepers et al., 2014) and green ports in maritime logistics (Davarzani, Fahimnia, Bell, & Sarkis, 2016). On top of that, Meixell and Norbis (2008) and Flodén, Bärthel, and Sorkina (2017) have reviewed scientific and grey literature on choice of freight transport mode from different perspectives. Compared to those earlier reviews, however, our study adds value by reviewing the relevant literature and providing avenues for future research on modal shifts focusing on road haulage and SSS.

In the remainder of this paper, Section 2 presents the methods used to identify literature for our review. The results, including the key features of articles reviewed and research categories, appear in Section 3. We conclude the paper by providing a summary of findings and directions for future research in Section 4.

2. Method

Literature reviews provide a comprehensive consolidation and evaluation of literature in a specific field of knowledge, as well as identify gaps in the field's body of knowledge that should be filled to further develop the field (Tranfield, Denyer, & Smart, 2003; Van Wee & Banister, 2016). In our systematic review, we followed the protocols referred to by Tranfield et al. (2003), Petticrew and Roberts (2006), Bossle, Dutra de Barcellos, Vieira, and Sauvée (2016), and Van Wee and Banister (2016). In particular, we followed Tranfield et al. (2003) rigid, scientific process proposed for literature searches and assessments of information retrieved. The research protocol followed appears in Figure 1.

2.1. The planning phase: refining the inclusion and exclusion criteria

Identifying relevant keywords for the literature search was a fundamental step in the planning phase of our study. In line with Davarzani et al. (2016), an iterative process was

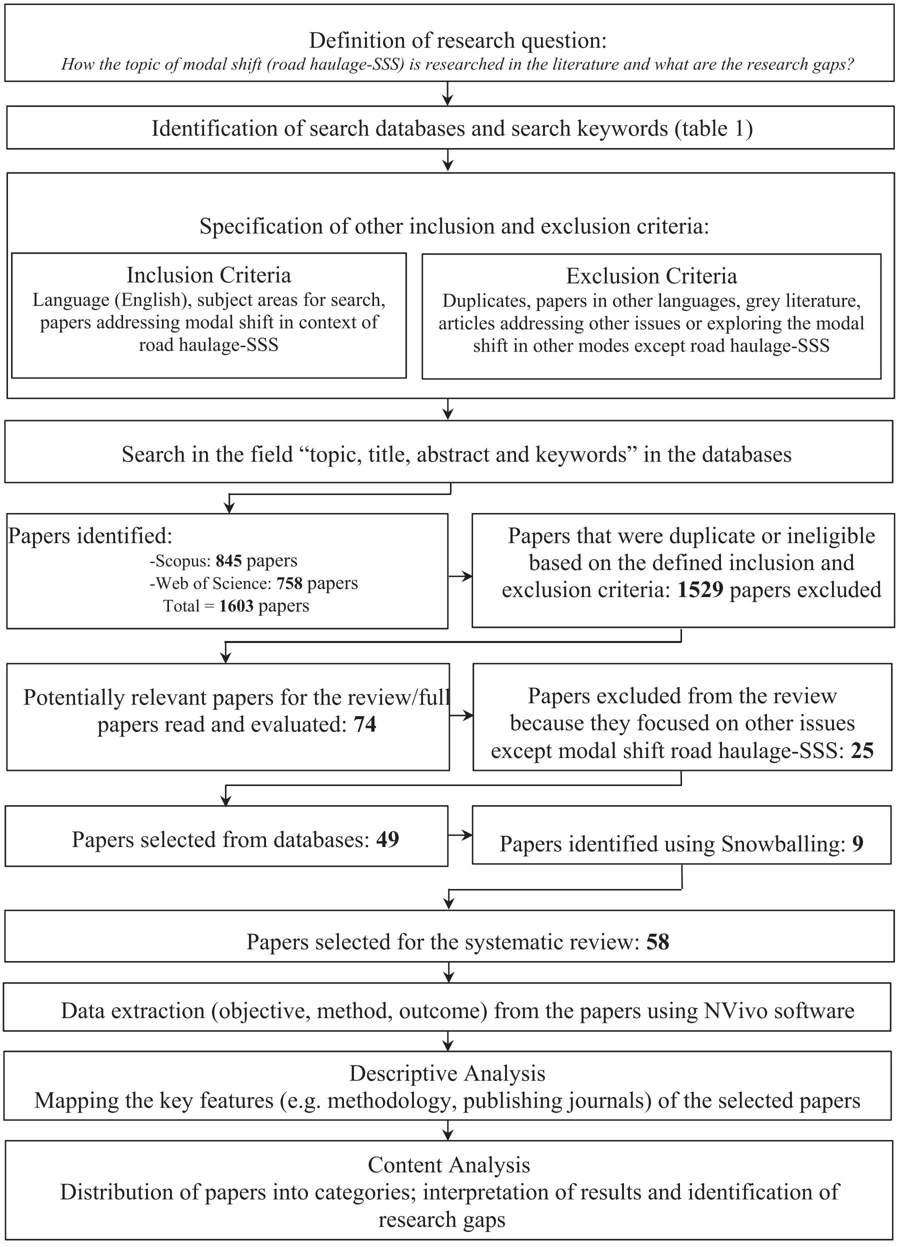

Figure 1. Steps followed in the systematic literature review. Source: Adapted from Tranfield et al. (2003), Petticrew and Roberts (2006), Bossle et al. (2016), and Van Wee and Banister (2016).

followed to design an appropriate structure for using keywords in the literature search. The process comprised multiple steps: determining a preliminary set of keywords and a search structure, examining articles and journals found in order to confirm appropriate coverage, updating keywords to exclude irrelevant articles, research, and subject fields, and updating the keyword structure accordingly. The four-level structure of the literature search using keywords (Davarzani et al., 2016) and Boolean operators appears in Table 1. The use of AND between two keywords requires both to be in each article returned. The use of OR means that either or both keywords will be in the returned articles. The use of AND NOT means that keywords before AND NOT are searched in the database, but articles containing the keywords after AND NOT are removed from the results. The use of AND NOT reduces number of articles returned and is done to get an amount of articles feasible to review, but may risk eliminate a few relevant articles. Therefore, to reduce the risk of missing any important article for this review, a forward and backward snowballing approach referred by Van Wee and Banister (2016) is deployed. Snowballing took the departure from five literature review papers, see, (Brooks & Frost, 2004; Medda & Trujillo, 2010; Paixao & Marlow, 2002; Paixao & Marlow, 2007; Suárez-Alemán, 2016).

Two databases – Web of Science and Scopus – were accessed to search for articles, both of which are endorsed as good sources of peer-reviewed articles in the social sciences, especially literature on business, logistics, and supply chains (Chicksand, Watson, Walker, Radnor, & Johnston, 2012; Dahlander & Gann, 2010).

2.2. The search phase: conducting and reporting the review

A comprehensive search for peer-reviewed articles was conducted in May 2017. To achieve broad coverage of relevant articles and reduce the risk of missing important articles, the search was mostly performed in the "topic" and "title, abstract, keywords" fields of both databases.

The search resulted in 845 articles from Scopus and 758 articles from Web of Science. To assess the relevance of articles based on the inclusion and exclusion criteria and to remove any duplicates, the titles and abstracts of all were read. As a result, 74 articles were retained and 1529 others were excluded, because they either did not meet the inclusion criteria or were duplicates. After the 74 articles retained were thoroughly read, an additional 25 articles were excluded, because they examined modal shifts in the context of other transport modes and did not focus on comparing SSS and road haulage. Ultimately, 49 articles remained from database search. In the existing literature several key words are interchangeably used to address the modal shift topic, therefore, it might not be feasible to

Table 1. Keywords used in the literature search.

Keywords
Four-level search framework
Short sea OR Shortsea OR coastal OR cargo OR freight OR truck OR road OR RoRo OR RoPax OR container OR sea OR intermodal OR multimodal OR combined
AND
Shipping OR transport OR service OR transportation OR movement OR transshipment OR forwarding, OR haulage OR delivery
AND
Modal shift OR Mode shift OR shift in transport mode OR modal (mode) switch OR modal diversion OR modal substitution OR modal split OR alternative mode OR mode competition OR competing mode OR mode competitiveness OR competitor
AND NOT
Inland shipping OR inland waterways OR barge shipping OR river shipping OR lake shipping OR hinterland OR urban freight OR modal shift from road to rail freight OR modal shift from air to land modes OR modal shift from private vehicles to walking, cycling, and public transport

argue that all the relevant papers have been found using databases. Thus, to address this problem the snowballing approach proposed by Van Wee and Banister (2016) was used and an additional nine articles were found by checking the reference section of the published scientific papers. Finally, 58 papers are included in the final analysis.

We used NVivo qualitative data analysis software to extract information from each article, including the name(s) of the author(s), year of publication, journal of publication, geographical area studied, chief contributions, and methodology employed.

3. Results

The data collected via the systematic review were analysed in depth in order to map the selected literature in descriptive analysis, categorise the articles, gain insights into the concepts on which they focus, and highlight gaps in research on the various topics. In writing this section, we have followed earlier reviews on transportation by Centobelli, Cerchione, and Esposito (2017) and Bontekoning et al. (2004).

3.1. Descriptive analysis

This section reviews the four basic features of the articles, all of which address modal shifts with a focus on the shift from road haulage to SSS:

(1) Distribution by journal of publication;
(2) Distribution by year of publication;
(3) Distribution by geographical area in focus; and
(4) Distribution by methodology.

3.1.1. Distribution by journal of publication

As shown in Table 2, 58 articles addressing the modal shift from road haulage to SSS have appeared in 21 scientific journals. Twelve journals on transportation published 27 of the articles (46%). Also, among the most prolific in work on the topic, journals addressing maritime transport published 27 of the articles (46%), of which *Maritime Policy and Management* contributed the most (i.e. 20 papers). The remaining four papers (7%) appeared in four different journals.

3.1.2. Distribution by year of publication

Research on the modal shift from road haulage to SSS has increased in recent years (Figure 2). Whereas 59% of the articles (i.e. 34 articles) were published in the 7-year period from 2011 to 2017, only 41% (i.e. 24 articles) were published during the 15-year period from 1996 to 2010.

3.1.3. Distribution by geographical area of focus

Research on the modal shift from road haulage to SSS has primarily focused on Europe (45 papers), as detailed in Table 3. Only a few papers have addressed the potential for modal shift in the context of other continents, including North America (i.e. six papers), Asia (i.e. two papers), Australia (i.e. four papers), and South America (i.e. one paper). The reason for

Table 2. Journals of publication and number of articles contributed.

Journal	Number of articles
Transportation	
Transport Reviews	6
Transportation Research Record	3
International Journal of Shipping and Transport Logistics	3
Transportation Research Part D: Transport and Environment	3
Transportation Research Part E: Logistics and Transportation Review	2
Transportation Research Part A: Policy and Practice	2
Transport Policy	2
Journal of Transport Geography	2
European Transport Research Review	1
European Journal of Transport and Infrastructure Research	1
International Journal of Transport Economics	1
Transportation Letters	1
Maritime transport	
Maritime Policy and Management	20
Maritime Economics and Logistics	4
Journal of Maritime Research	1
Marine Policy	1
WMU Journal of Maritime Affairs	1
Miscellaneous	
Sustainability	1
British Food Journal	1
Carbon Management	1
Transport	1
Total	**58**

the predominant focus on Europe may be that several EU countries have less intra-European trade, fewer regulatory barriers, and better connections via waterways than countries on other continents. Moreover, the European Union has enacted various policies to promote the modal shift in order to mitigate the rise of road-related negative externalities.

The affiliated institutions of contributing authors were also extracted and their host cities ascertained. Using such data in Tableau Desktop software, the geographical locations of institutions that have contributed to research on modal shift were mapped, as shown in Figure 3.

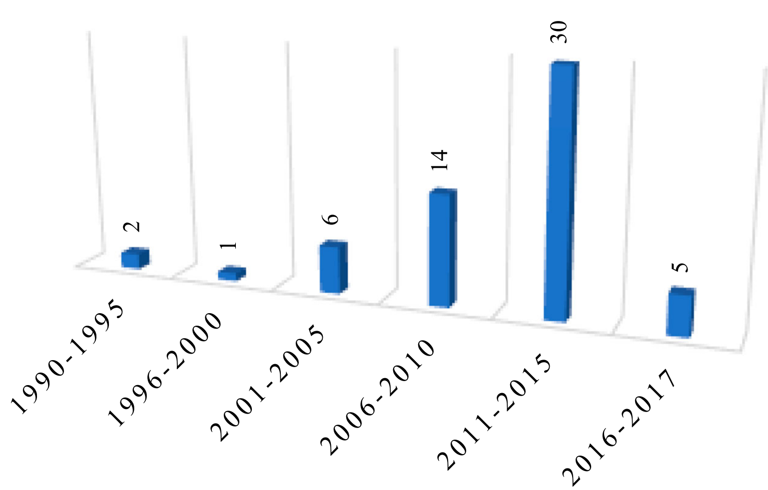

Figure 2. Distribution of articles reviewed by year of publication, 1990–2017.

Table 3. Authors, methods, and regions or countries of focus.

Author(s) and year of publication	Method	Region or country of focus*
Literature review		
Paixao and Marlow (2002)	Literature research	Europe
Brooks and Frost (2004)	Literature research	Canada
Sanchez and Wilmsmeier (2005)	Literature research	Central America
Paixao and Marlow (2007)	Literature research	Europe
Baird (2007)	Literature research	Europe
Medda and Trujillo (2010)	Literature research	Europe
Baindur and Viegas (2011)	Literature research	Europe
Douet and Cappuccilli (2011)	Literature research	Europe
Aperte and Baird (2013)	Literature research	Europe
Suárez-Alemán (2016)	Literature research	Europe
Mathematical models		
Ng (2009)	Integer programming	Europe
Chang et al. (2010)	Linear programming model	South Korea
Tsamboulas, Moraiti, and Vlahogianni (2010)	Probabilistic model	Europe
Holmgren, Nikopoulou, Ramstedt, and Woxenius (2014)	TAPAS simulation model	Europe
Suárez-Alemán and Hernandez (2014)	Non-linear programming	Europe
Juste and Ghiara (2015)	Gravity simulation model	Europe
Rodrigues et al. (2015)	Simulation model	Europe
Survey		
Paixao and Marlow (2005)	Survey	Europe
Paixao and Marlow (2009)	Survey	Europe
Feo, Espino, and García (2011)	Survey	Europe
Morales-Fusco, Saurí, and De Melo (2013)	Survey	Europe
Case study		
Hjelle (2010)	Case Study	Europe
Hjelle (2011)	Case Study	Europe
Corbett et al. (2012)	Case study	USA
Hjelle (2014)	Case study	Europe
Bergqvist, Turesson, and Weddmark (2015)	Case study	Europe
Galati et al. (2016)	Case Study	Europe
Mixed methods		
D'Este and Meyrick (1992)	Interviews and stated preference survey	Australia
D'Este (1992)	Literature research and stated preference survey	Australia
Becker, Burgess, and Henstra (2004)	Case study, literature research and interviews	Europe
Bergantino and Bolis (2008)	Interviews and adaptive stated preference technique	Europe
Brooks and Trifts (2008)	Survey and discrete choice methods	Canada
Perakis and Denisis (2008)	Literature research and SWOT analysis	USA
Garcia-Menendez and Feo-Valero (2009)	Interviews and disaggregate behavioural model	Europe
Lee, Hu, and Chen (2010)	External cost models and Interviews	Taiwan
Bendall and Brooks (2011)	Literature research and interviews	Australia, Canada, USA
Notteboom (2011)	Survey and comparative price analysis	Europe
Puckett, Hensher, Brooks, and Trifts (2011)	Survey and generalised mixed logit model	Canada, USA
Baindur and Viegas (2012)	Case study, interviews and simulation model	Europe
Brooks, Puckett, Hensher, and Sammons (2012)	Survey and stated choice experiment	Australia
Nealer, Matthews, and Hendrickson (2012)	Input–output analysis and life-cycle assessment	USA
Perez-Mesaa, Galdeano-Gomez, and Salinas-Andujar (2012)	Survey and AHP technique	Europe
Sambracos and Maniati (2012)	Case study and generalised cost methods	Europe
Woxenius (2012)	Case study, literature research and interviews	Europe
López-Navarro (2013)	Survey and partial least squares (PLS) analysis	Europe

(*Continued*)

Table 3. Continued.

Author(s) and year of publication	Method	Region or country of focus*
Panagakos, Stamatopoulou, and Psaraftis (2014)	Case study and modal split model	Europe
Tsamboulas, Chiappetta, Moraiti, and Karousos (2015a)	Case study and cost benefit analysis (CBA)	Europe
Suárez-Alemán, Campos, and Jiménez (2015a)	Case study and generalised cost method	Europe
Tsamboulas, Lekka, and Rentziou (2015b)	Case study, four-step model and CBA	Europe
Zis and Psaraftis (2017)	Case study, modal split model	Europe
Other methods		
Baird (1999)	Interviews	Europe, Japan
Saldanha and Gray (2002)	Delphi-type survey	Europe
Tsamboulas, Vrenken, and Lekka (2007)	Macro-scan approach	Europe
Morales-Fusco, Saurí, and Lago (2012)	Cost model	Europe
Martell, Martínez, and Martínez de Oses (2013)	DETCCM algorithm	Europe
López-Navarro (2014)	Marco Polo calculator's coefficients	Europe
Kotowska (2016)	External cost model	Europe
Suárez-Alemán, Trujillo, and Medda (2015b)	Theoretical model	Europe

*Country or region to which the research applies.

The size of the red circles in Figure 3 visualises the relative contribution of each institution. The figure also summarises the number of first-author contributions from each country. Over all, research on the modal shift from road haulage to SSS has been conducted mostly in Europe (i.e. 45 papers), followed by North America (i.e. six papers), whereas work from Africa, Oceania, and South America has rarely appeared.

3.1.4. Distribution by research method used

The articles showcase a variety of research methods used (Table 3, column 2). The authors of 10 articles conducted literature reviews to summarise policies and problems related to the modal shift, whereas the authors of 11 other articles used surveys and mathematical

Figure 3. Distribution of the geographical location of the affiliated institutions of the authors.

Number of contributions by country: Spain including Canary Islands (13); Greece (6); the United Kingdom (5); Australia and the United States (4); Canada, Norway, Portugal, and Sweden (3 each) France, India, and Italy (2 each); and Belgium, Chile, China, Denmark, South Korea, the Netherlands, Poland, and Taiwan (1 each).

models to analyse competition between road haulage and SSS in particular trade corridors. The authors of six articles employed case studies to qualitatively explore the modal shift, and those of 23 others used mixed methods by combining case studies or surveys with other quantitative and qualitative methods to ensure a methodologically balanced approach. Other methods, including interviews and Delphi surveys, were deployed by authors in eight articles.

3.2. Content analysis

In the literature reviewed, six research categories based on topics and problems covered were identified: (C1) factors influencing SSS competitiveness, (C2) the policy-oriented perspective, (C3) environmental legislation, (C4) SSS performance, (C5) port characteristics, and (C6) the multi-agent perspective. Some of the articles were classified into two to three categories due to their broad scopes.

3.2.1. Factors influencing SSS competitiveness (C1)

Factors influencing the competitiveness of SSS versus road haulage were identified and divided into two sub-categories:

(1) Drivers: Enablers or determinants (e.g. strengths or advantages of SSS compared to unimodal trucking and other conditions) that stimulate the use of SSS. Nineteen drivers identified were classified into six groups (D1–6), as shown in Table 4.
(2) Barriers: Impediments or factors (e.g. issues, limitations, or weaknesses of SSS) that hinder the use of SSS. Twenty-four barriers, classified into seven groups (B1–7), are listed in Table 5.

Research gaps. Because most articles have provided rather descriptive analyses, literature on the modal shift from road haulage to SSS has rarely offered empirical evidence for the majority of the reported drivers and barriers. For example, the reduced hours of trucking services and the imposition of increased tolls and eco-taxes on trucking have been mentioned as important regulatory drivers of the modal shift to SSS. However, the literature has not provided any evidence for determining in which corridors those drivers could be useful or evidence of the degree of modal shift generated by the drivers. Therefore, we believe that more empirical research using real-world data regarding the impact of drivers and barriers on the modal shift, derived from market reports, surveys, interviews of stakeholders involved, and other sources, is needed. Conducting large surveys amongst suppliers of SSS, as well as of current and potential SSS customers, to verify and weigh those barriers and enablers would be a good start for future research. Multi-criteria analysis could also be useful to interpret the results of such surveys in greater detail.

3.2.2. The policy-oriented perspective (C2)

Various types of policy initiatives, both economic and regulatory as well as both implemented and theoretical, aimed at encouraging the modal shift to SSS from road haulage were addressed in nine articles.

Table 4. Articles highlighting drivers of the competitiveness of short sea shipping (SSS).

	Driver groups and drivers									
	D1. Financial			D2. Capacity					D3. Operational	
Author(s) and year of publication	Lower required investment in infrastructure	Cost-effectiveness	Economies of scale	Underused shipping capacity	Availability of sufficiently long sea lanes	Capacity to carry large industrial unit loads	SSS as a new alternative	Easy to expand transportation network capacity	High energy efficiency	Flexible operating hours
Baird (1999)	•									
Paixao and Marlow (2002)	•	•	•	•	•	•			•	•
Brooks and Frost (2004)				•						
Sanchez and Wilmsmeier (2005)	•									
Perakis and Denisis (2008)	•		•					•	•	
Medda and Trujillo (2010)		•					•			•
Bendall and Brooks (2011)					•					
Morales-Fusco et al. (2013)			•	•						
Total	4	2	3	3	2	1	1	1	2	2

Author(s) and year of publication	Driver groups and drivers: D4. External: Reduced air pollution	Fewer accidents	Less congestion	Fewer noise emissions	Higher safety in dangerous goods transport	D5. Regulatory: Imposition of eco-taxes and carbon taxes on truck fuels	Imposition of more road tolls	Reduced hours of service by truck drivers	D6. Other: Alliances with trucking industry and port authorities
Baird (1999)			•						•
Paixao and Marlow (2002)	•	•	•	•	•	•		•	•
Brooks and Frost (2004)	•		•						
Sanchez and Wilmsmeier (2005)	•					•	•		•
Perakis and Denisis (2008)	•		•	•	•				•
Medda and Trujillo (2010)	•		•	•					
Bendall and Brooks (2011)	•		•			•	•	•	•
Morales-Fusco et al. (2013)									
Total	6	1	6	3	2	3	2	2	5

Table 5. Articles highlighting barriers to the modal shift from road haulage to intermodal short sea shipping (SSS).

