Drivers for environmental technologies selection in the shipping industry: A case study of the North European Sulphur Emission Control Area

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Abstract:

This study tackles the question: How do new air pollution regulations interact with other eco-innovation drivers in the adoption of environmental technologies in the shipping industry? In the North Sea, Baltic Sea, and the English Channel, short sea shipping is subject to strict requirements on sulphur emissions by the European Union and the International Maritime Organization after the creation of a Sulphur Emission Control Area (SECA). The creation of this SECA creates a critical case for analyzing the interactions of the regulations with technological pull, market demand, and green business strategies. The study found that a globalized industrial sector, such as shipping, tends to oppose regional regulations. These regulations benefit from market conditions which slightly push the shipping companies to embrace environmental technologies when operational costs increase due to expenses such as increasing fuel prices. Meanwhile, voluntary initiatives like participating in eco-labelling schemes can motivate eco-innovations, especially cleaner-processes, as shipping firms need to increase fuel efficiency to reduce high operational costs within SECA sulphur limits. The research contributes to the ongoing debate about eco-innovation characteristics in different industrial sectors, but more specifically, it moves forward the proposition of dynamic interactions between regulation, technology, business and markets, which modify the dominant focus on market pull and technological push.

Keywords:

Sulphur; shipping industry; eco-innovation; environmental technologies; environmental regulation; MARPOL

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Biographical note:

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1 Introduction

Air pollution from ships has become an important issue in recent years. In 1997, the International Maritime Organization (IMO) incorporated air pollution prevention as a further area of environmental protection by adding Annex VI to the International Convention for the Prevention of Pollutions from Ships (MARPOL) – which has been in place since 1978 (Mensah, 2007; Dalsøren et al., 2009; Winebrake et al., 2009). At the request of bordering countries to put limits to SO_X emissions, the IMO created Sulphur Emission Control Areas (SECAs) in the English Channel, North Sea, the Baltic Sea, and the North American coasts (IMO, 2013). The European Commission issued in 1999 one directive to enforce this regulation, subsequently amended in 2005 and 2012. According to the IMO and the EU regulations, compliance with SECA can be achieved by switching to low sulphur fuel, using exhaust cleaning technology, or using LNG – liquefied natural gas (Balland et al., 2013).

The SECAs in European waters are the first in the world to be enforced, and therefore no historical data is available regarding how the regulation interacts with other drivers for the innovation of maritime environmental technologies; however, previous research highlights the role of regulation in promoting some kind of innovation activities in the maritime industry (Makkonen and Repka, 2016). The drivers of eco-innovations have become important within the literature of ecological modernization (Díaz-García et al., 2015; Hojnik and Ruzzier, 2016). "Eco-innovation" is increasingly used in the literature to name innovations that drive environmental and economic goals (Carrillo-Hermosilla et al., 2009; Franceschini et al., 2016). Extant research on eco-innovation gives a high importance to the role of at least four drivers: regulatory push, technological push, market pull, and internal business aspects (Rennings, 2000; Rubik, 2005). Regulatory push is often referred to as standards, regulations, and policies set to address a given environmental impact (Ashford and Hall, 2011). Technological push refers to knowledge embedded in the firm-specific practices, devices, and processes (Horbach et al., 2012). Market pull is used to explain the influence of the consumer practices and choices that motivate cleaner production processes and development of greener products (del Río et al., 2016). Internal aspects deals with the organizational strategies put forward to accomplish sustainability strategies (Rubik, 2005). These drivers are often seen as independent and conflicting, thus the relations and interactions between them lack investigation (Hermann and Wigger, 2017). More recent publications seek an industry-specific understanding of drivers for the adoption of environmental technologies (Horbach et al., 2012; Bossle et al., 2016).

In this article, the author seeks to contribute to the understanding of the dynamics and interactions between the different drivers as an important mechanism for innovation and the adoption of environmental technologies. The main research question is

How do new air pollution regulations interact with other eco-innovation drivers in the adoption of environmental technologies in the shipping industry?

This case study focuses on short sea shipping within the North European SECAs (North Sea, Baltic Sea, and the English Channel). Environmental issues are playing a more important role and are top items in the maritime industry’s agenda as shipping firms develop more proactive environmental policies, and industrial customers have begun to ask questions regarding the environmental footprint of sea transport. In this context, this article serves to investigate these dynamic changes and explore the proposition of a conceptual model to understand the relationship between regulation, technology, business, and markets in the context of new air pollution regulations in Northern Europe.

The structure of the article is as follows: in section 2, a conceptual framework is developed based on a literature review. Section 3 explains how and why the case of sulphur limits in shipping is important for understanding the role of environmental regulation and the contextual frame. The study is part of an action research project and linked to personal and institutional practices in the adoption of environmental technologies in the shipping industry. Section 4 describes the dynamics and interactions between the different drivers as a mechanism for development and adoption of environmental technologies in the shipping industry. The last two sections discuss the theoretical relevance of the results and presents conclusions.

2 Drivers of eco-innovation

A conceptual framework for analyzing the drivers of development and the adoption of eco-innovations in the shipping industry needs to identify the extent to which a hybrid type of innovation such as eco-innovation is more complex to develop and adopt than a conventional one. Therefore, a typology of eco-innovations is developed before the specific drivers of environmental technology are characterized.

2.1 Eco-innovation

Eco-innovation is a core concept in ecological modernization (Jänicke and Jacob, 2005). Carrillo-Hermosilla et al. (2010) analyzed different definitions of eco-innovation, while acknowledging it as an umbrella term to cover such topics as environmental innovation, cleaner technologies, and others. Among all these definitions, eco-innovation is commonly associated with

> “All measures of relevant actors (firms, politicians, unions, associations, churches, private households) which develop new ideas, behavior, products and processes, apply or introduce them and which contribute to a reduction of environmental burdens or to ecologically specified sustainability targets” (Rennings, 2000).

2.2 Environmental technologies definition and typologies

Cleaner technology and pollution prevention have been defined rather broadly. In Denmark it is seen as "a continuous development process, with the prime purpose of minimizing pollution associated with the production processes and products rather than just treating the pollutants" (Georg et al., 1992, p. 548). In other words, resource use, emissions, and waste should be reduced at the source inside the production and when designing new products. An important distinction between end-of-pipe solutions such as wastewater treatment plants and “clean tech”, is that clean technology is seen as a preventive, process-integrated approach with focus on reduction and reuse.

Rennings (2000) differentiates between curative (e.g. soil decontamination) and preventive environmental protection. Preventive environmental protection involves process-integrated and end-of-pipe technology. Process-integrated technology is defined by Ekins (2010) as “a general term of changes in processes and production methods (i.e. making things differently) that leads to less pollution, resource, and/or energy use”. Examples of process-oriented technologies are the recirculation of materials, the use of less hazardous materials, and the modification of design of equipment -process-integrated systems

(Frondel et al., 2007). Process-integrated also consists of organizational innovations such as Environmental Management Systems or inter-organizational initiatives as industrial symbiosis.

End of pipe is defined as “isolating or neutralizing polluting substances after they have been formed” (Ekins, 2010). Examples are incineration plants for waste disposal, sound absorbers, exhaust gas cleaning systems, etc. (Frondel et al., 2007). End of pipe technology’s adoption is pushed by environmental regulations because they usually bring only environmental benefits and not economic benefits to the adopting firm (Markusson, 2011).

2.3 Eco-innovation drivers in shipping

Early research contributions on eco-innovation drivers had a focus on the factors of diffusion of cleaner technologies in the industry (Kemp et al., 1992). Later, this initial focus expanded from cleaner technologies to eco-innovations, i.e. Rennings (2000) and Rubik (2005). The following conceptual framework focuses on environmental technologies (cleaner technologies and end-of-pipe) as a subset of eco-innovations in order to compare the sector specific evidence of marine environmental technology adoption in the shipping industry. The model acknowledges that endogenous and exogenous drivers influence the adoption of environmental technology.

Rennings (2000) proposed that conventional innovations are driven by market demand and technological developments. These two factors are also valid for eco-innovations. In addition, regulations are a third driver for eco-innovations (Rennings, 2000). Environmental policy and regulations can have an influence on how firms develop and adopt eco-innovations (Ashford and Hall, 2011). Internal business aspects were later incorporated into the model. The reason is that some organizations are more receptive to developing and adopting eco-innovations depending on their internal dynamics (Rubik, 2005). These different drivers are usually sketched as influencing a company's decision on whether to adopt environmental technology. Figure 1 illustrates a possible interaction of these different aspects that drive eco-innovation in the shipping industry through Rennings (2000) and Rubik's (2005) original model. The model integrates some of the representative examples of drivers within each category.

Regulations are standards for technologies, environmental performance, or outcomes. Ashford and Hall (2011) make a distinction between "weak" and "strong" environmental regulation. A weak environmental regulation is that with comparably low standards. The technological response is the diffusion of end-of-pipe technology, process change, and product reformulation. In contrast, a strong environmental regulation will release the eco-innovation potential of affected firms. New entrants can arrive in the market and propose new products, product-services, or processes. International standards could eventually provide a similar effect as strong environmental regulations (Ekins, 2010). However, international regulations are not without challenges. The shipping industry, for example, is a globalized industry, with assets (vessels) registered in different countries and moving in different regulatory regimes (international, national, or local). There are practical challenges to enforcing IMO international environmental conventions: first, individual countries must establish national programs to enforce and monitor compliance with those conventions. Second, not all IMO member states communicate properly or establish effective mechanisms to do so (Comtois and Slack, 2007).