Author(s) and year of publication	Barrier groups and barriers											
	B1. Service quality					B2. Financial		B3. Technical				
	Longer lead times at ports and in transit and slower speeds	Lower reliability	Lower frequency	Additional cargo-handling costs	Capital intensity of SSS industry	Additional inventory costs for shippers	High labour costs	Incompatibility of equipment and ICT systems	Complicated customs clearance rules	Absence of integrated management systems	Lack of robust strategy in SSS firms	Lack of innovation and R&D activities
Baird (1999)	•											
Paixao and Marlow (2002)	•	•	•	•		•		•		•	•	•
Saldanha and Gray (2002)	•		•		•			•		•	•	•
Brooks and Frost (2004)	•			•								
Paixao and Marlow (2005)	•	•							•		•	•
Sanchez and Wilmsmeier (2005)								•				
Perakis and Denisis (2008)	•	•		•				•		•		
Medda and Trujillo (2010)	•		•			•						
Bendall and Brooks (2011)		•		•			•		•			
Baindur and Viegas (2011)					•			•				
Martell et al. (2013)	•								•			
Morales-Fusco et al. (2013)	•											
Total	9	4	3	4	2	2	1	5	3	3	3	3

Author(s) and year of publication	Barrier groups and barriers											
	B4. Communication				B5. Service and market				B6. Regulatory			B7. Administrative
	Poor industry image	Poor marketing activities by SS firms	Weak communication by SSS firms	Insufficient information available to SSS users	Poor port–hinterland connectivity	Lack of SSS integration into door-to-door transport chain	Shortage of RoRo vessels in the spot market	Volatility of transport demand	Construction of road infrastructure for trucking	Inconsistent policies	Imposition of taxes in SSS sector	Complex documentary and administrative procedures
Baird (1999)									•			
Paixao and Marlow (2002)	•	•	•	•	•	•						•
Saldanha and Gray (2002)		•		•	•	•						
Brooks and Frost (2004)								•		•		
Paixao and Marlow (2005)	•											
Sanchez and Wilmsmeier (2005)		•		•	•					•		
Perakis and Denisis (2008)	•									•	•	
Medda and Trujillo (2010)	•				•	•						•
Bendall and Brooks (2011)											•	
Baindur and Viegas (2011)							•	•		•		
Martell et al. (2013)												•
Morales-Fusco et al. (2013)												
Total	4	3	1	3	4	3	1	2	1	4	2	3

As a specific type of SSS, Motorways of the Seas (MoS), defined and promoted by the European Union, operate in four maritime corridors: the Baltic Sea, Western Europe, South-East Europe, and South-West Europe defined and promoted by the EU. Baird (2007) illustrated how different seaways, not only MoS, have developed and concluded that though a modal shift can be achieved with innovative carriers (e.g. new RoRo ships) and under different environmental circumstances, such measures often need to be supported by policies. Aperte and Baird (2013) investigated MoS policy in terms of how it aligns with other maritime polices and the European transport policy, as well as how it functions within the Trans-European Transport Network. They argued that MoS have had little effect in general, for reasons including limited support from policies. Baindur and Viegas (2011) identified critical factors for establishing MoS projects, including economic policies, (e.g. the internalisation of external costs) and regulatory policies (e.g. various measures to restrict or /discourage road freight).

Douet and Cappuccilli (2011) acknowledged that the European Union has promoted the modal shift from road haulage to SSS, albeit with disappointing results. They argued that such dismal outcomes could be explained, for example, by the fact that the European Union has mis-adapted policies promoting the shift, largely due to problems with inexact definitions of *SSS* that do not correspond to their programmes aimed at supporting the shift. For the benefit of policymakers, Brooks and Frost (2004) investigated key trends in SSS from a Canadian perspective in terms of limitations and impediments to increasing the use of SSS in Canada and across the US–Canadian border. Policy-hampering factors included the requirement that domestic traffic has to bear a Canadian flag, complicated tax issues, and duties on foreign-built ships. In response, they suggested that different policy measures, including the US Clean Air Act or Kyoto credit programme, could favour the modal shift to SSS.

In three articles, authors have modelled the effects of different policy measures. Among them, Garcia-Menendez and Feo-Valero (2009) found that, along with traditional determinants in terms of cost and transit time, additional policy-related variables may be of equal importance: the use of INCOTERMS, overland distance, relative value added, shipment size, and company type. Tsamboulas et al. (2007), who assessed the potential of policy measures to affect the modal shift, revealed that policy measures such as a directive for working hours and the internalisation of external costs have strengthened the competitiveness of sea versus road transport. Later, Tsamboulas et al. (2015a) showed that the implementation of the Ecobonus afforded significant cost savings and benefits to society in general, as well as exceptional returns on investments for the Italian government. Last, Becker et al. (2004) analysed whether SSS could be more successful with high-speed vessels but concluded that policies that promote high-speed vessels are neither in place nor should be, because the market would produce such solutions.

Research gaps. Although policy plays an important part in promoting the modal shift to SSS, the results of policies thus far have been somewhat disappointing. Aperte and Baird (2013) argued that seaway infrastructure equivalent to that of roadways is not the waterway but the deck of the ship and that adjusting policies to incorporate such a view could level the playing field between sea and land to promote a modal shift. In that sense, policies for road transport cannot easily be treated the same as those for sea transport. In response, researchers should address redefining policy measures that accommodate the unique characteristics of sea transport, for example, to encourage a modal shift to the sea that would complement the predominant shift from the road.

The Italian Ecobonus system is directed towards transport buyers, which is a strength according to Tsamboulas et al. (2015a). In contrast, Suárez-Alemán (2016) critically reviewed the SSS transport policy in the European Union, argued that poor results may be partly attributed to the fact that policies principally target transport buyers who shift goods from road to the sea and not how to make SSS more attractive by increasing efficiency, especially at ports. Therefore, important directions for future research are to more thoroughly compare how value for money is best attained and for which types of actors. A thorough analysis also needs to be made of European projects implemented in different countries. Such an analysis should include both qualitative methods (e.g. interviews with all important stakeholders in the cases) and quantitative ones (e.g. analyses of all possible metrics from the cases) and be executed via a case study. Moreover, relating inputs to outputs and understanding the accompanying processes are essential steps to substantiating conclusions to guide SSS-oriented policymaking.

3.2.3. Environmental legislation (C3)

The environmental friendliness of SSS is an essential driver of modal shift, as related in the discussion of category C1 in Section 3.2.1. However, increased sulphur emissions caused by overall shipping activities have prompted the implementation of a sulphur emissions regulation (i.e. MARPOL Annex VI) for vessels operating in the North Sea and Baltic Sea Sulfur Emission Control Areas (SECAs). In six articles, scholars estimated the potential impact of the regulation on the competitiveness of SSS, which can theoretically be worsened by higher compliance costs.

Notteboom (2011) conducted a detailed comparative cost and price analysis to evaluate competition between intermodal SSS and unimodal trucking for 30 routes connected to the North European SECA. The findings of that study indicate that using expensive marine gas oil (MGO) as the preferred SECA-compliant solution could substantially increase operating costs and, in turn, trigger modal backshift from SSS to unimodal trucking. Moreover, Bergqvist et al. (2015) reached similar conclusions for the Swedish forest industry. Panagakos et al. (2014) investigated the impact of the prospective designation of the Mediterranean Sea as a SECA and predicted that applying such a regulation in the Mediterranean would favour trucking over intermodal SSS only for clothing shipments between Greece, Italy, and Austria. By contrast, Holmgren et al. (2014) found that high-value containerised cargo shipments between Lithuania and the British Midlands are insensitive to sulphur regulations. Zis and Psaraftis (2017) showed that a recent decline in fuel prices to a certain extent mitigated the detrimental impact of the regulation on the modal shift but also that any potential increase in fuel prices would reverse the trend. However, Woxenius (2012) illustrated that the adoption of slow steaming as a strategy to deal with the sulphur regulation in the RoRo vessel segment operating in South Baltic Sea region may not jeopardise the competitiveness of RoRo shipping in the region as slow steaming reduces the vessel fuel consumption and thus lowers the operating cost. Overall, the findings suggest that environmental regulations (i.e. SECAs) impair the competitiveness of SSS.

Research gaps. Arguably, the above-cited studies suggest a consensus that the magnitude of the impact of sulphur regulations on the modal shift depends on the cost of compliant solutions (e.g. MGO price), route length, and the value of the cargo being shipped. Cost and price analyses have generally been based on the price of MGO as a compliant solution, whereas other compliant measures such as scrubbers and liquified natural gas have been overlooked in calculations. In addition, we observed that European infrastructure and electric vehicle charging systems (e.g. Eurovignette, a regulation for the trucking industry) have also been neglected in cost calculations, except by Holmgren et al. (2014) and Notteboom (2011). Moreover, IMO's CO_2 reduction targets and upcoming global sulphur limits of 2020, due to expensive compliance measures, may further increase freight rates for sea transport and eventually prompt modal backshift to road haulage in Europe. Such trends require more quantitative research, particularly with models that link volumes to costs and emissions, to clarify the real impact of current and forthcoming regulations on the modal shift from road haulage to SSS. Furthermore, because researchers have revealed a risk of modal backshift due to SECAs, an important path for future research is to investigate the effects of possible policy strategies to mitigate SECA's adverse impact on SSS. In particular, the possible measures of providing subsidies to SSS or imposing taxes on road haulage provide opportunities for future research.

Another overlooked aspect of the modal shift from road transport to SSS is that regulatory pressure stimulates innovation (Bossle et al., 2016) and that such innovations promote better environmental and business performance (Porter & van der Linde, 1995). Thus, empirical studies involving the analysis of the qualitative and quantitative effects of innovations in the context of environmental legislation affecting the maritime sector is a relevant direction for future research. The results of such research could stimulate SSS firms to invest more in innovations, which could at once support their compliance with environmental regulations and improve their business performance.

3.2.4. SSS performance (C4)

Addressed in 26 articles, the performance of intermodal SSS versus that of door-to-door road haulage ranks among the most extensively studied topics in the literature reviewed and has been approached in terms of three types of performance (Table 6):

(1) Economic performance, by calculating and comparing types of generalised and external costs for road haulage and intermodal SSS services in various trade corridors;
(2) Service quality performance, by comparing the performance of both modes in terms of quantified time-related attributes of service quality; and
(3) Environmental performance, by calculating and comparing environmental pollutants such as sulphur oxides (SOx), nitrogen oxides (NOx), particulate matter (PM_4), and carbon dioxides (CO_2) emitted from both transport modes.

Economic performance. The primary objective of studies on the relative economic performance of intermodal SSS versus road haulage has been to assess the cost-competitiveness of prospective intermodal SSS services against road haulage. Ng (2009) simulated and compared the generalised costs (e.g. monetary costs) and costs related to service quality (e.g. time costs) of SSS to those of road haulage for the transportation of containerised cargo shipments between the Baltic region and Western Europe. Among the results, SSS was more competitive only in certain regions and at certain ports, which suggests that policymakers should focus on those regions by providing infrastructure and other facilities

Table 6. Articles addressing the relative performance of intermodal SSS and road haulage.

Author(s) and year of publication	Economic performance	Service quality performance	Environmental performance
D'Este and Meyrick (1992)		•	
D'Este (1992)		•	
Bergantino and Bolis (2008)		•	
Brooks and Trifts (2008)		•	
Ng (2009)	•	•	
Chang et al. (2010)	•	•	
Hjelle (2010)			•
Lee et al. (2010)	•		
Feo et al. (2011)	•	•	
Hjelle (2011)			•
Puckett et al. (2011)		•	
Brooks et al. (2012)		•	
Corbett et al. (2012)			•
Morales-Fusco et al. (2012)	•	•	
Nealer et al. (2012)			•
Perez-Mesaa et al. (2012)	•	•	
Sambracos and Maniati (2012)		•	
Martell et al. (2013)	•	•	
Hjelle (2014)			•
López-Navarro (2014)	•		
Juste and Ghiara (2015)	•	•	
Rodrigues et al. (2015)			•
Suárez-Alemán et al. (2015a)	•	•	
Tsamboulas et al. (2015b)	•	•	
Galati et al. (2016)	•	•	
Kotowska (2016)	•		
Total	13	17	6

to achieve the modal shift to SSS. Feo et al. (2011) and Morales-Fusco et al. (2012) conducted similar studies for trade corridors in the Mediterranean region. The added value of those studies is that their analyses included the quantified values of attributes of service quality, including frequency and reliability. By using the updated values in the cost model developed by Morales-Fusco et al. (2012), Galati et al. (2016) compared different transportation scenarios (i.e. road-only transport, road transport with Accompanied-SSS, and road transport with Unaccompanied-SSS) for olive oil distribution from Spain to Italy and found that road-only transport was the most expensive option.

Focusing on the East Adriatic and Ionian Sea region, Tsamboulas et al. (2015b) identified prospective intermodal SSS links that are financially competitive under the European Commission's MoS programme. Martell et al. (2013) conducted a comparative cost analysis of road and SSS services in 112 Western European cities, the results of which suggested that SSS services perform better in terms of cost but rarely in terms of time. Thus, they highlighted the need for speed on the maritime legs of SSS chains.

A few articles have demonstrated that including external costs can affect the cost-competitiveness of SSS. Chang et al. (2010) and Suárez-Alemán et al. (2015a) estimated and compared the total costs of transport and time, including the external costs of air pollutants and greenhouse gases for road, rail, barge, and SSS in South Korea and Europe. Sambracos and Maniati (2012), Perez-Mesaa et al. (2012) and Juste and Ghiara (2015) performed similar comparisons for road haulage and SSS services in the Mediterranean region. A distinct feature of their studies was that to evaluate external costs, they include not only air pollution but also the other externalities such as highway congestion, noise emissions, climate change (global warming impacts), nature and landscape damages, and traffic accidents. By comparison, Lee et al. (2010), López-Navarro (2014), and Kotowska (2016) did not take into account generalised costs in their analyses but evaluated and compared only the external costs for road haulage and SSS services in Taiwan and Europe. Overall, the cited articles have indicated that including external costs in cost comparisons can make SSS seem more competitive.

Service quality performance. A number of articles have assessed the importance of service quality attributes that are considered by the shippers and play an important role in mode choice decisions. In this respect, D'Este and Meyrick (1992), D'Este (1992), Bergantino and Bolis (2008), Brooks and Trifts (2008), Puckett et al. (2011) and Brooks et al. (2012) compared the importance of service quality performance between road haulage and SSS from Australian, Canadian, Italian, and US forwarders' and shippers' perspectives. Their findings revealed that, among other factors, certain attributes of service quality, especially shorter transit time, frequency of a service, and reliability are more important than the higher freight rate paid for cargo transport. In support of these findings argues that the indirect and long- term costs of failure to deliver consignments on-time and intact may result in loss of markets and market share, loss of customer confidence and opportunities forgone.

Environmental performance. The better environmental performance of intermodal SSS versus road transport is often presented as an argument by policymakers to encourage the modal shift to SSS. In that regard, Hjelle (2010), Hjelle (2011), Corbett et al. (2012) and Hjelle (2014) evaluated the environmental performance with respect to for example CO_2, NOx, and SOx emissions from road haulage versus SSS options in Europe and the United States. They found that due to factors such as high fuel consumption and lower load factor, intermodal SSS generates more emissions, at least in the scenarios analysed, per tonne-kilometre than road haulage. Nealer et al. (2012) and Rodrigues et al. (2015) compared the CO_2 emissions produced by alternative modes using different scenarios for the United Kingdom and the United States. Both groups of authors proposed that measures such as using cleaner fuels in road haulage and improving the truck emissions-efficiency via innovative technologies might be better strategies to minimise CO_2 emissions in the transport sector than using SSS.

Research gaps. The use of different methods in different trade corridors and the inclusion of dissimilar factors in analyses of competition has generated inconsistencies in the results presented in the reviewed articles. For example, some have considered only the operating or fixed cost of a transport mode while overlooking the financial value of attributes of service quality or external costs. Similarly, most research on the fuel consumption and emissions of vessels is based on the assumptions or information provided by stakeholders, which may have prompted over- or underestimation of the results. Therefore, we emphasise the need for more route-specific research that is based on realistic data concerning the usage rates of vessels and trucks and their respective fuel consumption, as well as that incorporates all three dimensions of performance in its analyses. Such efforts would also call for research with measurements taken aboard ships of external effects and the development of detailed cost models.

In addition, technological innovations have revolutionised the freight transport industry, in which self-driving electric trucks and self-navigated electric SSS vessels might become realities. Such automation can substantially alter the cost and profitability structure of a transport mode as well as significantly reduce its environmental impact.

Accordingly, that possibility needs to be assessed in future research by, for example, evaluating the automation of ships and the use of alternative fuels.

3.2.5. Port characteristics (C5)

As central nodes for SSS activities, ports could play an instrumental role in enhancing the efficiency of SSS systems, which is essential for SSS to compete with road haulage, by reducing overall lead times and associated logistics costs. In six articles, scholars have addressed the impact of port characteristics and policies concerning SSS competitiveness and the modal shift from road haulage. Among them, Paixao and Marlow (2007) and Tsamboulas et al. (2010) emphasised that the development of major port-oriented attributes – port harmonisation, use of electronic data identification systems, port – hinterland connectivity, and administrative and customs procedures – are crucial to ensuring a modal shift to integrated SSS. In the same vein, Baindur and Viegas (2012) asserted that policy measures such as port liberalisation and improved port–hinterland connectivity can reduce the total cost of SSS services and facilitate faster cargo movements. In other work, Suárez-Alemán et al. (2015b) and Ng (2009) compared the monetary cost (i.e. price) and time cost of alternative transport modes and claimed that enhanced port efficiency strengthens the competitiveness of SSS.

Suárez-Alemán and Hernandez (2014) have suggested that promoting port efficiency might be a more suitable target than subsidising shippers to use SSS. Viewing port efficiency as time spent at a port, they investigated the potential effects of offering a subsidy per unit of reduced inefficiency to show that instead of providing fixed amounts to ports, a proportional payment that hinges the subsidy on improved port efficiency could be a better mechanism for incentivising ports. An improved port performance can eventually enhance the performance of SSS by reducing the total lead time.

Research gaps. Port efficiency and performance constitute an extensively studied area in scientific work on deep-sea ports. However, performance and efficiency from the perspective of SSS in ports should be other important topics in future research. Detailed data collection at port authorities regarding the volumes, costs, employees, and number and type of companies in SSS needs to be conducted for performance analyses.

At the same time, disruptions in ports can prompt disruptions in supply chains, which can deter transport buyers from choosing SSS. That dynamic is particularly important given that reliability and a poor image of SSS have been identified as two important barriers to its use, especially when European ports have had to cope with blockades and labour strikes. Such strikes at ports severely disrupt shippers' supply chains by crippling port operations and, in turn, can make SSS unattractive. Furthermore, in today's era of digitalisation, information technology (IT) systems are prone to cyberattack. For instance, on 27 June 2017, one of the world's largest container terminal operators, APM, suffered a cyberattack that halted its 76 terminals around the globe. Consequently, loading and unloading times at its terminals rose considerably, and customers received their cargo a few days later than expected. Thus, those types of disruptions can dissuade cargo owners from relying entirely on SSS. In response, we believe that research on supply chain disruptions and risks is important, especially if it can include investigations of the capacity of current IT systems as well as their safety and security risks.

3.2.6. The multi-agent perspective (C6)

The success of SSS depends on the seamless integration of individual services offered by agents, or actors, across transportation chains, as addressed in four articles. Saldanha and Gray (2002) emphasised that integration requires the cooperation of all agents within a multimodal logistics chain. They found that though both road haulage and SSS firms favour cooperation, the highly competitive and go-it-alone strategies of SSS firms prevent such cooperation. Similarly, Paixao and Marlow (2005) have suggested that to facilitate their integration into intermodal transportation chains, SSS firms should offer forwarding services and form partnerships with other agents in their chains. Such partnerships could strengthen the competitiveness of intermodal SSS versus unimodal road haulage.

Paixao and Marlow (2009) underscored best practices and strategies for logistics integration, including total quality management, freight-forwarding, partnerships, customs clearance, and outsourcing, all of which can improve customer service by enhancing the tracking and tracing of cargo and transport modes along transportation chains. Later, with a sample of 106 relationships between SSS and road haulage firms, López-Navarro (2013) verified that shared planning and joint decision making in the transportation chain positively affect the performance of both types of firms. Such cooperation can help firms to find mutually satisfactory solutions and improve the integration of both agents in intermodal transport chains.

Research gaps. Although shared planning, coordination, and alliance among members of transportation chains are essential to ensure the integration of SSS into intermodal transportation chains, research on inter-organisational relationships in the context of logistics chains involving SSS has been rare, at least as represented in the literature reviewed. Synergies among agents in transportation chains can offer better visibility, reduce costs, and enhance the responsiveness of intermodal transport chains, all to meet shippers' demands in more flexible, timely ways. We believe that more research that evaluates the economic or financial benefits of coordination for each agent in a logistics chain is needed, for the results of such work might encourage them to recognise the importance of integration within supply chains. The emergence of new technological solutions such as the internet of things and blockchains have the potential to overcome factors hindering the modal shift to SSS by enhancing trust, reliability, and collaboration among transportation chain agents and by increasing the efficiency of supply chain activities. Researchers should also focus on specific trade corridors and cases in which coordinated and shared IT system capabilities (e.g. via blockchains or the internet of things) have improved efficiency and reliability as well as lowered costs. Studies on the design of IT systems and expected savings in terms of costs and efficiency, along with increased reliability, are also needed, for their results could enhance the competitiveness of SSS.

4. Conclusion and research directions

As evinced by the increasing number of published articles on the topic, which has been more observable since 2011 (Figure. 2), the modal shift from road haulage to SSS has become an important topic of research. This paper has provided an overview of recent studies on the topic and identifies paths for future research.

A summary of the chief features of the literature reviewed (i.e. 58 articles on the modal shift) has been provided as the result of a descriptive analysis. The findings of the analysis highlight that the majority of the articles (i.e. 45 of 58) have focused on EU countries, possibly because several such countries are connected well by waterways and because the European Union has enacted various policies to promote modal shift as a means to mitigate the rise of road-related negative externalities. With respect to methodology, literature reviews and mixed methods (i.e. qualitative and quantitative methods) have dominated in research addressing the modal shift. Nevertheless, the authors of a few articles deployed surveys, mathematical models, interviews, and case studies in their work.

As a result of content analysis, the reviewed research was classified according to topics in six categories. For a modal shift to take place, SSS as an alternative to road haulage needs to have superior performance (C4). However, since the modal shift is not satisfactory so far, researchers have investigated factors influencing the competitiveness, i.e. barriers and drivers towards a modal shift (C4), as well as how policy measures can facilitate the modal shift (C2). These are the core issues of the modal shift and by far the most researched categories so far. For the modal shift to progress further, we believe that these are the most pressing issues to understand even better. From the review, the following venues for further research are provided;

First, to evaluate the competitive performance of SSS in different trade corridors, data should be gathered about three primary dimensions of performance: the economic dimension, the environmental dimension, and the dimension of service quality. Route-specific performance analysis incorporating real-world data about capacity usage and fuel consumption rates as well as all three performance dimensions should help policymakers to identify the most competitive transport mode for certain routes and could trigger SSS-oriented policy actions and investments needed to increase SSS performance. SSS firms using the results of such performance analyses might detect areas in which their performance is weak and devise strategies to improve their operations.

Second, rich, real-world, numerical data and operational research techniques are needed to identify the relative importance of individual drivers of and barriers to the satisfactory performance of SSS. Such endeavours would require EU member states to allot considerable amounts of money during a long-term yearly schedule, because collecting data about transport volumes, ship characteristics, costs, emissions, companies, employment, and services is a costly, time-consuming activity. Nevertheless, the collected data could inform policies geared towards affecting the modal shift from road haulage to SSS.

Third, several articles have revealed that policy, both economic and regulatory, is important to support the modal shift from road to sea, although the outcomes of such policy has been dismal. Identified reasons include that policies are somewhat misdirected, meaning that future research should focus on developing proper measures based on the unique characteristics of sea transport. Furthermore, it is important to pinpoint which groups of actors certain policies should target. Researchers should also extend their policy-oriented focus beyond the European Union to assess whether and, if so, then how it is possible to internalise the external costs of transports. Creating a large database of information about past SSS policy projects would facilitate the analysis of factors of policy success and failure.

Researchers have also acknowledged the importance of understanding impact of environmental legislation (C3), port characteristics (C5) and the multi-agent perspective (C6). Though aforementioned venues for further research may be the most important, we do believe that it is important to continue research on these areas as well, and suggest the following;

Fourth, determining strategies that moderate the adverse impacts of the recent sulphur regulations and other legislation on SSS is suggested. In that respect, providing subsidies to SSS on affected routes or imposing taxes on rival unimodal road haulage might be relevant strategies. However, such work entails not only computing the size of subsidies needed to be provided to SSS services operating in certain trade corridors and the taxes to be implemented on road haulage but also evaluating the potential benefits of such subsidy and tax policy. Policy actions based on these proposed strategies could reduce the negative impacts of regulations on SSS. In addition, measurements aboard ships should be taken to gather real-world data about emissions.

Fifth, the influence of contingencies, particularly port strikes and cyberattacks, on SSS operations and approaches for navigating such contingencies should be investigated. Contingencies in SSS disrupt shippers' supply chains and can persuade shippers to use alternative transport modes as part of their strategies to mitigate risks, which can reduce business volumes for SSS.

Sixth and last, the economic or financial advantages of coordination and alliance for each transport chain agent need to be evaluated. The results of such evaluations might encourage transport chain agents to realise the importance of integration within the supply chain, which could enhance the competitiveness of intermodal SSS.

Altogether, research responding to those suggestions can contribute to creating new insights into SSS usage.

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Paper II

sustainability

MDPI

Article

Slow Steaming as Part of SECA Compliance Strategies among RoRo and RoPax Shipping Companies

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Abstract: Many geographically peripheral member states of the EU are critically dependent on short sea Roll-on/Roll-off (RoRo) and mixed freight–passenger (RoPax) shipping services for intra-European trade. The implementation of the Sulfur Emission Control Area (SECA) regulation was expected to raise the operating cost for RoRo and RoPax shipping, and slow steaming was proposed as an immediate solution to save the increased cost. Previous research has investigated the issue of slow steaming and SECA using a quantitative approach. However, the reaction of the RoRo and RoPax shipping firms toward slow steaming as a mitigating factor in the face of expected additional SECA compliance costs using qualitative methodology has not been explored yet. In addition, the knowledge regarding the impact of slow steaming on the competitiveness of short sea RoRo and RoPax with respect to service quality is limited. This article has addressed these issues through the analysis of multiple cases focusing on RoRo and RoPax firms operating in the North and Baltic Seas. Overall, our findings suggest that the 0.1% SECA regulation of 2015 requiring the use of higher-priced MGO has not caused slow steaming in the RoRo and RoPax segments to a large extent. The increased bunker prices are partially transferred to the customers via increased Bunker Adjustment Factor and partly borne by the shipowners. We have found that out of 11 case firms in our study only one RoRo and one RoPax firm have reduced vessel speeds to compensate for the additional SECA compliance costs. We conclude that for RoPax and RoRo segment bunker prices, rigorous competition and, most important, different service quality requirements have significantly restricted the potential implementation of slow steaming.

Keywords: slow steaming; SECA compliance; short sea shipping; competitiveness

1. Introduction

Over the past several decades, emissions of noxious gases from maritime transport have considerably amplified, although the role of shipping for world trade continues to be strong [1]. To mitigate rising shipping emissions, in particular sulfur oxides (SO_x), the International Maritime Organization (IMO)—under Annex VI to the International Convention for the Prevention of Pollution from Ships (MARPOL Convention)—introduced limits on the maximum sulfur content allowed in the fuel used by ships [2]. Currently this regulation is implemented in specific zones called sulfur emission control areas (SECAs), where the stringent sulfur limits are applied progressively. All ships sailing in SECAs, which include the Baltic Sea, the North Sea, the English Channel, the North American east and west coasts, and the US Caribbean area, are now subject to this regulation. Under the sulfur regulation from 1 January 2015, the level of allowed sulfur content in the fuel of ships was reduced to 0.1 percent.

Furthermore, the regulation stipulates that from 2020, the global limit of allowed sulfur content will be 0.5% for ships sailing outside the SECAs [3]. The progression of sulfur limits within and outside the SECAs is presented in Figure 1:

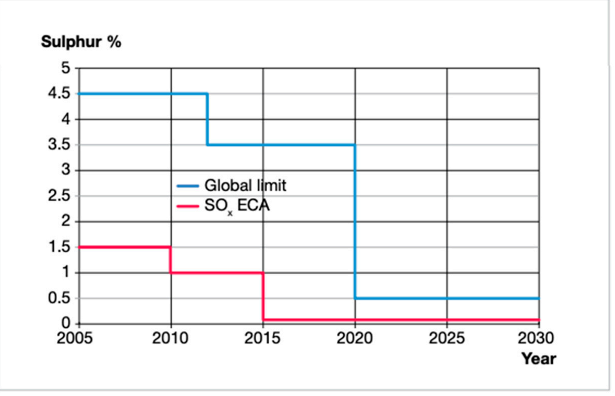

Figure 1. Fuel sulfur limits and implementation dates within and outside SECAs. Source: MAN [4].

In total, nearly 14,000 ships are active in the SECAs each year. From this total, about 2200 ships operate 100% in the area, while 2700 ships spend more than 50% of their time in the region [5,6]. Before and after the implementation of the 0.1% sulfur limit in SECAs, multiple research studies were conducted providing a techno-economic analysis of the two major compliance alternatives, namely scrubbers and low sulfur marine gas oil (MGO) available to shipowners. In this respect, Zis, et al. [7] found that the scrubber installation reduces the ship operating cost; however, the lower bunker prices delay the payback period of a scrubber investment. In addition, the findings of Jiang, et al. [8] and Lindstad, et al. [9] indicate that a scrubber is a better compliance option when the price spread between heavy fuel oil (HFO) and MGO is high (more than 231 Euros per ton), when the remaining lifespan of a vessel is more than 4 years, and when the vessel operates on a long-distance route with high fuel consumption.

On the other hand, it was forecast [10] that, due to the uncertain future of fuel prices as well as technological and regulatory uncertainty, a majority of shipping companies would switch to distillates such as marine gas oil (MGO) to conform to the sulfur regulation. A report by BPO [11] revealed that at the beginning of 2016 there were only 83 ships with scrubber installations and that this number was expected to exceed 200 by 2017. However, this represents a minority share of the 2200 ships sailing in the SECAs and corroborates the feeling that the majority of shipowners preferred low-sulfur fuel as a compliance solution.

The compliance with the sulfur regulation was predicted to negatively affect the competitiveness of short sea shipping (SSS), in particular the Roll-on/Roll-off pure freight (RoRo) and mixed freight–passenger (RoPax) sectors operating in the North and Baltic Seas, by substantially increasing their operating costs [12]. In this context, a reduction in sailing speed—also termed 'slow steaming'—as an energy efficiency measure is deemed an immediately feasible approach for reducing operating costs and cutting the shipping carbon footprints on the environment [13]. Due to the cubic relationship between speed and fuel consumption, which is even higher than a cubic as asserted by Psaraftis and Kontovas [14], particularly for ships that sail at a comparatively faster speed—such as containerships, RoRo, and RoPax—a nominal speed reduction leads to a substantial saving in total fuel consumption. In the existing literature, different speed optimization models and the cost-saving potential of slow steaming for the European RoRo segment in the context of SECA regulations have been identified [15] as low-impact fixes.

Admittedly, slow steaming is somewhat complicated for tank and bulk shipping, and still more complicated for deep-sea liner shipping. However, it is truly complex for RoRo and RoPax shipping, as the RoRo and RoPax segments face fierce competition not only from the neighboring shipping routes but also from land transport modes. Any speed reduction could affect the competitiveness of SSS in the form of service quality (SQ). Earlier research has approached the issue of slow steaming from multiple angles. In this context, using the route-specific data for 2014 and 2015 for RoRo and RoPax services, Zis and Psaraftis [16] quantitatively assessed the potential of slow steaming as an operational measure that could be deployed by shipowners to lower the operating costs in SECAs. Along the same line, Santos and Guedes Soares [17] developed a methodology to determine the optimum ship speed considering the RoRo ship operations in SECAs.

We have noticed that the existing research has explored the potential of slow steaming in the SECAs primarily deploying the quantitative methods. However, there is insufficient knowledge related to the actual reaction of RoRo and RoPax shipping companies pertaining to slow steaming in the aftermath of the 0.1 percent sulfur regulation of 2015. In addition, the knowledge is limited regarding the impact of slow steaming on the competitiveness of short sea RoRo and RoPax with respect to service quality.

Thus, the purpose of this article is to qualitatively investigate the feasibility of slow steaming for the RoRo and RoPax sectors in the context of SECA regulations. More specifically, we seek to identify the reaction of RoRo and RoPax firms toward slow steaming in the wake of the North Sea and Baltic Sea sulfur regulations, and to investigate how slow steaming affects competitiveness in these sectors. This is done through an in-depth analysis of multiple cases focusing on RoRo and RoPax firms. The data for this study is derived from the existing literature as well as from several interviews of the management of RoRo and RoPax firms operating vessels in the North and Baltic Seas emission control areas.

The article is structured as follows. A brief literature review focusing on SECA, slow steaming and competitiveness is presented in Section 2. Section 3 addresses the methodology, while Section 4 presents the findings of our analysis. Section 5 discusses the results and concludes the research implications.

2. Literature Review

2.1. SECA Regulation and Its Implications

Sea transport growth has caused a commensurate upsurge in anthropogenic aquatic and air contamination, and in order to mitigate the escalating airborne emissions from vessels, various regulations are being imposed at the global and regional levels. One of the instrumental regulations in this context is the creation of SECAs, which are a part of Annex VI of IMO's MARPOL protocol and came into force in May 2005. Under Annex VI, limits on maximum sulfur content in fuel used by the ships operating in the designated ECAs were incrementally reduced [12], as shown above in Figure 1.

In the wake of SECA regulations, a number of researchers have attempted to investigate the impact of SECA on the affected shipping sector, from technical, operational, environmental and economic perspectives [18–20]. To comply with the 0.1 percent sulfur regulation, shipping companies were faced with a number of possible solutions. They could switch from traditional heavy fuel oil (HFO) to distillate fuel (marine gas oil or ultra-low sulfur fuel) having a maximum sulfur content of 0.1%. Another option was to install after-treatment technologies (e.g., scrubbers) on board, or convert the vessels to use alternative fuels such as liquid natural gas (LNG), methanol or biofuels [21,22]. While all these alternatives would allow shipowners to operate within SECA waters, they were characterized by very different financial consequences. In addition to the required extensive additional capital costs for retrofitting the vessels, immature technology and price uncertainty regarding the latter two approaches (i.e., scrubbers and LNG) made these solutions unattractive for a number of shipping companies [23,24]. Distillates did not require capital investments, but their higher price could rapidly become a heavy burden for ship operators [7].

Fuel costs represent the largest share in the total operating cost of a vessel, and a fuel switch to MGO was likely to increase the freight rates on certain routes and eventually lead to the so-called modal backshift from sea transport to road transport [12,25]. This modal shift to road would not only put the local industry and many ship and port operators out of business but could also challenge the EU policy to improve the environment, as road transport causes severe congestion and more emissions [26]. Figure 2 depicts the price fluctuations in dollars per metric ton for MGO, HFO (IFO380), ultra-low sulfur fuel oil (ULSFO), and the price difference between MGO and IFO380 before and after the implementation of 0.1 percent sulfur limits of 2015.

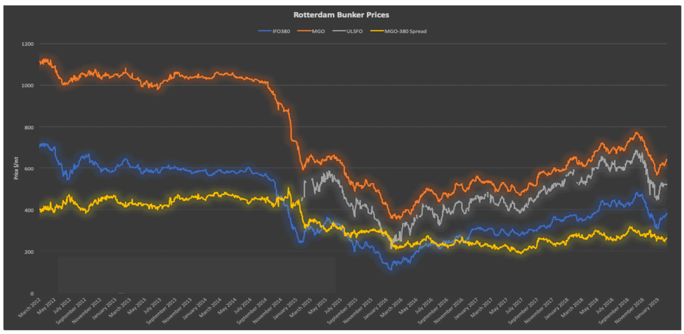

Figure 2. Fluctuations in bunker prices before and after enforcement of 0.1% sulfur regulation. Source: Ship and Bunker [27].

It can be seen in the figure that when the 0.1 percent sulfur regulation came into force in January 2015 the price of MGO dropped significantly compared to 2014. Thus, in 2015, because of a crash in bunker prices, the predictions regarding the modal backshift and negative repercussions of SECA for the shipping industry did not become reality [28]. However, again from 2016 bunker prices have shown a rising trend, which might reverse the situation and in particular the RoRo sector might lose cargo to competitive land-based transport modes as asserted by Zis and Psaraftis [12] and, therefore, additional operational measures such as slow steaming may be required to survive in the market [16].

2.2. Slow Steaming

It was anticipated that as a consequence of SECA regulations, ship operators may reduce the sailing speed to compensate for the extensive cost caused by SECA compliance, as noted by Zis and Psaraftis [16]. In order to analyze the impact of slow steaming on the carrier's and the shipper's costs, Mallidis, et al. [29] developed continuous-time analytical models. Further, Wen, et al. [30] presented a speed optimization algorithm that can be applied by shipowners to optimize the vessel's fuel consumption. Studies by Johnson and Styhre [31] and Zis and Psaraftis [16] suggested that reduced waiting time in port could support slow steaming and mitigate the additional cost effects of SECA for dry bulk shipping in the North and Baltic Seas. Using AIS data, Adland, et al. [13] found that the strict sulfur regulation of 2015 did not affect the speed patterns of the vessels crossing the North Sea ECA. Furthermore, they claimed that vessel speed is not generally determined by fuel prices or freight rates but is rather dependent on factors such as route characteristics, vessel type, weather, market segment and conditions and the nature of the commercial contract between a shipper and a ship operator.

The role of energy efficiency is immensely crucial for the short sea RoRo/RoPax sector as it faces fierce competition from the alternative transport modes of road and rail. Greater energy efficiency not only results in cost savings, but it also brings about a reduction in the emissions per unit of transport work. Due to the non-linear correlation between speed and fuel consumption as embodied in the propeller law [4], even a marginal speed reduction from full or normal steaming speed will result in a substantial reduction in fuel consumption. As with most energy efficiency measures, slow steaming is potentially associated with a negative abatement cost, that is, measures that reduce emissions will at the same time also reduce costs [32].

The positive role of slow steaming in gaining energy efficiency and supporting environmental sustainability is evident, but it may have negative corollaries for the shippers and shipping companies by affecting the entire supply chain. Slow steaming may increase the transit time and pipeline inventory costs for shippers due to delayed cargo delivery [33]. Shipping companies may need additional tonnage to maintain the schedule frequency which will result in extra costs and emissions [34]. Businesses with lean, just-in-time supply chains may be required to have additional safety stocks because of increased shipping time. In particular, shippers with perishable and short life-cycle goods are likely to be affected more [29].

In contrast to tank and dry bulk ships that transport low-value cargo for a single or a few shippers, the RoPax vessels will find the issue of speed to be even more complex. In bulk and tanker shipping, the transport cost is high compared to the value of the goods, and fuel costs constitute a major burden for the shipowners. On the other hand, RoPax bunker costs are less significant compared to time-dependent costs due to expensive vessels and large crews. Resembling deep-sea liner shipping, the value of cargo transported by RoRo shipping is also higher than that of tramp shipping, and thus the RoRo shippers are less price sensitive but are more conscious about the time-related service quality attributes such as reliability, speed, port turnaround time, transit time, convenient scheduling, and frequency [35,36]. RoRo/RoPax shipping in general operates like liner shipping on a regular schedule, at an advertised price, with predetermined routes and destination ports. A change in price, schedule, frequency and speed of the vessels can enhance or deteriorate the service quality of the shipping companies [37].

In the RoPax sector, the variety in demand is also as wide as it gets in the transport industry. Travelers with cars who want to cross the water to continue driving are mixed with passengers who want to eat, shop, or just entertain themselves on board. Time-critical cargoes like vegetables, components scheduled for assembly, and e-commerce deliveries are loaded on lorries on board and mixed with less demanding goods loaded in unaccompanied semi-trailers or containers. Revenues obviously stem from the transport service, but there is also a time-dependent element in terms of sales on board.

Hence, scheduling is a big compromise between different time requirements and the compromise differs depending on routes, time of day and season. Most customers want a high speed, but on some routes a slow speed is a value added for passengers who want to eat and for lorry and bus drivers who want to use the crossing as a rest period and thus, on some routes longer sailing times result in an increase in revenue from on-board spending, as stated by Zis and Psaraftis [16]. To further complicate the issue, a lower speed might force the shipping line to deploy more or larger ships, choose a shorter crossing route or skew the timetable between days. Competition with land modes and a fixed connection are also liable to be affected and a modal backshift from sea to road, in particular for cargoes of very high value, can also be a likely outcome of slow steaming [16]. If the speed changes significantly, the vessel might have to be reconfigured to get the right combination of shops, restaurants, bars, seating areas and cabins. In addition, operating far from the design speed is likely to necessitate modification of the hull, a change of propellers and possibly also adjustments to the engines [38].

2.3. Competitiveness

RoRo and RoPax vessels on some routes compete wing-to-wing with the alternative transport modes of road and rail. Reducing the speed beyond a certain level may put sea services in an unfavorable competitive position by negatively affecting their service quality. Mancera [39] defines service quality as the shipper's perceived quality of a transport process based on its performance, and sees SQ as comprising five main attributes, namely speed, reliability, lead time, freight rates, and cargo loss and damage.

Service quality is one of the most substantial components of competitiveness [40] and both Paixão Casaca and Marlow [36] and Yang, et al. [41] have verified that high service quality improves the competitiveness of shipping firms. High-quality services assist to differentiate a shipping firm from its competitors [42]. Among other factors, time is one of the key components of service quality, and time-related factors such as schedule reliability, sailing frequency, and speed are valued highly by cargo owners when selecting shipping services [43]. High performance in these time-related factors can considerably reduce the shippers' inventory, production, and logistical costs [37]. The positive effect of service quality on the competitiveness of shipping firms is empirically proved [42]. High performance in SQ improves customer satisfaction [44], and satisfied customers usually continue purchasing and even recommending the services to others [45]. Consequently, this may enhance a firm's competitiveness in terms of higher revenues or retained customers [46].

Some other studies suggest that employing larger vessels with more cargo on board on a single voyage and increasing port efficiency may counteract the side effects of slow steaming to some extent [47]. Similarly, ship operators pursuing a slow steaming strategy may gain competitive advantage over their rivals and attract more customers through service differentiation based on different transit times, reduced freight rates, and speed [42,48,49]. The methodology used in this article is presented in the next section.

3. Method

This study is exploratory in nature. Therefore, based on Yin [50], a multiple case study methodology has been applied. Yin [50] suggests that a case study investigates a contemporary phenomenon within the real-life situation, in particular when the relation between the phenomenon and context is complex. This observation is applicable to our research, as we explore the contemporary phenomenon of slow steaming in the context of SECA regulations and their impact on the competitiveness of shipping companies. Slow steaming is a complex topic and depends on multiple factors; therefore, a qualitative approach is more appropriate to explore this topic in-depth. Through interviews, it is possible to ask follow-up questions and to draw more information from the interviewees. This eventually helps to enrich the data and uncover the important topics and concepts that may be missed in quantitative research [50].

Around 387 RoRo and RoPax ships were affected by the sulfur regulation in the North and Baltic Seas SECA [11]. The case studies in this research comprise a sample of eleven case firms, that operate a total of 154 RoRo and RoPax ships in SECAs and represent about 40% of the RoRo and RoPax ships that are affected by the sulfur regulation. The main reasons for selecting the RoRo and RoPax segments for this study are that they play a pivotal role in intra-European freight transport and they operate fully within the SECA. In addition, these segments consume large amounts of fuel, were expected to be highly affected by SECA regulations, and have not been the focus of scientific studies. The service type, size, and other significant information about case firms and the respondents are summarized in Table 1.

After a comprehensive literature review focusing on short sea RoRo/RoPax shipping, slow steaming, SECA compliance strategies, and customer requirements regarding the service quality of RoRo/RoPax shipping, 25 RoRo and RoPax companies operating in the North and Baltic Seas were approached for interviews. In the end, 11 managers from such firms participated in semi-structured face-to-face or telephone interviews. Eisenhardt [51] suggests that when the objective of the research is explorative, this sample size sufficiently provides a clear picture of the context. All the interviews were audio-taped and transcribed. Follow-up interviews were conducted in January 2019 to collect the updated information regarding slow steaming in the context of increased bunker prices in 2018. The research questions (Appendix A) were provided to the interviewees beforehand, and they were reassured about the confidentiality of their identity and information. Company names are represented in the remainder of this article simply by capital letters.

Table 1. Summary of case companies.