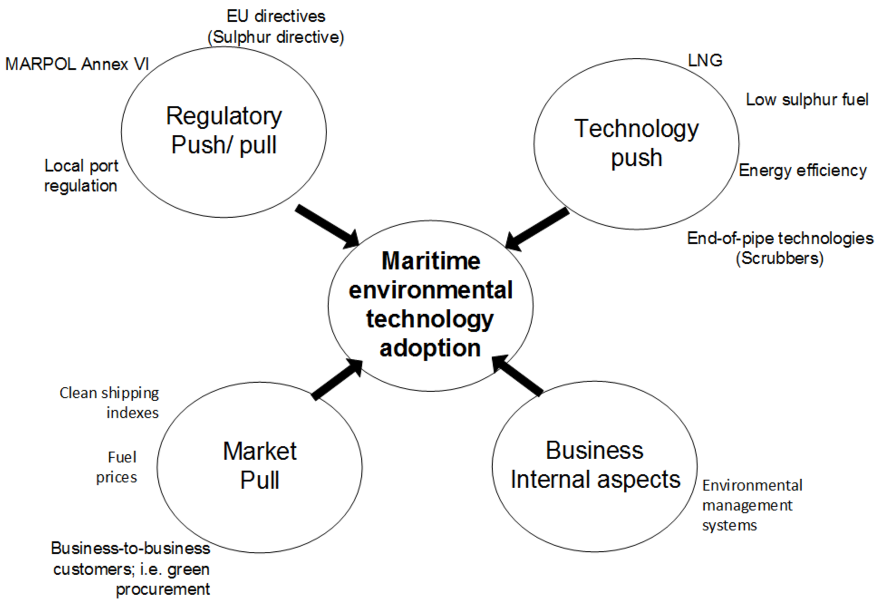

Figure 1- Eco-innovation drivers for the shipping industry: an adaptation of the classical eco-innovation drivers' model. *Source*: Adapted from Rennings (2000) and Rubik (2005)

The premise of market pull is that demand creates incentives to develop eco-innovations (Kemp et al., 1992). Recent contributions identify evidence on how consumers or business-to-business consumers motivate firms to adopt eco-innovations (Horbach et al., 2012). Examples include green public procurement programs that set environmental standards for their suppliers. Figure 1 illustrates that voluntary initiatives are part of market drivers in global industries. The cement industry started the Cement Sustainability Initiative (CSI), departing from the fact that regulatory frameworks are highly diverse at a national level. CSI seeks to reduce greenhouse gas emissions by promoting cleaner technologies among participating members (Busch et al., 2008). Fuel prices are an industry specific market pull factor in the shipping industry because fuel prices have consequences on the operation costs and the profit margins for the companies (Yao et al., 2012).

Kemp et al. (1992) claim that technological push is interlinked to market pull and both factors are complementary. Technological push is more likely associated to the supply. Technologies are not simply devices, but also organization, knowledge, techniques, and product (Müller, 2013). From this perspective, it is expected that different firms will have different capacities for technology push because they will differ in terms of organization, techniques, knowledge, and their products. Further, their capacity to invest on R&D influences each company's trajectory (Kemp et al., 1992). Marine equipment manufacturers increasingly have begun to develop engines using alternative fuels – e.g. biofuels, liquefied natural gas. These fuels will release less pollutant emissions than their heavy fuel oil counterparts (Bengtsson et al., 2011). Despite this, new technologies face selection pressures from the existing technological regime. Any marine equipment needs approval from the classification societies to certify that it complies with the IMO safety-standards.

Internal business aspects are a driver for knowledge generation and for building up eco-innovative capacity (Horbach et al., 2012). The internal aspects represent how a firm is prepared to spot and integrate external knowledge and turn it into eco-innovations. Hansen and Klewitz (2012) name this an absorptive capacity, which can be increased by some internal factors. An example is organizational innovations in the form of actor-oriented strategies. These strategies improve the inter-organizational collaboration in order to create synergies with other companies (Fjeldstad et al., 2012). Another example is Environmental Management Systems (EMS) which can overcome the lack of information linked to the introduction of cleaner technologies because EMS include information on savings generated by these alternative technologies (Horbach et al., 2012).