Case Company Profile							Respondents		
Name	**Vessel Types**	**Fleet Size**	**Main Service Region**	**Annual Cargo and Passenger Transport**	**Main Customers**	**Head-Quarters**	**Function**	**Position**	**Secondary Data**
Case RoRo									
A	Pure car truck carrier (PCTC)	21	All European seas	1.7 million car equivalent units	New cars, commercial vehicles, semi-trailers, high & heavy cargo	Norway	Head of sales and marketing, business generation and performance	Senior	Company website, annual reports, internal newsletters
B	Pure car truck carrier (PCTC)	10	North Sea and Baltic Sea	0.8 million units	New cars, commercial vehicles, trailers high & heavy cargo	Germany	Manager, quality & technology	Senior	Company website, annual reports, internal newsletters
C	RoRo	10	North Sea	-	RoRo, trailers, high and heavy	Norway	Director, shipping division	Senior	Company website, annual reports, internal newsletters
D	RoRo	5, including 3 RoRo	North Sea and Baltic Sea	-	Project cargo, paper products, rolling units	Sweden	Head, marine transportation	Senior	Company website, annual reports, internal newsletters
E	RoRo LoLo	11, including 8 RoRo vessels	North, Baltic, Mediterranean Seas	-	Project cargo, paper products, military transport	Sweden	Managing director	Senior	Company website, annual reports, internal newsletters
Case RoPax									
F	RoPax RoRo	37, including 31 RoPax and 6 RoRo	North Sea, English Channel, Baltic Sea	7 million passengers, 1.5 million cars, 2 million freight units	Passengers, RoRo cargo, new cars and project cargo	Sweden	Freight commercial manager Scandinavia	Senior	Company website, annual reports, internal newsletters
G	RoPax RoRo	50	North Sea, English Channel, Baltic Sea	6 million passengers, 31 million lane-meters of freight	New cars, passengers, trailers	Denmark	Director, environment and sustainability	Senior	Company website, annual reports, internal newsletters
H	RoPax	6	North Sea	4 million passengers, 0.9 million cars, 0.71 million freight units	Passengers, cars, trailers	Norway	Vice president, marine	Senior	Company website, annual reports, internal newsletters
I	RoPax	1	Baltic Sea	-	Passengers, trailers	Finland	Chief operating officer	Senior	Company website, annual reports, internal newsletters
J	RoPax	4	Baltic Sea	1.6 million passengers, 0.48 million cars, 0.73 million lane-meters of cargo	Passengers, trailers	Sweden	CEO	Senior	Company website, annual reports, internal newsletters
K	RoPax	4	North Sea	1.1 million passengers, 0.34 million cars, 50,000 trailers	Passengers, freight	Norway	Managing and technical director	Senior	Company website, annual reports

NVivo software (QSR International, Melbourne, Australia) was used to organize and analyze the interview text. In NVivo, the interview text was categorized into themes and concepts (Appendix B), which helped to identify the relevant and important concepts and strengthened our findings. It was an iterative process, where we moved back and forth between the collected data, analysis, and interpretation. The findings of this case study are presented in the next section.

4. Results

In this section, the results obtained through the analysis of case companies are presented.

4.1. SECA Compliance and Slow Steaming

In the pre-SECA phase, when managers were planning for SECA compliance, case firms reported that they commenced preparing prior to the 0.1% sulfur limit deadline of 1 January 2015. Various feasibility analyses were conducted for each SECA compliance option—MGO, scrubbers and LNG—and these analyses were based on individual vessel characteristics, operating routes, and the short- and long-term costs of each option. In addition, firms in both clusters outlined that they developed mechanisms for the Bunker Adjustment Factor (BAF) and that data regarding the extra freight rates were transferred to freight customers through information sessions. In general, customers understood the situation and accepted the extra costs caused by SECA. The actual compliance strategy of each case company and its reactions regarding slow steaming and increased BAF in the aftermath of the 0.1% SECA regulation are presented in Table 2.

Table 2. SECA compliance measures and SECA-driven slow steaming. Source: Interviews.

Company Name	SECA Compliance Measures	SECA-Driven Slow Steaming	SECA-Driven Increased BAF
RoRo			
A	MGO and LNG for new vessels	No	✓
B	MGO and scrubbers	No	✓
C	MGO and ultra-low sulfur fuel	No	✓
D	Ultra-low sulfur fuel (RMD 80)	No	✓
E	MGO	Yes—Reduced speed from 16.5 knots to 14.5 knots between Finland and Germany	✓
RoPax			
F	MGO, scrubbers, and methanol	No	✓
G	Scrubbers, ultra-low sulfur fuel and MGO	No	✓
H	Scrubbers and MGO	No	✓
I	MGO	Yes—reduced speed from 19.5 knots to 17.5 knots on a route between Finland and Sweden	✓
J	LNG and MGO	No	✓
K	LNG and MGO	No	✓

With respect to actual SECA compliance solutions, most of the RoRo and RoPax case firms followed a mixed strategy (Table 2). They switched to MGO and ultra-low sulfur fuel (e.g., RMD 80) for smaller and older vessels that were operating on comparatively short-distance routes and selected scrubbers or LNG for bigger, newer and high-fuel-consuming vessels operating on long-distance routes. Furthermore, the case of firm RoRo E was remarkably different, as it used MGO on its entire fleet and instead of choosing technological solutions to save on costs, firm E opted for operational changes that constituted schedule and route adjustments and slow steaming on some routes. In the same vein, RoPax I switched to MGO and reduced the vessel speed as an energy efficiency measure on its route between Baltic ports. On the other hand, the case of RoPax F, in contrast, is relatively different. For certain routes, RoPax F switched to MGO and converted one of its vessels to methanol.

Overall, it appears slow steaming as a SECA cost-reduction approach has not been part of the plan among the majority of the case companies. Out of 11 case firms, only two firms—RoRo E and RoPax I—as part of their pre-SECA plans, in addition to switching to MGO, also made some route changes and reduced the vessel speed on some routes, each increasing their total crossing times from 32 to 36 h and from 4 to 4.5 h, respectively.

It is found that neither the reduced bunker prices in 2015 nor the increased bunker prices in 2018 have affected the speed patterns in most of the RoRo and RoPax case firms. As the interviewee from RoRo E stressed:

> *There are a lot of other parameters besides oil price that we have to consider before making any change in our speed, and the biggest factors are competition, contract, and market situation.*

In RoRo and RoPax segments, the additional bunker cost driven by SECA compliance is borne by both the customers and the shipowners. All the case firms have transferred these additional costs to their customers through an increased BAF. The interviewee from RoRo A mentioned:

> *Yes, we have partially increased BAF. Basically, all contracts are governed by a bunker adjustment formula. This doesn't mean that bunker costs are irrelevant, but we cannot transfer all the extra bunker cost to our customers. If we are not efficient enough, we will then lose all contracts upon renewal due to the cost base being too high. But inside a contract the risk is limited for the shipping company.*

Moreover, for the new ships in the pipeline, the case companies intend to comply with SECA by burning comparatively cheaper and environmentally friendly fuels, such as LNG, or by using batteries. LNG would not favor slow steaming, while the use of battery power might be more favorable for slow steaming.

4.2. Slow Steaming in the RoRo and RoPax Cases

Regarding the feasibility of slow steaming in the existing market situation, significant divergences are noticed between the RoRo and RoPax case firms. The RoRo case firms picture slow steaming as a popular choice to save bunker costs, at least under the existing market conditions, and currently almost all of them have reduced their speed by 4 to 10 knots, except for RoRo B that has set a reduction of only 1–2 knots seasonally. However, it must be noted that this slow steaming is not driven by the 0.1 percent sulfur regulation; rather it is based on the market conditions and customer demand, and was in existence even during 2015 when the bunker prices were low. It was found that RoRo case firms have benefited considerably by steaming at a slower speed, as, for instance, was revealed by the interviewee from RoRo C:

> *Of course, on a route between Western Norway and UK using slow steaming we are saving cost and we save more by having two slow vessels rather than just one fast vessel.*

One of the reasons behind slow steaming in RoRo was also the economic downturn of 2008. As the interviewee from RoRo A mentioned:

> *This is something we started quite early in 2008 or 2009 because of the financial crisis. We were forced to do that and the main purpose behind this was financial savings.*

The interviewees from nearly every RoPax case firm favored slow steaming as an energy efficiency and cost-saving measure. For example, the interviewee from RoPax H mentioned that:

> *We are tweaking here and there. We are looking for minutes, 15 minutes or so, and there is a lot of money in there. In RoPax, we don't talk about hours, but we talk about minutes.*

However, in contrast to the RoRo segment, it was revealed that there is a very little potential for slow steaming in the RoPax sector. It was found that RoPax case firms have instituted some route-specific slow steaming in the range of 1–2 knots slower, and this varies seasonally. To meet market requirements, RoPax firms F, J, and K operate high-speed ferries on some routes with speeds in the range of 27–35 knots. For some routes, in the summer season, when passenger demand is high and extra time needs to be spent in port for loading and offloading, it is not usually possible to slow steam. The interviewee from RoPax H stated:

> *It is possible that we can change the itinerary in summer and winter times, but that's not good because the market wants to have the same schedule for arrival and departure times throughout the year.*

Technical reconfigurations and shorter routes might be needed to implement slow steaming. To facilitate slow steaming, all RoRo case firms, except RoRo B, have made some technical reconfigurations to their vessels by optimizing the pitch and rotation speed of the propellers. Moreover, case firms RoRo B, D, and E sometimes choose a shorter course for steaming slow. The interviewee from RoRo B stated:

> *We also sometimes adjust our routes to adjust the speed and it depends on fuel prices as well. So there is interplay between route, speed, and fuel price.*

However, RoPax case firms did not make any reconfigurations in either their cabins or engine rooms, nor did they change the sailing route as they have introduced only a minor speed reduction.

4.3. Slow Steaming and Service Quality

In addition, all interviewees strikingly emphasized that vessel speed is highly dependent on their customers' lead time requirements, inventory costs, bunker prices, and competitors' operating speed. As the interviewees from RoRo A mentioned:

> *We have to consider our customers' requirements that were set in the contract. So, to meet customer demand, we may even have to speed up although it might pollute the environment. As long as our competitors will go fast, we will also go fast. Otherwise, we will be out of business.*

Similarly, the interviewee from RoRo B emphasized:

> *We cannot play at least with lead time, as our customers give us lead time. For instance, if our customer wants their cars transported from Zeebrugge to Malmo, let's say in three days, we have to transport them in three days.*

This is verified in the case of RoRo D, who in order to meet the customers' demand, made some adjustments in their routes, accelerated the sailing frequency, and raised the speed from 12 knots to 14 knots.

Vessel speed in the RoPax sector also critically depends on offered transit time, vessel type, departure and arrival time, distance between origin–destination ports, and the competitive environment. The interviewee from RoPax H explained the situation in this way:

> *Compared to RoRo service, the RoPax segment is different in a way as we have passengers on board who are usually in a hurry. Cruise ships may do slow steaming, but for ferry transport it's not possible as it has a proper timetable and not many people want to arrive at midnight and leave before 6 in the morning. Passengers need to shop on board, relax and eat as well, so we have to adjust the time accordingly. In this segment, we compete on time. For a shorter distance, forget slow steaming. However, for a longer distance, it's different. For instance, a ship from Stavanger (Norway) to France can go a little slower.*

The speed and schedule sometimes vary en route and on a customer segment basis. As the interviewee from RoPax F stressed:

> *If there is a heavy freight route, then the drivers need time. Then, of course, it's better to spend 9 hours at sea instead of 2 hours, and if the route is very passenger heavy, they don't want to spend too much time at sea.*

However, the departure times are not based only on the drivers' time; as the RoPax case firms mentioned, they do not know where the truck is coming from and hence do not know if the drivers require a longer resting time on board the vessel. Scheduling, pricing and crossing timing is complex in the RoPax segment, and compared to RoRo, RoPax serves a wide variety of customers. Thus, it may not be possible to slow steam beyond a certain limit. As the interviewee from RoPax H stressed:

> *We have many markets on each ship. For instance, one of our ships has 13 different categories of passengers: cruise passengers, conference guests, truck drivers and so on. These 13 different passenger categories have different requirements when deciding whether they are sailing with us or not. Some customer segments can be affected if we sail slower, so at the moment the market is not favorable for steaming slower.*

Moreover, RoPax case firms have a fiercer competitive environment than RoRo, as depending on the route, RoPax competes with low-cost airlines, domestic ferry companies, trucking (cheaper double-driver effect), tunnels, bridges, landside conference centers, cargo ships or RoRo, and all other sources of entertainment. On some routes, vessel speed also depends on other ferry competitors' speed, as stated above. Some case firms indicated that currently they are at the optimum level; but if a new competitor shows up, then they will adjust it accordingly. The interviewee from RoPax H expressed the competitive situation as below:

> *Although the slower you go, the more energy you save for a container cargo, the competition is extremely high. For example, the Helsinki–Tallinn route in the Baltic Sea is one market where more than three companies are now operating more than ten ships—and even a helicopter line is operating sometimes—and their competitive advantage is if they go faster. If one goes 15 minutes faster, then another does the same. They go 27 knots and they lie still for 2 hours as they need to come back again at 27 knots. So, this is what markets want instead of sailing at 22 knots, lying still for 1 hour, and then going 22 knots back. That's how a bad market mechanism works in a free open market, because time is money in this market.*

In addition, RoPax case firms were extremely concerned about the cheaper and double drivers from low-cost countries employed by trucking companies, as they are undermining the competitive position of the shipping industry, and therefore, it further reduces the possibilities of gaining energy efficiency through slow steaming. Similarly, the interviewee from RoPax F mentioned:

> *If oil prices increase again, then slow steaming may come into play. But then there are some road taxation and other elements to consider in that situation.*

Therefore, it can be inferred from the above interview excerpts that the matter of speed reduction is highly sensitive for both RoRo and RoPax segments, as both segments need to comply strictly with the offered lead time while maintaining the service frequency. In the current market settings, too much gambling with speed may negatively affect the service quality of both shipping segments and eventually may reduce the competitiveness of this sector.

RoRo and RoPax case firms pointed out that demand for their services is highly elastic in terms of service quality (e.g., lead time, convenience of departure and arrival) and price on certain routes, and this is because the customers have multiple alternatives to travel and transport their cargo. The interviewee from RoPax I said:

> *Our leisure passengers are extremely price sensitive, and any increase or decrease in the price can affect the demand as they have various alternatives available.*

. . . and RoPax H pointed out:

We tried to reduce the speed and increase time to 3 hours from 2.5 on our route to country S, but customers didn't like it and then we reversed it back again.

Thus, service quality requirements, service price and route competition are some of the vital factors deciding the speed of RoRo and RoPax vessels.

4.4. Slow Steaming through Port Efficiency

The study found that there is some potential to improve port efficiency while reducing the speed at sea. All RoRo case firms expressed the view that improved port efficiency could enhance the feasibility of slow steaming. In particular, RoRo C and D are focusing on making slow steaming a favorable move by improving port productivity. As the interviewee from RoRo C emphasized:

In our fleet we have turned vessels earlier. This means we have reduced the loading and discharging time at port to get extra time at sea and reduce the speed. Port efficiency is important not only for slow steaming but also to maintain the schedule in bad weather as reliability is important for our customers.

Similarly, RoPax case firms agreed that to allow more time at sea at a lower speed they try to optimize the port operations as much as possible, and this also depends on the season. As the interviewee from RoPax K mentioned:

We have tried to optimize port operations so we could spend more time at sea at a lower speed. We have also shortened our turnaround time on a route between Western Norway and Northern Denmark. Instead of 2 hours, we now stay 1 hour in port and have spare time at sea to slow steam.

A follow-up question related to the above statement was asked by the interviewer:

Well, but don't you think that staying only 1 hour at the port limits your catchment area?

The interviewee from RoPax K responded:

No, no. It's not like that. Passengers and freight forwarders know the timetable so they reach on time and they go at that time every day. Of course, you have a catchment area, but the market is like this.

Although slow steaming through improved port efficiency is feasible, there are still some limits. RoRo operators cannot depart immediately after arrival as they have to complement their schedule with cargo arrivals at the terminals, and RoPax operators need to follow their posted departure time. In addition, slow steaming by reducing port turnaround time leads to a reduced catchment area for the customers and, thus, RoPax and RoRo companies may lose some business. So they always need to weigh the savings they make by steaming slow against the business they may lose in the form of reduced sales caused by short turnaround times.

4.5. Slow Steaming through Service Differentiation

Due to high competition and expensive cargo, service differentiation through slow and express services in the RoRo cases cannot be attained to any large extent in the existing market mechanism. As the interviewees from RoRo A and B stated, respectively:

I think it's not about speed; it's more about precision. If we follow this policy, then there will be a competitor who will do the same, so it's not possible for us.

Well, our customers who usually ship highly expensive cargo are not talking about such things, and it also depends on their customers as well. So there is no room for much speed reduction and our timing depends on our contract with customers.

This is evident by the fact that in 2010 RoRo E pursued a differentiation strategy by introducing the slowest RoRo service in the Baltic Sea. However, intensive competition from rival RoRo companies and an alternative rail service operating on the same route compelled RoRo E to close its operations on this route.

On the other hand, service differentiation and slow steaming may be feasible for at least some RoPax customer segments on certain routes. This differentiation can be illustrated in the case of RoPax H and RoPax K. RoPax H operates a cruise ferry on a route and the transit time is 3 h 15 min with a return ticket price for one person of EUR 56. Meanwhile, on the same route, RoPax K offers an express service only in the summer season that takes just 2 h 15 min and is even cheaper, with a return ticket price for one person of EUR 35.

So unlike deep-sea shipping where shipping firms compete mainly with other shipping firms serving the same route, the offer of reduced speed and price as a service differentiation strategy may not be feasible in the RoRo segment, which is also competing with land modes. For a RoPax firm, however, it may be realistic depending on the route and customer demand.

4.6. Slow Steaming through Increased Vessel Size

Finally, our study found that transporting more cargo onboard the larger vessels is not feasible for the RoRo and RoPax shipping segments, as they still would have to follow the lead time and frequency requirements of their customers. In addition, there might not be sufficient port infrastructure to cater for the larger vessels. Different opinions are noticed on this issue as the interviewee from RoRo D suggested:

> *I think for paper-shipping companies, it is possible as the customer can live with a little longer lead time.*

RoPax G in this respect stressed that:

> *We are increasing vessel capacity and unit size in our new vessels, but there will be no change in speed requirements.*

The interviewee from RoPax K commented on this by saying:

> *When you get larger vessels, you also reduce the frequency and that may not be a good idea. In deep-sea shipping, with low competition from alternative modes, it can work where you have crossing times in weeks from China to the EU. Then you can have bigger vessels and reduce the frequency. But in SSS, you also need frequency; otherwise, you will lose the load.*

The majority of RoRo and RoPax case companies rejected the idea of supporting slow steaming by building larger vessels, as it might affect their customers' logistical arrangements and lead to a modal shift to road transport. The results presented here are discussed in the context of the existing literature in the section below.

5. Discussion and Conclusions

In this article, we have addressed the feasibility of slow steaming to mitigate the anticipated SECA compliance costs from the perspective of RoRo and RoPax shipping firms. In addition, the impact of slow steaming on the competitiveness of short sea RoRo and RoPax segments with respect to service quality is explored. Multiple case studies focusing primarily on 11 short sea RoRo and RoPax firms with operations in the North and Baltic Seas were conducted.

Overall, our findings suggest that the 0.1% SECA regulation of 2015 requiring the use of higher-priced MGO has not caused slow steaming in the RoRo and RoPax segments to any great extent. The increased bunker prices are partially transferred to the customers via increased BAF and partly borne by the shipowners. Thus, our findings are consistent with those of Adland, et al. [13], who in their empirical study found no evidence of slow steaming in the wake of North Sea SECA regulations and asserted that vessel speed is not generally determined by fuel prices or freight rates but is rather dependent on factors such as route characteristics, vessel type, weather, market segment and conditions, and the nature of the commercial contract between the shipper and the ship operator.

Furthermore, time-related attributes of service quality, such as total transit or lead time, frequency, reliability, and convenient departure and arrival times, are found to be considerably more significant for the customers of RoRo and RoPax case firms. In this way, we agree with previous research studies by Meixell and Norbis [35], Bergantino and Bolis [52], and Pantouvakis [53], who claim that for ferry and RoRo transport customers service quality—in regard to schedule convenience, frequency, reliability, and transit time—is even more important than the price of the ticket or the freight rate. For the RoRo and RoPax case firms, the elasticity of demand in terms of price and service quality is significant, as verified by Notteboom [10]. Therefore, in the present market setting, the potential of slow steaming is not high, as it may increase the lead time or affect the frequency, reliability, and departure and arrival times of the services. The slow steaming strategy that neglects the customers' convenience is likely to diminish the service quality of RoRo and RoPax firms, leading to a poor competitive position in the market.

Furthermore, the idea of slow steaming by using larger vessels with more cargo on board, which may be effective when applied in deep-sea shipping [47], is not practical for short sea RoRo and RoPax shipping. As officials of the case firms interviewed for our article stressed, in short sea shipping frequency is highly critical for the customers, and to maintain sailing frequency firms will need to employ more vessels which is not possible currently.

Similarly, our findings strongly support earlier studies by Johnson and Styhre [31] and Zis and Psaraftis [16] which suggest that due to high port efficiency and low turnaround port time, slow steaming can be employed without affecting the total transit time for the customers. The examples of case firms RoRo C and D and RoPax K, presented in the findings section, justify this phenomenon.

Finally, service differentiation through slow and express services as proposed by Lindstad, et al. [49] may be feasible also for the short sea RoPax segment but only on certain routes. This has been demonstrated by the example of case firms RoPax H and RoPax K who compete on the basis of transit time by operating a slow cruise ferry and a fast-express ferry, respectively. Conversely, due to high inventory costs and competition from alternative transport modes for RoRo cargo, this differentiation may not be favorable in the RoRo segment. Previously, a Swedish RoRo shipping firm tried this concept as described by [54], but this service was discontinued in 2013 due to low market demand and fierce competition by direct rail service started between Germany and Sweden [55].

The quest to cut bunker costs and airborne emissions through slow steaming may result in negative ramifications for short sea RoRo/RoPax shipping and its customers by affecting entire supply chains. The case studies reveal that in the current market situation RoRo case firms are already steaming at slow speed and they may increase the speed based on the customers' demand.