3 Research design and methods

In this section, the case study selection and delimitation as well as the qualitative methods for data collection and analysis are discussed. The case study examines the main research question: *How do new air pollution regulations interact with other eco-innovation drivers in the adoption of environmental technologies in the shipping industry?* The case study analyzes how the implementation of the sulphur directive (Directive 1999/32/EC) and its amendment (Directive 2012/33/EU) drive the interest for this type of technology in the short sea- shipping industry. This main research question is ordered around the following three sub-questions, creating the organization of the case study:

- How is sulphur content in marine fuels being regulated within the Emission Control Areas and how it influences eco-innovation in short-sea shipping?
- How does air pollution regulation influence eco-innovation through interaction with other drivers?
- What could the future directions of the combination of regulation and other drivers for eco-innovation in the shipping industry be?

The first two questions will be developed within the case study; the third question will be analyzed as part of section 5.

3.1 Case selection

The author followed a qualitative single case study design (Yin, 2014). The case study selection was primarily instrumental as it was guided by a research question whose purpose was to provide insights on theory and redraw generalization (Stake, 2005). To select the case study, the author followed a criteria-based selection following two steps (Marshall and Rossman, 2006). The first step was defining the shipping industry as the industrial sector of choice. The shipping industry comprises seaborne transportation, including container, dry and liquid bulk, passenger (cruise and ferry), and gas (Fremont, 2009). Within the whole shipping industry, the focus was on short-sea shipping within the North European SECAs (North Sea, the Baltic Sea, and the English Channel). As explained in the Introduction, this SECA is in place as a result of two European directives (which adapted MARPOL Annex VI): Directives 1999/32/EC and 2012/33/EU. The SECA in the Baltic Sea entered into force on the 19 May 2006, whereas the North Sea and the English Channel SECAs entered into force on 22 November 2007 (Notteboom, 2011). As often pointed-out in the literature, the most contentious issue with air pollution regulations affecting the shipping industry in SECAs is the costs associated with compliance (Cullinane and Bergqvist, 2014). This contentious characteristic of the creation of the SECA in Northern Europe highlights the critical aspect of the case study. It is not just a coincidence that the establishment of an European SECA has been closely followed by the scientific community in recent years. Ship-owners and policy-makers have commissioned research reports to evaluate the SECA’s impact on short-sea shipping costs (Holmgren et al., 2014). Notwithstanding extensive research on the subject, there is not a total agreement about what the impact has been of the stricter limits of 0.1% sulphur content in marine fuels within SECAs after 1 January 2015 (Holmgren et al., 2014). The reason is some research focuses on certain routes, while fuel prices vary greatly over time (Holmgren et al., 2014). Studies after 1 January 2015, conclude that compliance costs will likely have an impact on certain routes, particularly those where land routes offer a clear price advantage (Holmgren et al., 2014). For example, the Scandinavian paper-industry will likely suffer from the rising costs associated with compliance (Hämäläinen, 2015). However, installing cleaner technologies and engaging in eco-efficient sailing practices, such as slow steaming, can have an effect on moderating these impacts (Hämäläinen, 2013). In addition, most of the impact assessments do not account with the possibility that the IMO will require sulphur content in marine fuels to be reduced below 0.5% depending on the market availability of low sulphur fuel after 2020 (IMO, 2017).

Paradigmatic cases seek 'to develop a metaphor or establish a school for the domain that the case concerns' (Flyvbjerg, 2006). We considered the situation of short-sea shipping in SECAs on Northern European waters as a paradigmatic case because it is the first time that a regulation on air pollution is enforced in a regional area and not a single port or city. From this perspective, the author considered that the case study could provide important elements for generalization in new SECAs, such as the North American coasts or in possible future European SECAs (i.e. The Mediterranean). In addition, previous research highlights how the maritime sector in Northern Europe is increasingly engaged in collaborative green innovation initiatives, partly inspired by forthcoming air pollution regulations (Mosgaard et al., 2014; Hermann et al., 2016; Hermann et al., 2016).

3.2 Data collection and analysis

The author relied on three qualitative methods to collect data for this case study: document review, interviews, and observation. The document and literature review was primarily undertaken through the websites of relevant global and European shipping stakeholders. The documents reviewed included regulations, public statements, commissioned studies, and position papers[1]. A discourse analysis of this material helped identify the positions of

[1] The sources included European Commission's Commissioned studies, directives, green papers; IMO's conventions and Environmental committee internal communications; European and Danish branch organizations (position paper, commissioned studies)

actors vis-à-vis the regulations and the environmental technologies. This first analysis was crucial in identifying which key informants were important for in-depth interviews.

Semi-structured interviews with key informants were the primary data collection methods. The key informants were two representatives of environmental NGOs, three representatives of the Danish authorities dealing with air pollution from ships, three representatives of European ship-owners associations, two experts from the European Commission involved in the development of sulphur control directives, one member of the European Parliament who directed the environmental commission of the European Parliament, and the environmental lawyer of a major Scandinavian short-sea shipping firm (Table A.1 in appendix A). The purpose of having semi-structured interviews was to allow certain flexibility to the interviewee; in this way, he/she could unfold information otherwise difficult to obtain with structured interview guides (Bernard and Ryan, 2009).