We believe that the potential of slow steaming for the RoPax and RoRo segments are impeded by a number of factors, including bunker prices, rigorous competition in terms of cost and time within RoPax shipping lines and routes as well as with land modes, and most important different service quality-related attributes. It is evident from the interviewees from the case firms that slow steaming across a certain limit in the RoPax segment may either lead to a loss of business volumes or otherwise will require more vessels to maintain the frequency. However, the present market situation does not favor additional tonnage in the sector as it appears that the market has found its equilibrium. Finally, the slow steaming strategy that works against the customers' convenience may deteriorate the service quality of RoRo and RoPax services, which ultimately may lead the sector into an unfavorable competitive position in the market. In the next section, the limitations and suggestions for future research are presented.

Limitations and Future Research

Even though some valuable insights have been generated, this article is not without its limitations. The experienced interviewees from the case firms provided their expert opinions on the subject that could fairly represent the viewpoint of the entire RoRo and RoPax sector, yet a larger sample size would perhaps have supported the findings better. Secondly, it would be valuable to conduct surveys involving more firms from different sectors and countries. Finally, findings regarding the service quality requirements of customers are based on the opinions of interviewees from RoRo and RoPax case firms and a survey with actual customers of these services might have added more balance to the results. All these limitations form the basis for future research.

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Appendix A Interview Questions

SECA

- How did you prepare before the introduction of the stringent sulfur limits of 0.1% implemented from January 1, 2015?
- What option have you chosen to conform to the SECA—e.g., LNG, MGO, methanol, scrubbers, or a combination of different alternatives?
- Did you test any low-sulfur fuels before the introduction of the 0.1% limit? What experiences/ lessons arose as a result?
- How has the ensuing situation been different compared with the assessments you did before the introduction of the SECA 2015 0.1% sulfur limits?
- Do you think that other RoRo/RoPax operators that chose other strategies (scrubbers, for example) implemented their strategies, or did they put them on hold due to the decreased bunker prices?
- If the oil price increases again, do you feel that you are better prepared than your competitors who retrofitted with scrubbers or LNG?

Slow Steaming

- Have you worked with any slow steaming in your RoRo (or RoPax) segment? How has it been differently customized based on vessel type, route, season, etc.?
- Have there been any discussions in your company to compensate for the additional SECA costs through slow steaming?
- Has the transition to low-sulfur fuels affected the slow steaming profile of the ships?
- Have you considered changing the route, such as searching for the shortest crossing to allow a lower speed?
- Do your vessels need to be reconfigured (cabins/seats, restaurants, car tire heights/ramps, etc.) to adapt to a different sailing speed and transit time? Do they need to be rebuilt (bulb adapted for a different speed, slow steaming kits, etc.)?
- Would it be possible for some lines to differentiate their services by increasing vessel speed and get a higher price or reduce the speed and get a lower price?
- Do you think increased port efficiency can encourage slow steaming?
- For the RoRo and RoPax segments, is it feasible to transport more cargo on bigger vessels in a single journey and slow steam?

Service Quality Requirements

- Which customer segments do your various lines serve? Is there a dominant segment that sets the conditions for service design, schedule, quality, price segmentation, etc.?
- What is your "value proposition"?
- What are your customers' service quality requirements?
- Do you have an idea of the elasticity of the customer demand curve in terms of transit time, frequency, price, departure and arrival timing?

Future Plans

- What plans/strategies/scenarios do you see ahead regarding slow steaming in the RoRo (or RoPax) segment?
- Are there any other important issues related to this topic?

Appendix B

Table A1. Code tree developed based on the in-depth analysis of interview transcripts.

Concepts Emerged
1. SECA regulation
1.1. Pre-SECA preparation
1.1.1. Low sulfur fuel tests
1.1.2. Commercial approach
1.2. Post SECA situation
1.2.1. Evolution of new fuels
1.2.2. Bunker price decline
1.3. Firms' SECA compliance solution and slow steaming
1.3.1. Scrubbers
1.3.2. MGO
1.3.3. LNG
1.3.4. Hybrid or ultra-low sulfur fuel
1.3.5. Methanol
1.3.6. Mix
2. Service quality requirements
2.1. Service frequency
2.2. Schedule flexibility
2.3. Price
2.4. Lead time
2.5. Inventory costs
2.6. Departure and arrival time convenience
2.7. Elasticity of demand for services
2.7.1. Price
2.7.2. Lead time
2.8. Customer segment that set quality requirements
2.8.1.Truck drivers or freight forwarders
2.8.2.Cargo owners
2.8.3.Car drivers and passengers
2.9.Core values of the firms
3. Slow Steaming
3.1. Existing slow steaming pattern
3.2. Slow steaming and vessel configurations
3.3. Slow steaming and shorter routes
3.4. Future potential for slow steaming
3.4.1. Slow steaming through port efficiency
3.4.2. Slow steaming through larger vessels
3.4.3. Slow steaming and service differentiation
3.4.4. Levy or CO_2 taxes
3.4.5. Future bunker price
3.4.6. Competitors' speed
3.4.7. Competition and market mechanism

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Paper III

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Article

The Integration of RoRo Shipping in Sustainable Intermodal Transport Chains: The Case of a North European RoRo Service

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Abstract: Roll on–roll off (RoRo) shipping represents a maritime segment that could easily form part of an intermodal transport system, as cargo does not need to be lifted in ports; it is 'rolled' to and from sea. This paper investigates the operation of RoRo shipping services in Northern Europe, focusing on a set of services chartered by a major shipper whose demand has a great impact on the service design, potentially affecting the frequency of departures and even stipulating the use of specific vessels. The case of cooperation between Stora Enso, a major forest company in Sweden and Finland, and the shipping company Swedish Orient Line (SOL) is analysed, giving some insight into the way these RoRo services operate and manage to integrate successfully into sustainable intermodal transport chains. Despite various initiatives taken by different stakeholders, the level of integration of shipping in intermodal transport chains has been quite slow. This paper's results could contribute to the identification of barriers that prevent RoRo shipping from being a viable alternative to road transport for certain transport routes and assist in the discovery of policies and incentives that could lead to developing sustainable intermodal transport chains.

Keywords: RoRo shipping; intermodal transport; Northern Europe; forest industry

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1. Introduction

Sea transport offers significant environmental advantages, as it transfers more than 90% of the global trade in volume while emitting around 2.2% of total global greenhouse gas emissions [1]. In 2015, maritime transport, including domestic and international shipping, emitted 151 million tonnes of CO_2 equivalents in the 28 European member states, accounting for 12.7% of the transport sector's total emissions [2]. However, integration of shipping into intermodal transport chains has not been achieved until now, despite various initiatives undertaken by stakeholders [3]. Significant differences amongst diverse segments of the shipping industry need to be considered for adoption of effective policies and incentives that could lead to further use of shipping in intermodal transport chains [4]. Roll on–roll off (RoRo) shipping represents a maritime segment that could easily form part of an intermodal transport system, as cargo does not need to be lifted in ports; it is 'rolled' to and from sea. However, the employment of RoRo shipping depends on several parameters, such as the type of cargo transferred and cargo volumes, and is strongly influenced by shippers' demands that 'define' its operations. RoRo shipping, in contrast to deep sea segments, faces strong competition from land-based modes of transport and constantly seeks to satisfy shippers' demands and offer high-quality transport services [5].

Although the development of maritime supply chains has been investigated extensively in the supply-chain management literature, limited focus has been given to the potentially different barriers that prevent different maritime segments from being part of intermodal transport chains [4,6–9]. It is exactly this scientific gap that this study addresses: the need to consider various maritime segments separately and research their potential to form part of intermodal supply chains and support sustainable transport operations. This paper aims to investigate how maritime transport and, in particular, RoRo shipping can be integrated into intermodal transport chains and highlight the potential environmental benefits from such an integration. A novel aspect of this research is that it takes into consideration the particular features of RoRo shipping and how they enable or prevent this maritime segment from being included in intermodal supply chains.

This paper explores the operation of RoRo shipping services in Northern Europe, focusing on a set of services chartered by a major shipper whose demand has a significant impact on service design, potentially affecting the frequency of departures and even stipulating the use of specific vessels. The geographical area of Northern Europe was chosen in our study, due to the extensive use of RoRo services in this region as well as the development of innovative business models for the satisfaction of the transport needs of major shippers, belonging to the automotive, forestry, food and drinks, and electric equipment industries.

The case of cooperation between Stora Enso, a major forest company in Sweden and Finland, and the shipping company Swedish Orient Line (SOL) is analysed, giving some insight into the way these RoRo services operate and manage to integrate successfully into sustainable intermodal transport chains. Stora Enso has developed a unique intermodal logistics system for the transport of its products using an innovative cargo unit, the Stora Enso Cargo Unit (SECU), which can be transported by ships and trains in Sweden and Finland. The hub of the logistics system is the port of Zeebrügge, but the Port of Gothenburg plays an important role for the Swedish flows as the SECUs are transhipped to RoRo vessels from the railway to reach continental Europe.

This paper's results could contribute to the identification of barriers that prevent RoRo shipping from being a viable alternative to road transport for certain transport routes and assist in the discovery of policies and incentives that could lead to the development of sustainable intermodal transport chains. The paper is structured in the following way: Section 2 describes the existing literature on intermodal and RoRo shipping operations and reviews the employment of RoRo services by the Nordic forest industry. In Section 3, the case study methodology used in our analysis is presented, while the case study of a Swedish RoRo shipping company cooperating with a major Swedish–Finnish forest company is analysed in Section 4. The significant findings of the paper, as well as our main conclusions, are summarised in Section 5.

2. RoRo Shipping

This section includes a brief presentation and analysis of the literature on intermodal transport and RoRo shipping, focusing on Northern Europe's RoRo services and coming to the employment of RoRo shipping by forest companies.

2.1. Literature on Intermodal Freight Transport and RoRo Shipping

Intermodal transport consists of the combination of at least two traffic modes for the transfer of freight and is considered to offer a more sustainable transport service compared to unimodal systems, due to the aggregated benefits of each single mode [10]. Given the growth of global trade and the increased transport volumes, intermodal transport can enable a shift from road to more sustainable traffic modes, such as rail, sea or inland waterways and reduce the external costs from these transport services, including air pollution and congestion as well as accident events [11]. However, the development of intermodal transport chains is more complex than unimodal systems, as it implies the integration of different stakeholders and decision-makers that need to collaborate to ensure the efficient operations of the intermodal system [6,7,10,12]. Recent literature has focused on the various constraints that have a negative impact on the development and operations of intermodal logistics chains and prevent their further development [13]. Pricing problems in intermodal freight transport are highlighted by Tawfik and Limbourg [14]. According to their findings, certain intermodal operators choose to set the prices of their transport services on the basis of profit maximisation, even though they can predict the possible reaction of their shippers to choose a road alternative.

Special attention has been given to the integration of shipping in intermodal transport chains during the last decades [3]. Apart from its environmental performance, maritime transport has unlimited capacity and does not require high infrastructure investments, as compared to rail [15]. Maritime transport is divided into various segments that present substantial differences in their operations as well as their market structure [5]. RoRo shipping is largely differentiated from the other maritime segments due to its elasticity of demand that is much higher than the other segments, as it faces strong competition from land-based modes of transport. In general, RoRo services are liner services where frequent, scheduled seaborne transport services are offered between predestined ports of call. RoRo vessels are characterised as horizontally loading vessels, as their cargo can be towed into the vessel or brought in on wheeled vehicles without any special equipment, in contrast to LoLo (lift on/lift off), where the cargo needs to be loaded and uploaded by cranes [8,16].

According to Medda and Trujillo [17], RoRo vessels represent one of the main categories of the short sea shipping (SSS) market and are amongst "the most innovative shipping technologies from which we can effectively determine competitive SSS operations", as the horizontal handling of RoRo units implies low transhipment costs and fast cargo handling, essential for enhancing the competitiveness of SSS. Douet and Cappuccilli [18] outline the potential that RoRo shipping offers a modal shift in Europe due to the existence of road hauliers that (could) act as customers of the intermodal transport chain. However, RoRo operations require large cargo volumes and high frequency of departures to be economically feasible due to the initial capital cost of these vessels, which is significantly higher than a container feeder vessel of equivalent size [19]. Zachcial [9] also mentions the high construction and operational cost of RoRo vessels—due to their inevitably lower load factor compared with containerships"—as a possible explanation for their ''limited" employment in Europe. In addition to the economic parameter, he points out the need for a 'cultural' change from the sides of both shipowners and shippers for the development of efficient RoRo logistics operations that require different working methods, where inland and maritime carriers' operations are complementary rather than competitive. Ng et al. [3] underline the importance of ports for the establishment and successful operation of intermodal RoRo services, mentioning the high cost of cargo handling in ports that can significantly reduce their competitiveness and feasibility. Apart from port costs, extended times in ports can negatively influence the competitiveness of intermodal RoRo services [20]. Port interfaces, transit time and extra cargo handling costs were also identified as some of the main challenges for the development of short sea shipping in Canada [21]. According to Konstantinus et al. [22], considering the importance of synergies, effective policies are necessary to support SSS, developing cooperation among the transport chain members and improving the trust between them.

The sustainability aspects of RoRo and Roll on-Roll off Passenger (RoPax) shipping operations were highlighted by López-Navarro [23], who used the external cost calculator for Marco Polo freight transport project proposals in order to compare the environmental performance of road haulage and SSS. The Marco Polo calculator coefficients consider air pollution and climate change in SSS, are measured in euros per ton-kilometre and depend on the speed the RoRo/RoPax vessels operate at as well as the type of fuel they use. The RoRo vessels examined in this study operate at 15 knots and use low-sulphur fuel. This means that, according to Marco Polo calculator coefficients, the external cost of these vessels' operations is 0.0045 euros per ton-kilometre, compared to road transport that accounts for 0.0185 euros per ton-kilometre. Medda and Trujillo [17] and Paixão and Marlow [24] mentioned the reduced fuel consumption and related emissions of SSS compared to road and rail transport. This fact is verified by recent European transport statistics, where SSS accounts for 1% of the energy consumption and 12.1% of the emissions related to the European transport sector, while transferring 32% of the total freight volumes [25]. Nevertheless, the sustainability performance of RoRo shipping was strongly questioned by Hjelle [26], who pointed out that the low load factor of RoRo/RoPax vessels in addition to high operating speeds can result in high energy consumption and related emissions, suggesting road transport as the most environmental-friendly alternative. According to Hjelle [26], RoRo shipping represents the greenest transport alternative only in the case that NOx abatement technologies and low-sulphur fuels are used, operational speed is low and the utilisation rate of the RoRo service is high.

2.2. RoRo Shipping Segments

RoRo shipping is further divided into four submarkets: (a) the deep sea car carrying trade that includes the seaborne vehicle trade all over the world and is transported mainly by Pure Car and Truck Carriers, (b) the deep sea liner trade with RoRo facilities that combines the transport of containers and RoRo cargo on the same ship and is usually called the 'ConRo' (container-RoRo) submarket, (c) the shortsea RoPax ferries for the transport of both passengers and freight and (d) the shortsea unaccompanied freight (only) transport submarket [27]. The shortsea RoRo shipping segment (RoPax and unaccompanied RoRo) plays a significant role in the European seaborne trade, accounting for 14% of the total SSS of goods to and from main European Union ports in 2015 (Figure 1).

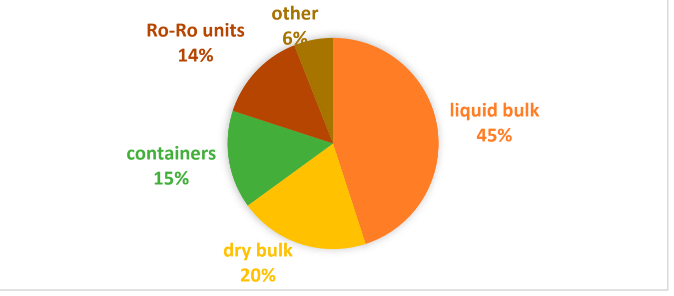


Figure 1. Short sea shipping of goods by type of cargo in the European Union in 2015 (% gross weight of goods). Source: Own elaboration based on data from Eurostat [28].

The integration of SSS in European intermodal transport chains has been an issue of major concern during the last decades, as it represents an environmentally friendly, energy-efficient and safe alternative to road transport that can facilitate the connection of remote and peripheral regions without requiring high infrastructure investments [15]. Sufficient cooperation with other modes of transport, low port costs and simplification of administrative and documentation procedures in ports are crucial factors for the further employment of SSS in intermodal logistics chains [3]. According to Paixão Casaca and Marlow [29], the improved efficiency of the carrier's transport network and the adoption of a different management approach that relies on carrier–shippers' relationships could enable the integration of SSS into multimodal transport chains.

This paper focuses on the operations of the fourth submarket of RoRo shipping, unaccompanied freight transport, which is largely employed by the forest-products companies in Northern Europe for the export of their products. Vessels involved in the unaccompanied freight RoRo submarket are old, rather large vessels that share the limitation of carrying up to 12 drivers [27]. López-Navarro et al. [30] mention that unaccompanied freight transport requires a quite complex organisation and is often chosen by large companies that handle high cargo volumes, as it implies major operational and organisational changes. These changes are related to five key operational areas: organisation of haulage and fleet restructuring, restructuring of driving staff, changes in the operating model and development of coordination capabilities, improving the commercial capacity at the destination, and establishing an adequate infrastructure to organise haulage in the destination country [31].

According to Eurostat [28], in 2015, 184 million tons of unaccompanied freight RoRo units were handled in main European Union ports, with the United Kingdom having by far the largest cargo volume of 51 million tons, followed by Italy, Belgium, Sweden and Germany. At port level, Immingham, Rotterdam, London and Gothenburg are major ports for the transport of mobile non-self-propelled RoRo units. In the next section, we focus on shortsea unaccompanied freight RoRo services in Scandinavia and the North Sea, which represents the major areas of these RoRo vessels' operations.

2.3. RoRo Shipping in Northern Europe

Unaccompanied RoRo services are widely used in Northern Europe to satisfy the transport needs of the automotive, forestry and electric equipment industries as well as imports of food and drinks. A large share of the shortsea RoRo traffic is located in the North Sea, linking Scandinavia, the UK and continental European ports and accounting for about 38% of the total European RoRo market [28]. The existence of this type of cargo, in addition to the topography of Northern Europe, consisting of countries with long coastlines and industrial and production centres near the coast, favour the use of RoRo shipping in relation to other maritime segments and land-based modes of transport [24]. Moreover, adequate cargo volumes in Scandinavia and the North Sea guarantee high frequency of departures for shippers and high-capacity utilisation for the shipping companies, which are both vital for the economic feasibility of the RoRo services [32]. According to Ng [33], "reasonable frequency, regularity and interoperability between land and maritime components" represent key factors for the competitiveness of SSS.

RoRo shipping holds a substantial share of the total cargo handled in the main ports of Northern Europe [28]. Finland and Sweden are amongst countries where this maritime segment plays a predominant role in freight transport, representing almost one-fifth of the total cargo handled in Finnish ports and more than one-quarter of the cargo handled in Swedish ports.

The transport demand of the Swedish automotive and forestry industries occupies the largest volume of short sea RoRo operations and determines the services provided. Both industries are characterised by the existence of a few large companies that need to transfer large volumes of cargo and often charter RoRo vessels to transport their goods. The unaccompanied freight transport RoRo shipping segment in Scandinavia is operated by a few shipping lines, such as Transfennica, employing 12 ice-strengthened RoRo vessels between Finland and major European ports; DFDS, with 21 RoRo vessels operating in the North and Baltic Sea; Finnlines, operating 21 RoRo vessels in the North and Baltic Sea; and SOL, with eight RoRo vessels (company websites). Many of these RoRo services are contracted for long periods by forestry companies that 'guarantee' the baseload.

2.4. RoRo Shipping and the Nordic Forest Industry

The forest industry is one of the most important business sectors in Sweden and plays a vital role in the country's economy, accounting for 9–12% of the employment, exports, turnover and added value in Swedish industry [34]. As can be seen in Figure 2, the forest industry is the sixth-largest exporting sector in Sweden, following engineering products, electronic goods and the automotive industry. Note the large net export value in comparison with the automotive industry. The situation is quite the same for Finland, where forestry is the second-largest Finnish industry, accounting for 20.3 billion euros in 2016 (Figure 3).

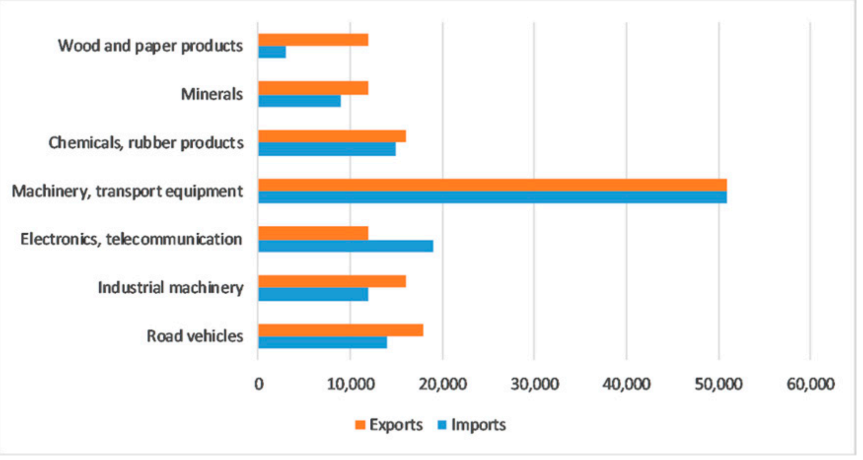


Figure 2. Swedish imports and exports in product groups (in million Swedish Kronas (SEK)—~100 k€) in 2017. Source: Own elaboration based on data from Statistics Sweden.

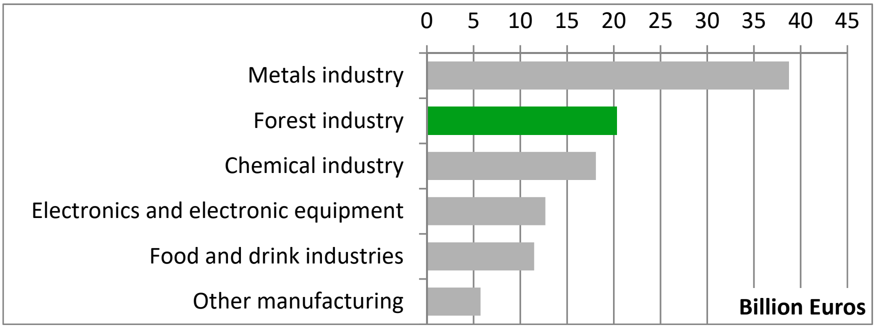
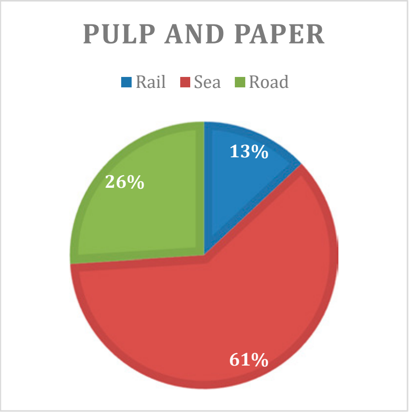


Figure 3. Annual turnover of the largest industries in Finland (in billion €) in 2016. Source: Own elaboration based on data from the Finnish Forest Industries Federation.