The selection of interviewees began with their identification after the document review. However, a fair representation of different types of stakeholders involved in the amendments of the Directive 1999/32/EC was also important. A total of 14 interviews were carried during the period of implementation of the Sulphur standards in European waters, which allowed a balanced interaction of the new regulation with aspects of market and technological change (Table A. 1 in appendix A). The interviews lasted between 30 and 60 minutes, but were followed-up by email or telephone meetings if something was not clear after analyzing the data. The interview guide included five topics: i) How will the new Sulphur regulations likely impact the shipping firms? ii) How does the company plan to comply? iii) How the new regulation affects the technology adoption and market opportunities at firm level, iv) Collaboration with other actors for complying with the new rules, and v) Innovation activities in preparation for the new regulations.

Direct observation allowed the author to get acquainted with the discourses surrounding the implementation of SO_X limits in the SECA. At the time of collecting the data, the author collaborated with the Maritime Centre for Operations and Development (MARCOD, Denmark). The Centre is in close interaction with European, Scandinavian, and Danish shipping stakeholders on a regular basis. This interaction allowed the author to take part in different activities, such as meetings, seminars, conferences, and networking (Table A.2 in Appendix A). After each event, the researchers created narrative memos including the most important issues at stake. These narrative memos were processed as explained below.

The author analyzed the data through an analytical induction process (Patton, 2002). Analytic induction starts when the researchers create theoretical propositions, which are subsequently verified with the qualitative data (Taylor and Bogdan 1984 in Patton, 2002, p. 454). The way the analytical induction was first applied was by creating theoretical inspired codes (Saldaña, 2009), based in the literature review on environmental technologies and drivers for eco-innovation. Along with this deductive part, the author looked for patterns arising from the data, which generated new codes. All codes were grouped into categories and then into issues, which at the same time arose from the sub-questions. The themes, categories, and codes are listed in Table B.1 (Appendix B). The coding of the interview transcripts and observation memos was carried with the support of a Computer-Assisted Qualitative Data Analysis software (Fielding, 2008).

4 Results and main findings

As described in section 2, regulation co-exists with drivers such as technology, markets, and business. To illustrate how these interacting drivers function, the main findings are presented from three different perspectives. In the first perspective, the author analyzes the EU sulphur directive's influence on the adoption of environmental technology, with a focus on the characteristics of the regulation. In the second perspective, the analysis shows how the regulation interacts with the other drivers, especially technological developments for reducing sulphur emissions and other pollutants. Finally, the third perspective analyzes how the organization of business is a driver for adopting environmental technology in combination with the other drivers.

4.1 Regulatory drivers for eco-innovation in shipping

This first part of the case study deals with the two emergent themes from the interviews with EU policy-makers and ship-owner associations directly affected by IMO/EU air pollution regulations. The first theme is the tensions between the global orientation of the shipping industry (e.g. global operations) and national and regional orientation of environmental regulations. The second is the tensions between the regulatory (environmental) demand and the business (economic) conditions in the shipping industry compared to other regulations.

The first emerging theme was how implementing the SECA in Northern European waters, but not in other places, becomes an entrenchment issue between policy-makers willing to control air pollution from ships, and ship-owners/operators who have to comply with these new regulations. As mentioned in the literature review section, air pollutants from ship fuels are generally regulated by international agreements with some exceptions of local ports and sub-national level regulations like in California. That is why, in the logic of EU policy-makers, the current location of SECAs resulted from proposals by bordering countries. The first challenge is reaching an agreed upon protocol that is fair for all 170 Member States. Ship-owners, however, require that creating a SECA goes in line with level playing field conditions for all shipping companies, independent of their geographic situation. As a representative of the European ship-owners claimed:

> "If you look at the discussions now in the European council, you will perceive the different perspectives between those Northern countries bordering the SECA vs those Southern countries not yet affected by a SECA. There are already some divergence of views and, of course, it's kind of level playing field that it's not reached. We represent both northern and southern ship-owners, so we are always trying to find the common case. Officially this kind of divergence, are not really expressed. But it does exist. This is also why we are not pushing for an extension of the SECA to the Mediterranean. The reason why most of the Northern countries push for new SECAs is level playing field. As I told you earlier, we are not opposed to new SECAs, but we claim that must be agreed in the IMO according to an IMO process. So that is also for this competitive issue that we always refer to the IMO. Shipping is international, so if member states want new SECAs, we ask them to do through the IMO process and not through the single EU process" (Ship-owners representative, interview 8).

While ship-owners who are affected by the creation of the SECA in Northern European waters call for level-playing field conditions to counter unfair competition issues, the European Commission has the power to influence bordering states to implement MARPOL Annex VI. The EU directives are transposed into national legislation by the Member States. Port State Authorities within each country are responsible for checking compliance. Port State Authorities survey the characteristics of the fuel used by vessels calling into a port. The authorities keep registries of these characteristics and report them to the European level:

> "The EU is not a member of IMO. We have an observer status but we do not have a vote. The history of previous SECA designations is that all member states, including the EU, jointly prepare such a submission, and try to support it. The commission has not power to support, any member states that are not in a SECA to submit a proposal to the IMO and it is

> also important that this is designated by IMO when there are closed, submissions. There are very limited possibilities to enforce regional provisions. Once it is an international agreement, the enforcement can be easier. That is why the Commission strongly counts on IMO" (Regulator, interview 10).

To accomplish this task, the European Commission prepared one directive in 1999, which was subsequently amended in 2005 (Directive 2005/33/EC) and in 2012 (Directive 2012/33/EU). The enactment of these directives allows the EU Commission to monitor the compliance of Member States. With the support of the European Maritime Safety Agency (EMSA), the Commission collects compliance reports from Member States. In this way, the Commission can address situations where a Member State is not enforcing the regulations. Enforcement comes with challenges, and policy-makers acknowledge that this can be a reason for possible mistrust and criticism towards the current MARPOL regulations:

> "I will have to look at that in the impact assessment and the communication, where are there compliance problems, here the fuel sampling. There are some reports on sampling. So, that many samples are above 1.0%, most of them are below 1.5% but this 1.5% SECA provision seems not to be enforced very vigorously, this was the reason for us to argue, that these IMO provisions must be transposed into EU legislation. In that case it will be possible to have a strong, strict enforcement, because IMO is only international obligations of parties but they do not police it" (Regulator, interview 10).

A second emerging theme on regulation push is how the European Commission implemented MARPOL Annex VI, opening the way to alternative means of compliance, which at the same time opened a window of opportunity for shipping firms' eco-innovations.

The North European SECAs were regulated by EU directives 1999/33/EC and 2005/33/EC. However, in 2006, the IMO revised Annex VI and the EU directives needed an update to harmonise the implementation and control of MARPOL Annex VI across the EU as well as in non-SECA ports (Interview 10). The new amended directive (2012/33/EU) also integrates alternative methods of compliance such as scrubbers and alternative fuels (e.g. LNG or methanol). Before the EU Parliament approved the Directive 2012/33/EU, the European ship-owners associations were highly concerned for the directive's impact on the short sea shipping sector. The first concern was the proposal (now included in the directive) to use fuel containing 0.1% of sulphur while the ships are at berth in any EU port. The second concern was that passenger ships did not have any exceptions for complying with the stricter limits of SECAs (e.g. the use of fuel with a sulphur content of 1.5% out of the SECAs). The interviewed ship-owners' representative justified their position because they considered that "the EU shall avoid regional regulations because that may entail loss of competitiveness for the European shipping industry" (Interview 8).

The regulatory push manifested in the establishment of a SECA in Northern European waters and the different facets of implementing more detailed directives to enforce MARPOL Annex VI. As a result of the need to avoid air pollution came a tension between the regulatory bodies and those actors who shall comply with the new rules. Section 4.1 highlighted these tensions, but also put in evidence that besides using low sulphur fuel, alternative technologies were also allowed by EU directives, which suggests that regulation can push for eco-innovation solutions.

4.2 How air pollution regulations influence eco-innovation through interaction with other drivers

After presenting the characteristics of the sulphur regulation in section 4.1, the author explains how the current and future air pollution regulations influence eco-innovation in the European shipping industry by interacting with other drivers. The findings show how marine eco-innovation is connected to the development of market dynamics such as increasing fuel prices. The findings also show the importance of linking the ways in which regulation interacts with the continuous changes in markets and business.

4.2.1 Fuel price as a market driver

The sulphur regulation opens up different technological means of compliance. There are, however, great differences in the shipping industry depending on the type of technology used for compliance, the type of route used (short-sea or transcontinental shipping), or factors specific to the ships. The regulations prioritize the use of distillate fuels instead of heavy fuel oil. Distillates can be marine gas oil (MGO), marine diesel oil (MDO), or intermediate fuel oils (IFO). Ship-owners do not particularly welcome the fuel shift alternative. However, European ship-owners consider associated fuel costs as the main threat to the competitiveness of short sea shipping in SECAs, and do not agree with the way the authorities have requested the use of low sulphur fuels. A number of European ship-owner associations commissioned independent studies to evaluate the impact of the sulphur shift in the industry’s cost structure. These studies raised different reactions in both ship-owners and authorities. The representative of an important European ship-owners’ branch association is somehow representative of the general mood of the short-sea industry when it comes to the shift towards low-sulphur fuels:

> "You just accept shifting fuel with sulphur content of 0.1% after 2015 in SECAs. You have to take the costs into account, maybe by installing scrubbers on the ship or retrofitting it with LNG. But there is no a single encompassing-wise alternative. You know what I mean? We can perceive that from our members operating in the SECAs. For example, there is this route going from a Hamburg-Bremenhaven to Klaipeda (Lithuania) that goes parallel to road transport. You can easily send your cargo by trucks. The elasticity we have between the price that is charged to put the trucks on board of ships and be sent that far, and their decision to actually just drive, is still small and we have to be aware that we cannot impose huge additional costs. The person sitting in trucking companies will just say: 'Sorry you'll have to drive around and stop trucks going on ferry'. For those routes which are very small, you could clearly see the big competition with the road. This needs to be analyzed, that is our suggestion. We are speaking for Denmark about maximum four to five routes. For these we should let them sail with a high sulfur limit a little longer, providing that they proved they are working to solve this issue" (Ship-owners, interview 4).

European regulators claim that the effects of the additional operational costs associated with complying with MARPOL VI on SECAs, are not easy to assess. Furthermore, giving the strategic consideration of shipping as an environmentally friendly mode of transport is a good indicator that the sector will not lose competitiveness in the future:

> "There is a series of many studies going into the question of what effects has the implementation of the SECA into the short sea industry operational costs. In all this research, a common agreement is that this massive modal shift is usually due to high fuel price scenarios. Recently, I have not heard these arguments based on high fuel scenarios anymore. The shipping community seems to settle at a price increase of 70% of high sulphur to 0.1% sulphur fuel. However, the extreme scenarios derived from peak fuel prices in 2008 are not used anymore. So, if the modal shift takes place, it will be as plastic as some portrayed. On the other hand, the Commission considers shipping as a sustainable mode of transport and considers a shift back to land based transport as not desirable" (Regulator, interview 9).

Further, while it is still possible to be concerned about the likely impact of the regulation on some macro-economic indicators, member states have the possibility to ask for some exceptions:

> "You know, when we implemented the Directive 1999/32/EC all Greek ferries were exempted. You can, as an EU member state if you want, get this through the Council and convince the other member states. You can list certain ships that are exempted from having to conform to the higher fuel standards. This is what Greece has exactly done. They claimed that they could not transfer the costs of MDO on to a problematic sector that is anyway subsidized. I have my doubts, because if I look at old ferries in particular, none of them is using heavy fuel oils. You know, I am a naval architect by training, so I can tell you that heavy fuel oils became usable in medium speed engines only the last 20 years. Medium speed engines always needed a higher quality fuels in the past and medium speed engines were the only ones you could really choose for ferries, because a low speed engine is too big to install on a Ro-Ro ship or a ferry. So I think if we would do a honest analyses, probably a lot ships are already running" (Regulator, interview 10).

4.2.2 Interactions between regulation and technological push

The sulphur regulation allows for different forms of alternative (environmental), technological solutions in order to comply with the demands of low sulphur content in fuel. One of the environmental solutions is the use of scrubbers.

The development of scrubber technology is primarily connected to marine equipment manufacturers offering scrubbers to shipping companies. These scrubber manufacturers joined the Exhaust Gas Cleaning Systems Association (EGCSA). The EGCSA has succeeded in promoting the scrubber technology during the amendments to Directive 1999/32/EC at the European Parliament. The Commission's position is that scrubbers should be available along with the distillate fuels to comply with the SECA requirements. Costs related to scrubber investments seemed to be a major barrier for more installations after the 2015 stricter SECA limits. Financial support by EU Member States is a key issue in fostering the installation of scrubbers in the SECAs. Such Member State support must, however, be regulated and timed to avoid competition distortions among EU Member States (Interview 12)..

The demand of scrubbers is not as high as expected, despite the optimism by regulators, manufacturers, and shipyards (Interview 8, 9). Ship-owners' public communications and interviews highlighted the technical reasons that explain the situation. As pointed out by the representative of the largest European ship-owners' association, the scrubber technology still needs to be fined-tuned and a closer collaboration between manufacturers and ship-owners is necessary:

> "Scrubbers are not available. I mean, the technology exists, but it is a land-based technology. Scrubber manufacturers try to transpose it to ships and in the lasts years there have been many problems. What you really know comes from the EGSA, for example, that technologies are available and in reality, they are not. It is not the case, so there is almost no ships equipped with scrubbers and we are actually in contact with scrubber manufactures, we have meetings with them and there is a need for pilot cases. We try to look for a kind of cooperation with scrubber manufactures to install scrubbers on board ships to test them and to make the technology more reliable. That is the situation, we cannot just go to a ship yard and ask to install a scrubber, because it's not, it's not natural, yet" (Ship-owner representative, interview 8).