In 2016, 11.6 million tonnes of pulp, 10.1 million tonnes of paper and 17.8 million cubic metres of sawn timber were produced, making Sweden the world's third-largest exporter of these products [34]. As the Swedish forest industry is strongly export-oriented—80% of the forest products are exported—and the transport of large volumes of products is required, it represents Sweden's largest purchaser of transport services, accounting for SEK 25 billion (~2.5 billion €) annually. It is characterised by a small number of large companies—such as SCA, Stora Enso, Holmen and BillerudKorsnäs—that have developed their own intermodal transport systems which combine railways, RoRo vessels and road transport. These systems provide them with a sort of flexibility and secure capacity for the satisfaction of their transport needs.

The forestry industry is the business sector that utilises Sweden's railways the most, accounting for one-quarter of all rail freight transport [35], but shipping is employed for exporting the largest part of the Swedish forest products. As much as 61% of pulp and paper is exported by sea, while this percentage reaches 57% for sawn timber (Figure 4).



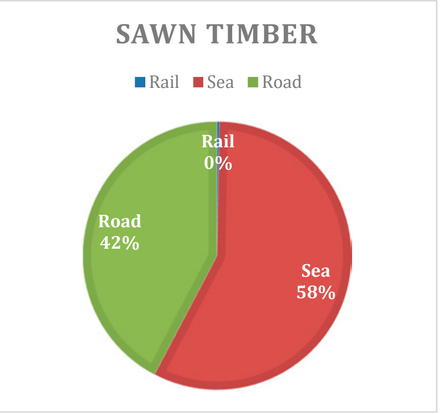


Figure 4. Modes of transport for the export of Swedish pulp and paper in 2016 (in million tonnes) Swedish sawn timber in 2016 (in million tonnes) Source: Own elaboration based on data from the Swedish Forest Industries Federation.

The Port of Gothenburg is the largest forest port in Sweden, playing a key role and serving as a freight hub for the export of forest products [35]. The Port of Gothenburg offers a wide range of services and destinations, with 80 RoRo and 20 container ship departures each week to a range of destinations in the UK and on the European continent. The port has three RoRo terminals specialising in European traffic, operated by Gothenburg Roro Terminal, Stena Line and Logent Ports & Terminals, where all types of unitised rolling goods, as well as containers and goods loaded onto cassettes, are transhipped. The RoRo terminals are also linked to the rail system, with tracks running directly to the quayside, enabling intermodal transport of forest products. The fact that around 70 trains arrive and depart from the port each day gives some insight into the large cargo volumes handled in the port and integrated into an intermodal logistics system.

3. Methodology

The previous sections showed that RoRo shipping can offer an environmentally friendly and cost-efficient option to meet the transport needs of various industries. A contemporary phenomenon or event, which cannot be explored beyond its context, is better investigated through a case study approach [36,37]. To discover and understand the real-life phenomenon of successfully integrating SSS into intermodal transport chain on certain routes, an in-depth case study was conducted, highlighting the main drivers (enablers) that enhance SSS integration within the intermodal transport chain from a large shipper's perspective.

Eisenhardt [38] emphasises that in case study research, sample selection should be tightly aligned with the purpose of the research. This paper focuses on a RoRo service designed and operated by Stora Enso in cooperation with SOL for transporting its own as well as external parties' cargo. Voss, Tsikriktsis and Frohlich [36] recommend interviewing more than one respondent in situations where a single respondent does not have all required knowledge of the phenomenon, or where different interpretations of a phenomenon are expected. Thus, to overcome subjectivity and bias issues and enhance the reliability of our data, we conducted one semi-structured interview with Stora Enso (a forest-product shipper and vessel charterer) and a second semi-structured interview with SOL (a ship management and forwarding agent that collaborates with Stora Enso).

Input from the shipping line, the major shipper and another user of the RoRo service enhances the perspective of this article to study the case of integrating sustainable RoRo shipping services into intermodal transport chains. The interview with the major shipper Stora Enso aims at identifying the way RoRo is successfully integrated into its intermodal transport system and the way this transport system works in practice. The interview with the shipping company verifies these findings and gives some additional data on the types of cooperation amongst the two parties (shipper and carrier). In addition, an interview with a forwarding company, France Sped, which uses the shipping service, confirms and reflects on some statements by the two main actors.

A crucial step in this research was identifying appropriate respondents from each company with deep knowledge of their logistics needs and practices. From Stora Enso, Kristian Kisch, the manager of European shipping services, was identified as the main interviewee [39], and an additional interview was done with Knut Hansen, senior vice president of Stora Enso and Chief Executive Officer of Stora Enso Logistics AB since 2008 [40]; the interview mainly focused on an ongoing labour market conflict in the Port of Gothenburg. Furthermore, a telephone interview was conducted with Stig Wiklund, who was employed in managerial positions by Stora/Stora Enso from 1985 to 2012 and then assumed a role of senior advisor until 2016 [41]. Another interview was conducted with Henrik Kappelin, network design and transport analyst for Stora Enso, involved in route/supply chain optimisation based on cost, service level and sustainability criteria [42]. The second main respondent, Ragnar Johansson, is the managing director of SOL [43]. As a representative of the third-party users of the service, Kristina Bengtsson, CEO of France Sped, was also interviewed [44].

Interviewees were chosen based on their positions and experience. As the main respondent from Stora Enso, Kisch holds a strategic position in the company's sea freight transport system and is knowledgeable in the way this system operates and manages to satisfy the company's transportation needs in a sustainable way combining three traffic modes (rail, RoRo shipping and road). Hansen assisted in understanding Stora Enso's current priorities, and Wiklund, who served in various positions including interim vice president, business development of Stora Enso Logistics from 2008 to 2012 and acting CEO from 2007 to 2008, helped capture the history of Stora Enso's logistics development and verify the statements from the other two Stora Enso respondents. He also contributed by putting the development into a proper strategic context. Kappelin provided valuable input on Stora Enso's current supply-chain network design, based on liaising with land and sea procurement categories to improve and facilitate transport supplier negotiations. At SOL, Johansson is responsible for sustainable operations of the RoRo vessels employed by Stora Enso and provided valuable input into the way the two companies cooperate and manage to generate additional environmental and financial benefits. The CEO of France Sped contributed with valuable insights from a smaller user of the service as it is marketed in the open freight market. We sent the interview protocols to the respondents in advance, as this might have helped them collect their thoughts. The interviews lasted 60 [39], 75 [40], 30 [41], 45 [43], and 30 [44] minutes, respectively, and the interviews were audiotaped and later transcribed. Email correspondence was used for the interview with Kappelin. For additional data, benefitting from a triangulation technique [37], we used respondent companies' websites, external reports and newsletters. Furthermore, a few less-detailed interviews were carried out with personnel from the case companies. The manuscript was sent to all respondents to verify the facts and citations used.

The research design does not allow for generalising the findings on the development of sustainable RoRo operations and their integration into intermodal transport chains due to the rather limited number of interviewees. The focus is on the dominant shipper of the RoRo service, but a third-party user of this service is also interviewed. Further research is needed to support the findings. Additionally, only one case study of shipper–carrier cooperation is analysed in this research. It cannot be considered as representative of transport practices in general, as the main shipper demonstrates a high commitment to sustainable transport procurement, and the carrier operates in Northern Europe, where high sustainability requirements in sea freight transport are applied. The results are likely to be different in other industrial segments or geographical regions of the world. Nevertheless, the successful integration of RoRo shipping in the intermodal transport systems of Stora Enso and SOL is worth investigating due to the valuable, practical input it offers and the identification of potential environmental and financial benefits from such integration.

4. Results

The results of the case study are presented in this section.

4.1. Stora Enso

Stora Enso was formed through a merger between the Swedish forest company Stora and its Finnish competitor Enso in 1998. It produces paper and packaging products, biomaterials and wooden constructions and provides them all over the world. The company employs around 26,000 people in more than 30 countries. In 2018, Stora Enso had a turnover of 10.5 billion €, while its operational earnings before interests and taxes (EBIT) reached 1.36 billion € [45]. Most of the company's sales and operations take place in Europe, with Germany and Sweden being the biggest markets for the company's production in Europe.

Stora Enso makes extensive use of sea transport, which accounts for approximately 89% of the transport work, while road and rail transport constitute 9% and 2%, respectively [46]. According to Kappelin [42] at Stora Enso, many factors influence the company's choice of transport mode. Nevertheless, cost and capacity play a crucial role, and after that, the others are considered. Stora Enso has developed a unique intermodal transport system based on SECUs transported by ships and trains; the latter, however, only in Sweden and Finland with generous loading gauges. SECUs are large intermodal containers, similar to standard 40-foot containers but bigger, with dimensions 13.8 × 3.6 × 3.6 m and a cargo capacity of 80 tonnes compared to the (International Organization for Standardization) ISO container's 26.5 tonnes. Stora developed the SECUs before its merger with the Enso, but they were implemented after the merger in 1998 [41] after a decade of 8–10% annual volume growth and with high expectations for further growth. According to Georgopoulou et al. [47], SECUs are included in baseline green technologies for the establishment of green corridors and are categorised as innovative units for multimodal transport. However, moving SECUs onto ships and rail wagons requires special translifters. This equipment can be found mainly in ports in major production and consumer countries for Stora Enso, such as Finland (Kotka and Oulu), Sweden (Gothenburg), Belgium (Zeebrügge), the UK (Tilbury, Immingham) and Germany (Lübeck). These areas form the backbone of Stora Enso's SSS network.

4.2. Stora Enso's Short Sea Network of Services

According to Kristian Kisch [39], the company has established an SSS network of services to satisfy its transport needs, from the production units to customers (Figure 5). Production units and customers' locations are shown by the circles, while different coloured lines represent the different short sea shipping services offered by the company. Wiklund [41] states that Stora experienced strong dependence on German State Railways (DB) in its export to continental Europe that crossed German soil at a time of national rail monopolies. After the fall of the Berlin Wall in 1989, east–west flows increased and DB put less emphasis on competitive north–south services. Stora then decided to find an option to circumvent the problems in Germany by using RoRo to Zeebrügge. As rail is used to distribute goods from the port to customers in continental Europe, the customers are not affected by Stora's decision to use direct rail or maritime transport for a transport leg [41].

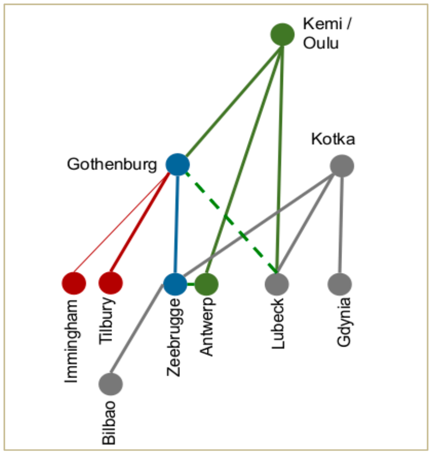


Figure 5. Stora Enso short sea shipping network. Source: Material obtained at the interview with Kisch [39] from Stora Enso.

The operation of these services presents great differentiations depending on cargo capacity, competition and market condition. Kisch mentioned that ship ownership or operation management are not Stora Enso's main function. The company chooses to charter vessels instead of owning them, maintaining flexibility to release them in the event of production pattern changes or reduced production volumes.

Kisch provided a comprehensive picture of the company's SSS network. He stated that until 2009, the company itself managed and operated the eight RoRo vessels engaged in the SSS transport system. According to Wiklund [41], it was partly a strategic decision for the company not to actively operate ships itself, partly a lack of nautical competence and partly because it wanted to implement a larger system requiring third-party goods for reasonable frequencies. Three vessels were employed on the Gothenburg–Zeebrügge route, three vessels on the north Finland routes from Kemi/Oulo and two on the south Finland routes from Kotka. However, in 2009, the company outsourced the vessels' operations and selected SOL for ship operation management of its short sea system. According to Ragnar Johansson, CEO and interviewee from SOL, SOL set up a new company, called SOL North Europe Services (SNES), which is a single-purpose company working for Stora Enso. Johansson emphasised that since then, SNES has been Stora Enso's shipping department that acts exclusively on behalf of Stora Enso as the long-term charterer of the vessels [43]:

> *SNES is responsible for the operation and maintenance of the vessels, the instruction of captains on board, the scheduling and booking of Stora Enso's cargo to their contracted shippers.*

Kisch pointed out that at the same time, Stora Enso was selling some freight capacity, either empty space on board or empty space in the northbound SECUs, to third parties on all routes of the SSS network and had long-term contracts with other shipping companies offering these third-party services. In 2014, those contracts ended and Stora Enso began its cooperation with SOL on third-party services on the Gothenburg–Zeebrügge route. Kisch emphasised that in the same year, Stora Enso restructured its short sea transport network and changed the hub of its logistics system, replacing the Port of Gothenburg with the port of Zeebrügge in Belgium and shifting about 1.5 million tonnes of cargo per year [48]. According to Knut Hansen [40], the RoRo terminal at the Port of Gothenburg struggled and still struggles with too-high costs and unreliable service. This was confirmed in the interview with Wiklund [41]. After the shift to Zeebrügge as a hub, cargo from paper mills in Kemi and Oulu in Northern Finland was transferred directly to Zeebrügge, increasing the logistics system's efficiency. As Johansson [43] stated:

> *Then North Finland vessels did not need to come to Gothenburg as they moved to Zeebrügge. It was a big change that saved a lot of money and increased efficiency in the system.*

Both interviewees mentioned, though, that the Port of Gothenburg still plays an important role in the flow from Stora Enso's four mills in Sweden, all located rather far from the coast. Stora Enso's cargo from Southern Finland is transferred directly to Poland, Germany and Belgium by the shipping company Finnlines, as before.

According to both interviewees, since 2015, Stora Enso has cooperated with SOL not only for ship operation management, but also for selling the remaining freight capacity to external customers, either empty space on board or empty space in the northbound SECUs. Under this scheme, SOL has the responsibility for third-party sales and gets a commission, but Stora Enso charters the vessels and carries the full commercial risk of utilising the vessels. As Johansson [43] emphasised:

> *Then SOL took responsibility for third-party sales and got the commission, but SOL did not charter the vessels, and Stora Enso had 100% risk of the vessels.*

Kisch highlighted the two cooperation types of Stora Enso with SOL. The first type of cooperation concerns SNES' operation management of vessels on behalf of Stora Enso, while the second type of cooperation is related to SOL selling the excess freight capacity to third-party shippers [39]:

> *When it comes to cooperation with SOL, we have two such cooperation types … SNES operates the line and SOL is just selling like sales agents. SNES is preparing schedules, instructing captains on board, maintenance and so on, but they ask Stora Enso for confirmations. SOL's continent line is just marketing, and it's important for us to keep these two firms separate so we can scale up and down in each sailing. For managing the line, they get a management fee.*

Kisch from Stora Enso also stated that the entire service around third-party freight capacity was developed considering the needs of road haulage firms and rail operators. Large external customers on the Gothenburg–Zeebrügge route are LKW Walter, NTG Transport, DSV Global Transport and Logistics, and other freight forwarders that occupy the empty space on board loading semitrailers, while Hoyer Group and Bertschi fill the empty space in the SECUs. A smaller user of the SOL–Stora Enso service is France Sped, a comparatively small forwarder operating 30 semitrailers for part-load transport services between Sweden and France. According to CEO Kristina Bengtsson [44], France Sped uses the SOL–Stora Enso Gothenburg–Zeebrügge route in the same way as it uses Cobelfret's service on the same route and DFDS on the Gothenburg–Ghent route. In all, they buy maritime transport of some 1500 semitrailers annually, deliberately distributed between the three shipping lines to foster competition [44].

According to Johansson, both Stora Enso's and other customers' cargo is allocated in each sailing depending on the agreed capacity and current demand. France Sped has a fixed allotment, but notifies SOL of the specific need for capacity on the day of departure [44]. SOL reserves an agreed capacity for Stora Enso and is not obliged to transport volumes above that level, but Stora Enso stores SECUs in Gothenburg to fill up empty capacity in a standby consignment scheme. Johansson revealed that priority is usually given to third-party forwarders so as to not to risk losing these external customers:

> *Well, we have agreed capacity for Stora Enso also. For instance, we are obliged to transport Gothenburg–Zeebrügge route 260 SECUs per week, anything above that level we don't need to take it. Otherwise, we can lose DHL or LKW Walter etc., so we prefer third-party forwarders.*

Bengtsson [44] confirmed that France Sped had not experienced Stora Enso having priority amongst users. Johansson added that when Stora Enso needs extra capacity to satisfy its customers' needs, it often moves a vessel from North Finland to Gothenburg despite the additional transport cost.

According to Kisch [39], this commercial cooperation developed quickly, and in 2017, SOL sold RoRo services for nearly 100,000 third-party units on the Gothenburg–Zeebrügge route, with the utilisation rate for RoRo operations in both directions reaching about 95%. This high utilisation rate is crucial for developing sustainable RoRo services, as it implies reduced fuel consumption and related emissions per unit of transport work. The company reaches such a high utilisation rate due to the flexibility of its operations. As Kisch [39] pointed out:

> *On Mondays, we ship more SECUs, and on Tuesdays more semitrailers, etc. If there is an accident in the port, we have standby SECUs, and at the same time if there are late bookings. We are flexible, as the final load plan is made half an hour before the vessels depart, and that's why we have such a high utilisation.*

Another beneficial outcome from this commercial cooperation was the expansion of Stora Enso's SSS network and the shipment of larger volumes on its chartered vessels. As Kisch [39] stated:

> *Further, SOL helped us expand our network with other partners and increase the cargo volume for our chartered vessels. So we have cooperation with P&O in the North and Mediterranean Seas and SOL in Scandinavian regions.*

4.3. The SECU Rail System

Stora Enso's mills in Sweden are located inland and connected via the SECU rail system to the Port of Gothenburg, where the cargo is transhipped to RoRo vessels. The trains involved are owned and operated by the state-owned rail operator Green Cargo. Stora Enso has certain control of the 190 wagons deployed in its system, although Green Cargo owns them. Three trains arrive daily in the Port of Gothenburg. As Kappelin [42] pointed out, the company makes extensive use of rail due to the higher loading capacity that makes it more cost efficient compared to trucks. Johansson [43] emphasised that the close cooperation with Stora Enso enables the efficient handling of cargo flows at the port:

> *We have close communication with Stora Enso to know how much volume is coming to the port. This system has worked for so many years, and everybody knows how to handle it.*

Kisch highlighted the fact that while transhipment of cargo from rail to RoRo vessels is operationally efficient, the cost of port operations is extremely high, accounting for 60% of the company's total shipping cost. Also, Hansen [40] emphasised cost issues for port handling in Gothenburg. From his perspective, Johansson from SOL stated that the frequency of departures of RoRo vessels offers them a competitive advantage in relation to feeder services and lines and facilitates their integration in intermodal transport chains due to the shorter times in port. SOL offers high frequency of departures was also mentioned by Kisch as an important feature of RoRo services that is lacking in container services, as they stay longer in the port.

SECUs stay a maximum of a few days at the port before they are shipped, due to the flexible allocation system with external customers that enables utilisation of excess capacity by third parties. Both interviewees mentioned that each SECU is given a date, based on the cargo unit that has the earliest arrival time in the destination port, and then SECUs are put in lanes with dates. In this way, the right SECU is delivered to the right customer at the right time and place. As Kisch [39] mentioned:

> *Each box is put in lanes with dates based on the cargo it has and the unit in the box which has the earliest arrival time in the destination port and then given a date to the whole box. This helps us make sure that the right box at the right place, its customer orders in the box and the destination are decided in advance.*

He further emphasised that using SECUs enables Stora Enso to transport its cargo efficiently from the mills, which are located inland, reducing the need for warehouses [39]:

We don't need warehouses, we just produce, load SECUs and ship.

The interviewee added that in Northern Finland, SECUs act as floating warehouses, as sometimes the company needs to produce earlier depending on the client's required delivery time. Another interesting point is that the SECUs are always stripped before they reach the final clients and the goods are reloaded to semitrailers, so the last leg of the transport chain is always by road.

4.4. The Gothenburg–Zeebrügge RoRo Route

A major frequent service in Stora Enso's SSS network is the connection between Gothenburg and Zeebrügge. According to Kisch, for trade between Gothenburg and Zeebrügge, Stora Enso charters a couple of vessels from Wagenborg shipping that make two round trips per week. These vessels are purposely built for Stora Enso's cargo backed by a 15-year charter contract [41], with two levels of loading ramps, which reduces the vessels' time at ports and allows them to run at 15 knots, compared to 18–19 knots, which is the sailing speed of their competitors. The forest industry is used to plan for the long duration of its assets, and the long charter time was not internally controversial due to strong volume growth at the time, but might not have been as well received in today's business climate [41].

Bengtsson [44] at France Sped stated that the vessels' lower speed was no real problem to them. The intra-European part-load segment, in which they are mainly active, has a rhythm of collecting by the end of one week and conducting long-distance transport over the weekend; delivery early in the next week allows for slow transport over the weekend. The size of the vessels is 2500 lane metres, and ISO containers on cassettes can be double-stacked. The slow sailing speed in addition to the high load factor of these vessels enhances their sustainable operations and evidence Stora Enso's commitment to sustainability.

Regarding the employment of larger RoRo vessels, Johansson supported that it is neither efficient nor feasible on the Gothenburg–Zeebrügge route despite the reduced unit cost due to economies of scale. Kisch pointed out that larger vessels would increase operating times, as the driving distances on board would be longer, and all cargo would have to wait until the vessel is full. Both interviewees emphasised that frequency of departures is imperative in this route, and it would be difficult to retain it in addition to obtaining high-capacity utilisation of very large vessels. On the Gothenburg–Zeebrügge route, SOL offers five departure per week in both directions [49]. They also stated the infrastructure is a major challenge for the employment of larger vessels.

The interviewee from Stora Enso [39] stated that the Gothenburg–Zeebrügge line has grown significantly over the years, as many companies have changed their production patterns, moving their operations around Gothenburg and increasing their shipments in this line:

... the corridor has grown significantly. We had been working with a lot of companies to change their production patterns, and Volvo for instance in this respect has increased their production around Gothenburg, and this has led to growth in the shipments.

According to Johansson [43], a modal shift from land-based modes of transport to sea-based has also favoured the use of Gothenburg–Zeebrügge line.

... there were also market changes, a lot of modal shift from road to sea and from rail also ...

5. Discussion and Conclusions

Due to negative externalities related to unimodal road haulage, the promotion of SSS has been an essential part of the political agenda in the European Union for decades. Regardless of the multiple initiatives undertaken by authorities to increase the usage of SSS, unimodal road haulage still accounts for nearly 50% of total freight transport by volume in the European Union. The success of the SSS option, to a large extent, is dependent on the seamless integration of individual activities and services offered by different agents or stakeholders involved in a multimodal transport chain.

In the existing research, the topic of SSS and its integration into the intermodal transport chain has mostly been studied from transport providers' perspective, while the role of a shipper has received little attention. In this paper, through an in-depth case study, the role of a shipper (cargo owner) to integrate multiple traffic modes into a seamless intermodal transport chain and the drivers (enablers) for such integration are explored. Interviews, secondary data and existing literature are the main data sources for this case study.

We found that Stora Enso, a leading forest-products producer, employs an innovative intermodal logistics system for the transport of a huge volume of its products. Instead of relying on third-party logistics providers, Stora Enso has designed a logistics system and purchased rail transport of its cargo from Swedish mills to the Port of Gothenburg and chartered RoRo vessels to cover the long leg of the journeys. By chartering the RoRo vessels, Stora Enso saves capital costs and can release the vessels if an unexpected event, such as a decline in its product demand, occurs. In addition, the usage of the SECU, with the capacity of up to load 80 tons of cargo, reduces total transport and warehousing costs. We believe that these innovative strategies have provided the company with a significant competitive advantage in the market by reducing the per-unit cost of its products and enhancing overall system efficiency.

Stora Enso does not utilise 100% capacity for its own cargo transport on board the chartered vessels. Thus, to sell extra freight capacity to third parties and manage the operations of its chartered vessels, Stora Enso formed a strategic cooperation with SOL. As a result of this cooperation, in 2017, the utilisation rate on Stora Enso´s Gothenburg–Zeebrügge RoRo service route reached 95% in both directions, although many northbound SECUs are empty. This high load factor is rare for a RoRo service, as SOL sold nearly 100,000 units to third parties and through the use of standby SECUs. Apart from the financial benefits for both Stora Enso and SOL from this cooperation, sustainable transport operations are promoted. The high utilisation rate of the service implies lower greenhouse gas emissions (GHG) emissions per transport unit through improved voyage planning and is in accordance with implementation of the Ship Energy Efficiency Management Plan (SEEMP) [50]. Under the SEEMP, mandatory for all vessels since January 2013, guidance is provided on the way vessels could optimise their operational efficiency performance through technical details, including improved voyage planning, just-in-time arrival of vessels at ports and speed optimisation (MEPC 58/INF.7 2008). In addition, Stora Enso's purpose-built vessels, with two levels of loading ramps that reduce vessels' time in ports and allow them to run at lower speeds, have a high operational efficiency performance that leads to reduced fuel consumption and GHG emissions from their operations, as stated by both López-Navarro [23] and Hjelle [26]. The use of low-sulphur fuel in addition to the low operational speed (15 knots) and the high utilisation rate (95%) of the RoRo service examined in this study turn it into the greenest transport alternative and enhance the sustainability aspects of RoRo shipping operations.

Although Stora Enso is the charterer of the vessels, priority is usually given to third-party forwarders, which helps sustain these third-party customers. France Sped confirmed that as a small user, it does not see that Stora Enso is prioritised [44]. This finding reflects that by adopting a unique management approach and developing cooperation with SOL, the shipper Stora Enso efficiently transports its own cargo as well as lowers its costs by selling the capacity to third parties on board its RoRo vessels, eventually leading to an increased integration of RoRo into a multimodal transport chain. This is in line with Zachcial [9] and Paixão Casaca and Marlow [4], who emphasised that cooperation amongst transport chain agents and a different management approach are amongst the key drivers for SSS integration into intermodal transport chains.

Moreover, in contrast to Saldanha and Gray [51], who in their Delphi survey found that shippers cannot play any key role in integrating different traffic modes "as a spin-off from serving their own needs", we assert that large shippers are at the centre of a logistics chain, and because of having control of large cargo volumes, they can assist in increasing the integration of multiple traffic modes as illustrated in our case study. In this context, Paixão Casaca and Marlow [19], Ng [33] and Styhre [32] corroborate that large cargo volumes ensure higher frequency of a transport service for shippers and increase capacity utilisation of a traffic mode (especially in the RoRo shipping segment), and both these factors are fundamentally important in running an economically feasible RoRo service and facilitating the integration of RoRo services within an intermodal transport chain.

Our findings are consistent with those of Ng, Sauri and Turro [3], who emphasised that high cargo-handling cost in ports is amongst the top barriers to enhancing the integration of RoRo services into intermodal transport chains. In our study, we found that port costs account for nearly 60% of Stora Enso´s total shipment costs. We believe that a reduction in port costs could make intermodal RoRo services cheaper compared to unimodal road haulage and may increase the competitiveness of this mode.

We believe that the results of this paper bring new insights to various actors involved in a transport chain. Ship operators and large shippers might realise the importance of cooperation and shared planning with other agents of a transport chain. Intermodal integration between different traffic modes or strategic collaboration between cargo owners, ship operators and forwarding agents might enhance system efficiency; reduce lead times, emissions and costs; and generate additional revenues for all collaborating parties. Large shippers, especially in the forest industry, may reconsider their logistics and management strategies and may benefit by commencing their own unique transport networks following the case of Stora Enso as presented in this paper.

Based on the findings of this paper, we suggest that to enhance the integration of SSS into intermodal transport chains, policymakers should draft policies considering shippers´ needs and encourage innovations in the sector, as innovations may in return reduce unnecessary costs involved (e.g., port costs). In addition, to encourage the use of intermodal transport over unimodal road haulage, behavioural change campaigns targeting all stakeholders of a transport chain should be a part of future policies, as environmental sustainability is dependent not only on technological change, but also on behavioural change.

The major limitations of this research are that the methodology of a case study of shipper–carrier cooperation cannot be considered as representative of transport practices in general, as the carrier operates in Northern Europe, where high sustainability requirements in sea freight transport are applied and the shipper demonstrates a very strong commitment to sustainable transport procurement. The results might be different in other industrial segments or geographical regions of the world. Moreover, although we tried to overcome subjectivity and bias issues and enhance the reliability of our data by conducting semi-structured interviews with various stakeholders involved in the Stora Enso–SOL cooperation, the answers express the personal views and opinions of the interviewees and allow some sort of subjectivity.

The study provides implications for further research. More case studies on instances of shipper–carrier cooperation that have managed to integrate RoRo shipping into intermodal logistics chains could be analysed, giving some insight in other industrial sectors, such as the automotive or steel industry. The case study methodology could also be supplemented with quantitative studies that could further explore the potential development of intermodal RoRo services.

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Paper IV

The effect of Regulation-Driven Green Innovations on Environmental and Economic performance of Short Sea Shipping in Europe

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Abstract

Despite its pivotal role in European trade, today's short sea shipping (SSS) industry faces the dual challenge of lessening its environmental footprint while improving its economic performance. To reduce the pollution caused by their operations, SSS companies are required to comply with increasingly stringent environmental regulations enacted by global and regional authorities such as the European Union and the International Maritime Organization. However, the companies tend to regard those regulations as imposing an additional burden of cost that compromises their capacity to enhance their economic performance. This paper examines the impact of external institutional driver namely regulatory pressure on the adoption of green innovations in SSS and in turn, the impact of those innovations on the environmental and economic performance of SSS companies. To investigate the hypothesised relationships of those constructs, a structural equation model was developed and tested with data from a survey conducted amongst 101 short sea shipping companies headquartered in Europe. As detailed in the paper, the analysis revealed that regulatory pressure has generated green innovations that have enhanced the environmental and economic performance of European SSS companies and, as a result, led to a win–win situation for all parties involved. The paper discusses what those findings imply for SSS firm managers and policymakers who seek to improve the environmental or economic performance of Europe's SSS industry.

Keywords: Environmental regulations, green innovations, environmental performance, economic performance, short sea shipping

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1. Introduction

Globalisation has considerably reshaped supply chains around the world, in which products are manufactured with components shipped from various locations and transported worldwide. In that context, maritime transport continues to be the second-most preferred mode of freight transport in Europe and transports 90% of all freight worldwide (UNCTAD, 2018). Moreover, due to the ever-increasing size of shipping vessels as well as technological improvements, maritime transport has become the most cost-efficient mode of (long-distance) transport per tonne-kilometre of transported cargo (Cullinane and Bergqvist, 2014). As a result, the decreased price of maritime transport services has dramatically increased the demand for such services during the past several years.

Although shipping transport in general depending on the route, vessel characteristics and ship speed possesses environmental and socio-economic advantages as compared with alternative transport modes such as trucking. These advantages include lower CO2 emissions per ton kilometer of cargo transported and avoidance of road accidents, congestion and noise that is caused by trucking (Ng and Song, 2010; Vierth et al., 2016). However, some research studies such as Hjelle (2014) and López-Navarro (2013), based on a comparative analysis have revealed that on certain routes in Europe energy consumption and emission of SOx and NOx per ton kilometre of cargo transported is higher from shipping than trucking. Shipping activities have raised concerns about their negative impact on the environment in general (Tiquio et al., 2017), as well as about their emissions of noxious gases such as CO2, NOx and SOx (Eyring et al., 2005), their use of hazardous and toxic materials (Grote et al., 2016), their noise pollution (Chen et al., 2017), their waste (Wilewska-Bien et al., 2016) and their high energy requirements (Poulsen and Johnson, 2016). As the negative impacts of shipping activities on the natural environment have become increasingly evident, demands to reduce their environmental emissions have risen as well.

Compared to other industries and modes of transport, the maritime transport industry, given its international nature and offshore operations, has long escaped the attention of environmental regulators. However, in response to increasing environmental concerns and to control the creation of detrimental shipping pollutants both above and below the sea surface, various environmental regulations have been promulgated by regional and global authorities in recent years. For instance, under the International Convention for the Prevention of Pollution from Ships (MARPOL), the International Maritime Organization (IMO, 2019a) has regulated shipping companies as a means to reduce the air and water pollution from their operations. In particular, MARPOL Annex VI has incrementally reduced limits on the maximum sulphur content in fuel used by ships operating in designated sulphur emission control areas (SECAs) by 0.1% and at the global scale to 0.5% (IMO, 2019b). Furthermore, short sea shipping (SSS) companies operating in Europe have also become subject to the environmental regulations of the European Union (EU), which has drafted a regulatory framework aligned with international maritime laws and environmental standards. The most important EU environmental regulations related to shipping put forward by the (European Comission, 2019) stipulate the use of environment-friendly tankers (Regulation 417/2002/EC), the provision of suitable waste reception facilities (Directive 2000/59/EC), the reduction of sulphur emissions (Directive 2012/33/EC) and punishment for pollution-related offences (Directive 2005/35/EC). Whereas some of those regulations have already entered into force, others await implementation in the near or distant future.

Researchers such as Lindstad et al.(2017) and Notteboom (2011) have reported that, for SSS companies, complying with environmental regulations requires additional investments and energy use that increase operating costs, leads to modal backshift to road and, in turn, detrimentally affects the companies' economic and environmental performance. Nevertheless, encouraged by regulatory pressure, shipping companies have begun to adopt various green technological and process innovations and practices, including slow steaming, optimised route planning, hull coating, improved engine design and the use of scrubbers and alternative fuels (Lindstad and Eskeland, 2016; Woxenius, 2010) which eventually improve their environmental (Yang, 2018) and economic (Yuen et al., 2017) performance.

Regulatory pressure plays an instrumental role in stimulating green innovations. In particular, as Porter and van der Linde (1995) have argued, regulations direct firms' attention to likely resource inefficiencies and potential ways to bring about technological and process improvements. In that sense, regulations can raise corporate awareness and, in turn, create pressure that spurs innovation, which may simultaneously improve firms' environmental and economic performance in a win–win scenario for all parties involved.

Most of the SSS operates near the coastal and populated areas, and therefore, in contrast to the deep-sea shipping, the impact of SSS on the local and regional environments has raised more concerns among the society and policy makers. The negative effects of SSS on the climate and human health are more severe than the deep sea shipping (Hjelle, 2010). As a result, achieving economic growth while reducing the adverse environmental impacts of their activities has become considerably important for SSS companies as they face regulatory pressure. However, despite the research on environmental regulations that has focused on the sulphur regulation, options for technical compliance and the costs of compliance for individual vessels and trade routes within European SECAs, no empirical research is conducted that examines the impact of environmental regulations on the adoption of green innovations and the resulting impact of such innovations on the environmental and economic performance in the European SSS industry. In response, this paper aims to examine the impact of external institutional driver namely environmental regulations on the adoption of green innovations and the effect of such innovations on the environmental and economic performance of SSS companies. The empirical data for this study is derived through a survey of managers of SSS companies headquartered in Europe.

In the remainder of the paper, Section 2 provides the literature review and the corresponding hypotheses. Section 3 details the methods and process of data collection, after which Section 4 presents the results of the empirical analysis. Last, Section 5 elaborates upon the results and concludes the paper by articulating what the findings of the research imply for the managers of SSS firms in Europe and policymakers.

2. Theoretical background and hypotheses development

Institutional theory postulates that organisations´ actions are shaped by the social influence toward conformance (DiMaggio and Powell, 1983; Scott, 2001). The theory argues that organisations are susceptible to strong pressure to seek social approval, protect and enhance their legitimacy and gain access to resources (Deephouse, 1996). Legitimacy is "a generalized perception or assumption that the actions of an entity are desirable, proper, or appropriate within some socially constructed system of norms, values, beliefs, and definitions" (Suchman, 1995). On the contrary, non-conformance to institutional expectations can imperil organisational performance (Scott, 2005) and long-term growth (Teo et al., 2003). As a consequence, concern for legitimacy prompts firms to adopt socially valuable practices and incorporate institutional rules within their organisational structures. A study by Riverta et al. (2006) indicates that "literature on voluntary environmental programs shows a growing consensus consistent with institutional theory that gives external pressures a significant role in determining the adoption of these initiatives." In the same vein Delmas and Toffel (2004) show that institutional theory provides a plausible explanation for the occurrence and diffusion of green practices and innovations.

Institutional theory provides three mechanisms through which the influence of institutional environments transfers to organizations (DiMaggio and Powell, 1983; Scott, 2001):

(1) Coercive isomorphism resulting from pressures exerted by other organizations on which the firm depends, which may be felt as force, persuasion, or an invitation to join in collusion;

(2) Normative isomorphism or sets of expectations in particular organizational contexts about what constitutes appropriate and legitimate behavior, as established by social organizations, professional associations, or academic institutions; and

(3) Cultural-cognitive isomorphism that results from the firm's rational desire to imitate the behavior of other organizations because of its perception that the imitated behavior is legitimate or has technical value.

Although all three mechanisms can simultaneously influence firms to adopt environmentally friendly practices and innovations (Zhu and Sarkis, 2007), the degree of their influence remains heterogeneous and their relevance specific to context (Berrone et al., 2013). For environmentally sensitive industries such as shipping, as researchers (Frondel et al., 2008; Kammerer, 2009; Yuen et al., 2017) and Bossle et al.'s (2016) comprehensive review have revealed, coercive isomorphism resulting from pressure exerted by external organizations is the mechanism that predominantly triggers green innovations at firms and, as such, merits further attention. Accordingly, in this paper, the focus is on the external institutional driver namely regulatory pressure which is exerted by stakeholders such as IMO, EU and individual states.

2.1. Regulatory pressure and green innovations

The paper focuses on the driver that emanate from the external environment of an organization namely regulation. Regulation is a legitimacy-based activity that exerts coercive institutional pressure. With such institutional pressures associated with environmental issues, a firm's desire to enhance its environmental performance may provide a boundary condition for the effectiveness of economic performance. That is, institutional theory suggests that when there is institutional pressure from various stakeholders, improved environmental legitimacy can be observed by stakeholders. Hence, it is suggested, in response to regulatory pressure, firms adopt green practices and innovations.

Growing public concerns over the adverse environmental impact of shipping operations have prompted a significant increase in environmental regulations—laws, acts and directives, among other forms—across the globe (Abadie et al., 2017). Pressure from such regulations is reinforced by governments and their representative bodies (e.g. IMO and European Commission) with the power to influence firms' business operations.

Regulators have the authority to mandate firms to use pollution control technology and to reduce the negative externalities caused by their operations (Darnall, 2009). Furthermore, they can encourage firms to implement green innovations in the processes that can help to lessen the detrimental impacts of their operations on the environment (Johnstone and Labonne, 2009). In that process, they drive green innovations by incentivising firms to engage in innovative activities and to comply with regulations, by using either so-called "carrots" (e.g. subsidies) or "sticks" (e.g. fines) for respectively complying with regulations or not (Guoyou et al., 2013). At the same time, environmental regulators promote green innovations by providing information to firms about how to adapt their technologies and processes to diminish their environmental footprints (Doran and Ryan, 2016). Non-compliance with regulations, however, can saddle firms with penalties and lawsuits, if not cause them to lose their operating permits (Sarkis et al., 2010). Khanna et al. (2009) have argued that the mere anticipation of stringent regulations is often sufficient to induce green-innovations that can assist firms with gaining a competitive advantage by adhering to industry standards and creating potential barriers to market entry for competitors.

In the European SSS industry, regulatory pressure can be extended by the IMO, the EU or a state by requiring firms to comply with environmental targets for reduced sulphur and CO2 emissions and water pollution from ships, for example, or to use scrubbers or cleaner fuels and ballast water treatment systems aboard vessels (Yang et al., 2013). As a result of such regulations, to gain legitimacy and avoid penalties firms feel pressure to engage in green practices and innovations (Zhu et al., 2013). Consistent with Yan et al. (2016), in this paper green innovation are divided into two types—green technological innovation and green process innovation—and a two-part hypothesis regarding such innovation and regulatory pressure in the context of European SSS is proposed:

H1a. Regulatory pressure has a positive effect on green technological innovations.

H1b. Regulatory pressure has a positive effect on green process innovations.

2.2. Green innovations and environmental performance

Although used interchangeably with environmental innovation and eco-innovation (Long et al., 2017), green innovation refers to the production, application or exploitation of a good, service, production process, or management or business method that is novel to the firm and that results in a reduction of environmental risk, pollution and the adverse impacts of resource use, including energy use, compared to relevant alternatives (Kemp and Pearson, 2007). A prominent feature of green innovation is its particularly positive effect on the environment, regardless of whether that effect was the primary objective of innovation. Accordingly, any innovation with a positive effect on the environment may simultaneously fall into different categories of innovation, including product innovation and incremental innovation (Kemp and Pearson, 2007). In this paper, consistent with Yan et al. (2016), green innovation is defined as new ideas, changes, solutions or processes that are novel to a firm and offer value to both customers and the firm while improving environmental performance.

Also in line with Yan et al. (2016), green innovation practices in the SSS industry are classified as green technological innovations or green process innovations, both of which differ from each other in multiple aspects. For one, green technological innovations principally involve adopting advanced or novel technologies, whereas green process innovations typically involve increasing process efficiency to achieve a higher rate of the use of capacity, save energy and reduce waste generated during operational processes (Benner and Tushman, 2003). Moreover, green technological innovations often require implementing new technological solutions or the redesign of existing equipment, the initial required investments for which can be so high that firms may be unable to gain adequate returns in the short term. By contrast, green process innovations often require improving existing processes, which generally demands less initial investment and offers a shorter payback period than green technological innovations (Adner, 2002). In either case, however, green innovations can help firms to achieve superior environmental performance and, as a result, comply with environmental regulations. For instance in shipping industry reduction in emissions can be can either be achieved by green technological innovations such as by using scrubbers, or the same effect can be achieved by green process innovations such as slow steaming.

Environmental performance refers to the ability of shipping firms to reduce emissions and waste from their operations and perform their activities in an environmentally friendly manner (Zhu and Sarkis, 2007). Environmental performance can be measured in terms of different indexes, including the reduction of air emissions (e.g. CO2, SOx and NOx), the reduction of water pollution, the reduction of waste (e.g. oily waste, sludge and rubbish) and legislative compliance (Yang, 2018). Among researchers who have focused on how green innovations can influence firms' environmental performance, Lee and Min (2015), referring to data from 2000 to 2010, found that green innovations decreased carbon emissions and increased firm value for Japanese companies. Meanwhile, Chiou et al. (2011) and Zhang et al. (2012) revealed the positive impact of green technological and process innovations on the environmental performance of firms in Taiwan and China, respectively. For SSS companies, green innovations improve environmental performance by enabling enhanced energy efficiency, the reuse or recycling of resources, the reduction of waste and hazardous substances and the lessening of emissions from business operations (Zhu et al., 2010). Considering all of those above, another two-part hypothesis referring to the context of European SSS was proposed:

H2a. Green technological innovation increases environmental performance.

H2b. Green process innovation increases environmental performance.

2.3. Green innovations and economic performance

In literature on regulation and economic performance, two opposing views circulate regarding the impact of environmental regulations on firms' economic performance. On the one hand, the traditional or cost-based view emphasises that costs incurred by a firm in complying with regulations decrease the firm's productivity and economic performance. Proponents of that view argue that if green innovation was profitable, then profit-maximising firms would opt for such innovation of their own accord (Jaffe et al., 1995). To conform to the requirements of environmental regulations, firms redistribute their existing labour and capital resources, which thus become diverted away from productive investments (Doran and Ryan, 2012). Consequently, proponents of the view maintain that regulations interfere with the competitive nature of firms and often adversely affect their economic performance.

Against that view, Porter and van der Linde (1995) have contended that environmental regulations induce innovations and enable win–win opportunities that lead to both a cleaner environment and increased productivity. They have argued that, in a static world, firms seek a trade-off between less pollution and business growth. However, because firms make cost-minimising choices that do not change over time, the introduction of new regulations raises costs and detrimentally affects their performance. Nevertheless, in the real world, where dynamic competition exists, environmental regulations may trigger innovations that can partially, fully or even more than fully offset the costs of complying with them. Central to that win–win view is the belief that green innovations can precipitate changes in production and processes at firms, which may reduce their production costs and thus improve their economic performance.

Research on the relationship between green innovations and economic performance has produced mixed empirical findings. By studying 4200 facilities in seven member countries of the Organisation for Economic Co-operation and Development, Lanoie et al. (2011) observed that environmental regulations promoted green innovation and, in turn, offset the costs of complying with them. The following year, with a sample of 4650 Irish firms, Doran and Ryan (2012) found that green innovations have had a positive, significant impact on firm performance. Focusing on Taiwanese and Chinese firms, respectively, Chiou et al. (2011) and Chan et al. (2016) revealed that green product and green process innovations have provided firms with a competitive advantage by increasing cost efficiency and profitability. Addressing Asian airline companies, Yan et al. (2016) found that green technological innovations have reduced fuel consumption, that green process innovations have enhanced operational efficiency and that both have improved firms' economic performance. By contrast, Amores-Salvado et al. (2014) and Jaffe and Palmer (1997) detected a negative relationship between green innovations and the economic performance of firms. Meanwhile, Lirn et al. (2014), and Yang et al. (2013) both of whom investigated container shipping companies located in Taiwan and Singapore, found that environmentally friendly practices at those companies had improved their economic performance. Given all of those findings, I proposed a third two-part hypothesis regarding European SSS:

H3a. Green technological innovation increases economic performance.

H3b. Green process innovation increases economic performance.

Fig. 1 illustrates the proposed research model.

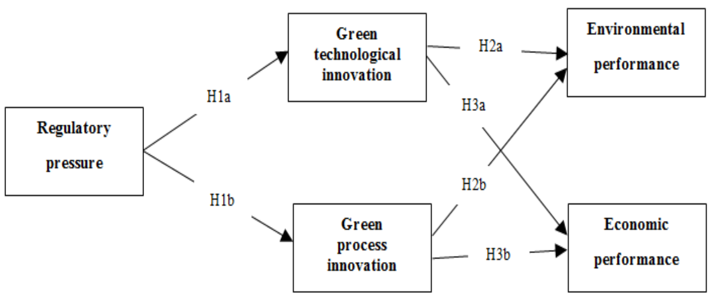

Fig. 1. The research model.

3. Material and methods

3.1. Measurement of variables

In line with earlier studies the items for evaluating regulatory pressure, green technological innovations, green process innovations, environmental performance and economic performance were adapted from previous research (Table 1). In addition, to gauge the content validity of the initial questionnaire, a pilot test with five experienced short sea shipping practitioners and five academics was conducted, as suggested by Malhotra and Grover (1998). Based on feedback received from the pilot survey, the observed variables were refined, deleted or added to ensure that the items were understandable and relevant to practices (Hensley, 1999).

Items for regulatory pressure were responded to on 5-point scale (1 = not at all important, 5 = very important), as were ones concerning green technological and green process innovations that asked respondents to what extent their companies have taken actions oriented towards green innovations (1 = not at all, 5 = to a great extent). For items regarding green performance and economic performance, respondents were asked to indicate on another 5-point scale the degree to which they agreed that various green technological and process innovations have afforded benefited their firms (1 = do not agree at all, 5 = completely agree).

Table 1
Construct items

Latent construct	Label	Item	Sources
Regulatory pressure (RP)	RP1	The IMO's environmental conventions, directives and regulations (e.g. MARPOL)	Yang (2018) and Zhu et al. (2013)
	RP2	The EU's environmental conventions, directives and regulations (e.g. EU Sulphur Directive)	
	RP3	National environmental regulations	
Green technological innovation (GTI)	GTI1	Our company has adopted energy efficiency measures for ships in our fleet (e.g. optimised hull or propeller, improved engine design, waste heat recovery systems and hull coating)	Lam (2015) and Yang et al. (2013)
	GTI2	Our company has implemented a ship energy efficiency monitoring system	
	GTI3	Our company has used technical equipment that reduces pollution (e.g. scrubbers and ballast water management systems)	
Green process innovation (GPI)	GPI1	Our company has adopted slow steaming	Lam (2015) and Yang (2018)
	GPI2	Our company has adopted optimal route planning	
	GPI3	Our company has adopted an environmentally friendly process for waste management	
Environmental performance (ENP)	ENP1	Reduction of air emission (e.g. CO_2, SOx and NOx)	Huang et al. (2016), Yang et al. (2013) and Zhu et al.(2007)
	ENP2	Reduction of water pollution	
	ENP3	Reduction of wastes (e.g. rubbish, oily waste and sludge)	
	ENP4	Improved compliance with environmental regulations	
Economic performance (ECP)	ECP1	Decreased cost of fuel consumption due to decreased energy consumption	Burki et al. (2018), Yang et al. (2013)
	ECP2	Decreased cost of the disposal of hazardous materials due to efficiency modifications	
	ECP3	Decreased cost of waste treatment	
	ECP4	Increased profits	

3.2. Data collection and sample size

The selected sample for the study comprised European companies in the SSS industry. To improve the generalisability of the study and the proposed model, the sample encompassed a variety of sectors in the SSS industry: RoRo and RoPax, container, bulk, multipurpose and general cargo. Although the main reason for selecting the European SSS industry was that it plays a pivotal role in intra-European freight transport, and the shipping industry is a comparatively high air-polluting mode of transport subject to various regional and international regulations (IMO, 2019b). Indeed, SSS might be more harmful than deep-sea shipping, for nearly 70% of maritime emissions are emitted within 400 km of land, where they can adversely affect both ecosystems and human health (Eyring et al., 2010). Furthermore, in response to stringent regulatory pressure, European SSS companies have implemented various green innovation practices in order to comply with regulations and improve their environmental performance (ECSA, 2016). The target group for the survey was managers or their equivalents at SSS companies who are knowledgeable about how green innovations and regulations affect their firms' economic and environmental performance. The units of analysis were individual companies, whereas the unit of data collection was one manager from each company.

Following Yuen et al. (2017), the list of companies was obtained from Lloyds List Intelligence: Maritime Intelligence. An online survey, distributed with a cover letter explaining the purpose of the survey and assuring the anonymity of respondents, was developed at www.qualtrics.com, and web-links to the survey were sent via email to managers at 493 companies. Ultimately, 101 usable responses were returned, for an overall response rate of 20.32%, which met the recommended minimum level of 20% for studies involving surveys (Malhotra and Grover, 1998).

3.3. Common method bias assessment

Since all data were collected from one respondent at the 101 companies, common method bias might have posed a problem (Podsakoff et al., 2003). In response, Harman's single factor test was performed for exploratory and un-rotated single factor analysis. The results revealed that no single factor explained the majority of the variance and that the variance of a single factor, 36.32% of the total variance, was less than the threshold limit of 50% (Doty and Glick, 1998; Podsakoff and Organ, 1986). Thus, based on this, it is confidently concluded that common method bias does not exist in this study.

3.4. Data analysis

To test the hypotheses and analyse the data, the structural equation modelling (SEM) technique suggested by Anderson and Gerbing (1988) was employed. SEM is a statistical method of representing causal processes involving observations on multiple variables. According to Golob (2003), SEM can accommodate multiple endogenous and exogenous variables, as well as latent (i.e. unobserved) variables specified as linear combinations (i.e. weighted averages) of the observed variables.

To evaluate the reliability and validity of the measurement model, confirmatory factor analysis was performed. After the measurement model was validated, the structural model was estimated to define the relationships amongst the latent variables and to test the hypotheses. All analyses were performed in the Statistical Package for the Social Sciences version 25.0 for Windows and Amos 25 software programmes.

4. Results and analysis

4.1 Descriptive analysis

Table 2 presents the key characteristics of the survey respondents and their companies.

Table 2

Distribution of survey respondents based on key characteristics (*N* = 101)

Characteristics	**Respondents (*n*)**	**Percentage (%)**
Job title at the firm		
Director or above	20	20
Manager	67	66
Other (e.g. environmental advisor)	14	14
Firm's primary sector		
Container	15	15
Bulk	21	20
RoRo-RoPax	24	24
Multipurpose	13	13
General cargo	19	19
Other (e.g. reefer)	9	9
Firm's fleet size (number of vessels)		
10 or fewer	59	58
11–20	18	18
21–30	5	5
31–40	10	10
More than 40	9	9
Average fleet age (in years)		
5 or fewer	2	2
6–10	29	29
11–15	31	31
16–20	20	20
More than 20	19	18

In general, managers or directors are actively involved in key decisions related to technological investments and ship operations and hence possess sufficient knowledge about their companies′ innovations and business performance. The answers to survey questions by highly informed mangers can possibly lead to more reliable results compared to lower level employees of the company who are usually not involved in the big decisions and may lack knowledge across different departments. As presented in Table 2, the overwhelming majority of respondents (86%) held positions at least at the managerial level, which endorsed the reliability of the survey's findings.

The sampled companies represented multiple sectors of Europe's SSS industry—container shipping (15%), bulk shipping (20%), RoRo or RoPax shipping (24%), multipurpose shipping (13%) and general cargo shipping (19%)—which secured not only the sample's diversity of sectors but also a relatively even distribution of respondents by sector. In terms of size, 59 companies had fewer than 10 vessels in their fleets, whereas only nine had more than 40, which demonstrates the difference in the fleet size of the sampled firms. Table 3 lists some of the companies in the sample.

Table 3
Partial list of companies in the sample ($N = 101$)

- Aegean Bulk
- Color Line
- Containerships (CMA CGM Group)
- DFDS
- Eimskip
- ESL Shipping
- Faergen
- Furetank
- Golden Ocean Group
- Grimaldi Group
- Hellenic Sea Lines
- Maersk
- Neptune Lines
- Samskip
- SCA Logistics
- Scandlines
- Seatruck Ferries
- Smyril Line
- Swedish Orient Line
- Spliethoff Group
- Stena Line
- Thun Tankers
- Tri Bulk Shipping
- United European Car Carriers
- Unifeeder
- Unity Line
- Vertom Shipping
- Viking Line
- Wagenborg Shipping
- Wallenius Wilhelmsen
- Wilh Wilhelmsen
- Wilson Shipping

Table 4 provides the descriptive statistics of the items.

Table 4

Descriptive statistics of the survey items

Factor	Items	Mean	Std. Deviation	Minimum	Maximum
Regulatory pressure	The IMO's environmental conventions, directives and regulations (e.g. MARPOL)	4.47	.807	2	5
	The EU's environmental conventions, directives and regulations (e.g. EU Sulphur Directive)	4.44	.805	2	5
	National environmental regulations	4.07	.972	2	5
Green technological innovation	Our company has adopted energy efficiency measures for ships in our fleet (e.g. optimised hull or propeller, improved engine design, waste heat recovery systems and hull coating)	3.63	1.065	1	5
	Our company has implemented a ship energy efficiency monitoring system	3.55	1.204	1	5
	Our company has used technical equipment that reduces pollution (e.g. scrubbers and ballast water management systems)	3.02	1.428	1	5
Green process innovation	Our company has adopted slow steaming	3.84	1.075	1	5
	Our company has adopted optimal route planning	3.63	1.056	1	5
	Our company has adopted an environmentally friendly process for waste management	4.02	.905	2	5
Environmental performance	Reduction of air emission (e.g. CO_2, SO_x, NO_x)	4.15	.888	1	5
	Reduction of water pollution	3.77	1.148	1	5
	Reduction of wastes (e.g. rubbish, oily waste and sludge)	3.57	1.099	1	5
	Improved compliance with environmental regulations	4.13	.868	1	5
Economic performance	Decreased cost of fuel consumption due to decreased energy consumption	3.81	1.056	1	5
	Decreased cost of the disposal of hazardous materials due to efficiency modifications	3.02	1.157	1	5
	Decreased cost of waste treatment	3.02	1.149	1	5
	Increased profits	3.27	.999	1	5

4.2 Measurement model analysis

Confirmatory factor analysis (CFA) was performed to examine the fit, reliability and validity of the measurement model. Table 4 lists the standardised factor loadings (λ), Cronbach's α, average variance extracted (AVE) and composite reliability (CR) of the constructs. The results of the CFA indicated that the measurement model exhibited acceptable levels of model fit to the data ($\chi 2/df = 1.626$, GFI = 0.841, CFI = 0.930, IFI = 0.932, RMSEA = 0.079).

The reliability of the model was assessed in terms of both composite reliability (CR) and Cronbach's α, for which values exceeding 0.6 and 0.7, respectively, are considered to be acceptable (Bagozzi and Yi, 1988; Nunnally and Bernstein, 1994). Composite reliability is an indicator of shared variance amongst observed variables used as indicators of latent construct (Fornell and Larcker, 1981). Table 5 shows that Cronbach's α and composite reliability values exceed the threshold values, which suggests that the items reliably represented their intended constructs.

By contrast, the validity of the constructs was evaluated in terms of convergent and discriminant validity. Convergent validity indicates the degree to which different methods of evaluating a variable provide the same result, whereas discriminant validity indicates the degree to which latent constructs are unique and capture phenomena that other constructs do not (Hair et al., 2010). Following Chin (1998), convergent validity was assessed using standardised loadings and average variance extracted (AVE). Among the results, all standardised loadings exceeded the recommended value of 0.5 except Item GPI3 (.430), the loading of which was situated on the boundary of the threshold. Furthermore, the AVE for each construct also exceeded the threshold of 0.5 (Fornell and Larcker, 1981), which provides strong evidence of convergent validity among the constructs. Next, discriminant validity was tested by comparing the square root of the AVE of each construct with the possible inter-construct correlation coefficient (Fornell and Larcker, 1981). As shown in Table 6, all diagonal values (in bold) representing the square root of the AVE were greater than the correlations (i.e. the off-diagonal values) between all possible pairs of constructs, which confirmed the discriminant validity of all the constructs.

Table 5

Convergent validity and reliability of the measurement model

Latent construct	Label	Standardised loading	Cronbach's α	Composite reliability	AVE
1. Regulatory pressure (RP)	RP1	.892	.884	.906	.765
	RP2	.962			
	RP3	.758			
2. Green technological innovation (GTI)	GTI1	.826	.750	.760	.516
	GTI2	.679			
	GTI3	.637			
3. Green process innovation (GPI)	GP1	.893	.745	.776	.555
	GP2	.826			
	GP3	.430			
4. Environmental performance (ENP)	ENP1	.674	.801	.831	.553
	ENP2	.782			
	ENP3	.768			
	ENP4	.746			
5. Economic performance (ECP)	ECP1	.573	.840	.848	.600
	ECP2	.940			
	ECP3	.956			
	ECP4	.524			

Table 6
Results of discriminant validity testing

Latent construct	RP	GTI	GPI	ENP	ECP
RP	**.875**				
GTI	.240	**.719**			
GPI	.371	.539	**.745**		
ENP	.518	.686	.421	**.744**	
ECP	.224	.308	.197	.663	**.775**

Note. Values in bold along the diagonal represent the square root of the AVE, whereas off-diagonal values indicate the correlation coefficients of the constructs.

4.3 Hypothesis testing

A structural equation model was developed to test the proposed hypotheses. According to the results (Table 7), the model fit indices conformed to recommended standards (Bagozzi and Yi, 1988) and were thus reasonably acceptable for the proposed model (Figure 1). Table 7 presents the estimated results of the structural model.

Table 7
Results of the structural model

Hypothesis	**Path coefficient (β)**	***p***	**Result**
H1a. Regulatory pressure → Green technological innovations	.352	.002	Supported
H1b. Regulatory pressure → Green process innovations	.382	.000	Supported
H2a. Green technological innovation → Environmental performance	.677	.000	Supported
H2b. Green process innovation → Environmental performance	.067	.583	Not supported
H3a. Green technological innovation → Economic performance	.303	.049	Supported
H3b. Green process innovation → Economic performance	.037	.788	Not supported
Model fit indices: χ^2/df = 1.75, GFI = 0.830, CFI = 0.914, IFI = 0.920, RMSEA = 0.086			

In two parts, the first hypothesis (i.e. H1a and H1b) addressed the effect of regulatory pressure on green technological and green process innovations at SSS firms in Europe. As indicated by the results shown in Table 7, regulatory pressure indeed had a positive, significant effect on the adoption of both green technological and process innovations (β = .352, p = .002; β =.382, p = .000), meaning that H1a and H1b were supported.

4.3.2 Green innovations and environmental performance

The effect of green innovations on the environmental performance of SSS firms in Europe was addressed by H2a and H2b. According to the results, because green technological innovation had a positive, significant effect on environmental performance (β = .677, p = .000), H2a was supported. By contrast, because green process innovation did not significantly affect environmental performance (β = .067, p = .583), H2b was rejected.

4.3.3 Green innovations and economic performance

Last, although green technological innovation also had a positive, significant effect on a firm's economic performance (β = .303, p = .049), green process innovation did not (β = .037, p = .788), which supported H3a but not H3b.

5. Discussion and conclusion

The main results of this study reveal that environmental regulations as an external institutional driver is positively and significantly related to the adoption of green technological and process innovations amongst Europe's SSS companies. This result is consistent with those of previous studies such as Yang (2018) and Yuen et al. (2017), which proclaimed that regulations exert coercive institutional pressure on the shipping companies in Taiwan and Singapore and this pressure has a positive effect on the adoption various types of green innovations and sustainable practices. The significant role of environmental regulations in driving environmentally friendly innovations is evident. For example, after the oil spill incident of the ship Exxon Valdez incident, the Oil Pollution regulations of 1990 exerted pressure on the ship companies to build new vessels with doubled-hull tanker vessels. Similarly, spurred by environmental regulations during the past several decades, SSS companies have adopted various technological and process changes, including energy-efficient systems, scrubbers, ballast water treatment systems, alternative fuels, slow steaming, and optimised route plans.

Moreover, the results of this study indicate that the adoption of green technological innovations is beneficial to economic and environmental performance of SSS companies, although such innovations are influence by institutional pressures. Research shows that green practices and innovations improve environmental (Lirn et al., 2014; Yang, 2018) and economic (Lirn et al., 2014; Yuen et al., 2017) performance of shipping companies.

An interesting result of this research is that in contrast to green technological innovations, green process innovations have had limited impact on the environmental and economic performance of Europe's SSS firms. As corroborated by Raza et al. (2019) and Chen et al. (2018), plausible explanations for that finding are factors such as substantially reduced ship bunker prices since 2014 and intense competition with alternative modes of freight transport (e.g. rail and trucking), which might have discouraged SSS companies, particularly ones operating RoRo and RoPax, from adopting slow steaming and route optimisation to the same degree as deep-sea shipping firms.

Overall, the results show that regulations as an external institutional driver encourages green innovations in the SSS industry in Europe. By engaging in green innovation activities, SSS companies can enhance their environmental and economic performance, because green innovations prompt increased productivity, reduced emissions, energy consumption and waste treatment costs and, in turn, increased profitability.

From a theoretical perspective the results of this paper strengthen institutional theory by providing further evidence regarding the impact of external institutional pressure on the adoption of green innovations from the perspective of European short sea shipping industry. The results show that to maintain their social legitimacy, avoid penalties, improve their environmental and economic performance SSS companies have to submit to the pressure exerted to them by external institutional drivers. Non-compliance to regulations can lead to penalties and jeopardize the brand image of a shipping company as for example recently a shipping company was fined 80000 US Dollars for violating the sulphur regulation in the Norwegian Sea (WMN, 2019). Further, the empirical findings of previous research (e.g Vachon and Klassen, 2008) indicate that green innovation is predictor for environmental performance. In contrast the results of this paper demonstrate that green innovation is a mediator after the pressure external institutional driver (i.e. regulation) is introduced. It implies that pressure of environmental regulations impact positively green innovations that in turn affect the environmental and economic performance of SSS.

From the policy perspective, although regulations encourage green innovations in the SSS industry and, as a result, improve firms' environmental and economic performance, Porter and van der Linde (1995) have argued that only flexible, carefully designed regulations generate positive outcomes. Concerning the shipping industry, Lindstad et al. (2017) have explained that the IMO's stringent sulphur regulations may elevate fuel consumption on a well to propeller basis—that is, either when refineries remove sulphur from heavy fuel oils (HFO), or when scrubbers clean the exhaust gas from combustion of HFO at sea. Furthermore, the discharged wash-water from the open loop marine scrubbers contains noxious pollutants such particulate matter and sulphur, as well as metals including lead, nickel and zinc. The discharge of such contaminated wash-water in the marine environment pollutes the seawater, negatively affects the marine chemistry, and biodiversity. Therefore, some Southeast Asian nations including, Singapore, China, Hong Kong, and Malaysia have banned the ships that have open-loop scrubbers from entering into their local waters (Sipalan, 2019). Similarly, although expected to be much cleaner in terms of criteria pollutants, the use of low sulphur fuels require additional energy in the upstream stages of the fuel cycle (i.e., fuel processing and refining), and thus raise questions about the net impacts on greenhouse gas emissions (primarily carbon dioxide) because of production and use (Corbett and Winebrake, 2008).

Therefore, before devising and implementing new regulations, policymakers such as IMO and EU Commission should consider all of the potential repercussions of the regulations from perspective of the energy life cycle. On top of that, these policymakers should also weigh the environmental benefits possible from regulation against possible losses at the firm level. In addition to using regulations (i.e. "sticks"), policymakers should additionally consider providing incentives (i.e. "carrots") to companies as a means to encourage desired environmental outcomes and promote green innovations (Interreg, 2019; Doran and Ryan, 2016).

From the managerial perspective, this study's findings highlight the importance of green innovations to respond to external institutional pressures and to improve their environmental and economic performance. Further, the type of green innovations being pursued is pivotal. Results from the study show that green technological innovations, including ones related to energy efficiency, have a stronger impact on firms' economic and environmental performance. Accordingly, managers at SSS firms can enhance the environmental and economic performance of their companies by dedicating resources to developing green and energy-efficient technological solutions. At the same time, they should not wait for regulations to begin developing green innovations but take a proactive approach to pursuing such innovations, which can benefit the performance of their companies.

In short, SSS companies should regard environmental regulations not as threats but as opportunities. Because regulations direct firms' attention to likely resource inefficiencies and potential technological and process improvements in response, regulations can raise corporate awareness and create pressure to pursue innovation, which may concurrently engender environmental and economic benefits for SSS firms.

5.1. Limitations and future research

Although environmental regulations as an external institutional driver was treated as a predictor of green innovations in the sampled SSS companies, other external institutional drivers—for example, coercive pressure by the customers of SSS companies, normative pressure by non-governmental institutes and mimetic pressure by competitors—can also influence the adoption of green innovations, which researchers should consider in their studies on the topic. Further, the paper does not include all the possible dimensions that can be used to represent the constructs of green innovations, and environmental and economic performance, and the inclusion of other items in the model may generate different results. Therefore, the findings of this paper are context specific and should be generalized with caution. Moreover, as in most empirical studies, cross-sectional data is used in this paper; however, other researchers should consider using longitudinal data to investigate the short- and long-term effects of green innovations on the environmental and economic performance of SSS firms.

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