In addition to scrubbers, the EU also considers alternative fuels such as LNG as a compliant technology. The European Commission endorses the LNG technology in the Sustainable Waterborne Transport Toolbox (European Commission, 2011). The Trans-European

Transport Network (TEN-T) Policy financially supports a project to build LNG bunkering infrastructure in the Baltic Sea SECA. The TEN-T project addresses the hitherto main concern with the scaling-up of LNG. The lack of bunkering infrastructure has been pointed out as the main barrier in the scaling-up of this technology. However, ship-owners agree the LNG technology is not yet mature, and the EU investments take time:

> "There are still many, many problems and you know the technical solution is the use of LNG. This is, this is an excellent option as well, but it's not for tomorrow, so the time scale is 2020. So it, it's not solving the 2015 requirement. For this reason, we ask for postponement of this requirement. Maybe you saw that in the amendment of the parliament that there is reference to exemptions in MARPOL Annex VI. Certain routes or certain ships, it is not defined yet. But this is an option. And the last option, which is not the preferred one to use combined fuel ship, but it's a huge cost" (Ship-owners representative, interview 8).

> "LNG is another problem: the chicken and the egg issue. Do you first need to have the LNG terminal or the ships to be equipped? Some of us have already equipped ships so actually maybe this discussion about the chick and egg is already over. We have LNG fueled engine, now we need somewhere to bunker LNG, with rules for bunkering because it takes time. Do you do it when you have people loading and unloading on the ships? It is probably not possible. You will need a ship for bunkering while another is loading, upgrade in a different manner, it demand different ways of operating ferries" (Danish Ship-owners representative, interview 4).

In conclusion, sulphur regulation is open for different types of environmental technologies, and the development and adoption of the different types are dependent on the interaction between different drivers. The market (represented by fluctuating demand and fuel prices) is seen as a very important factor, which influences how the North European short-sea shipping industry responds to the regulation and what kind of technological solutions are seen as valuable.

4.3 Market dynamics and their interrelation with regulation and eco-innovation in the shipping industry

This section focuses on how market drivers are linked to regulations. Environmental technology is seen as an investment from a market perspective, where the effects on cost or product value are important as a means to reducing risks and to complying with the upcoming changes in markets and regulations. Section 4.3.1 addresses common barriers to the adoption of environmental technology. The second explains the increasing importance of voluntary initiatives.

4.3.1 Market drivers and adoption barriers for environmental technology

The change in market conditions has been an important driver for stakeholders' increasing interest in marine environmental technology. However, stakeholders estimate in different ways the value potential of environmental technology and compliance. Some stakeholders consider environmental regulation and environmental technology as an extra cost; others consider it as a potential for creating value for their customers – a view which is closely linked to the different actors' position in the value chain. As presented in the previous sections, for authorities, marine environmental technology serves to comply with regulations. However, marine equipment manufacturers and ship-owners have broader understandings of marine environmental technology. The European Marine Equipment Council (EMEC) includes in this category (EMEC, 2010)

- Efficient and high-tech products.

- Existing technology to help mitigate the environmental impacts of ships.
- Technology responding to future regulation for the 'greening' of shipping.

A set of environmental technologies for possible installation on board is presented in a catalogue. The purpose is to reach potential customers (ship-owners) and authorities in order to make them aware of different alternatives for compliance with regulations.

Many ship-owners are not considering marine environmental technology's potential for value creation. This lack of value potential is linked to the way business activities are usually organized in the shipping industry. During the interviews, different stakeholders pin-pointed the 'conservative' character of the shipping industry, and also resistance to implementing efficient technologies on board:

> "If you think, fuel efficiency can be increased for any cargo or ro-ro ship by 30% easily with existing technology. You could get your fuel consumption 30% down anyway. That is an interesting question that you may ask: 'Why are ship-owners not doing that?' My study at DG Clima is looking into why we are not having the take up of existing fuel saving technology if fuel is so expensive. We found the most important factor is operating expenses (OPEX), basically much more than labour. We also found out that the split responsibilities are the key problem. The one who buys the ship is not typically the one who operates the ship. The ship buyer looks at the capital expenditure and the operator looks at operation expenditure. The guy who looks at the capital expenditure wants the cheapest ship, and then he gets it from China. It is not particularly advanced in technology, innovation, basically it is 30 years old technology. It is not really the best you could do, but because it doesn't matter to him, because he is not operating that ship, he does not have the elevated OPEX. As result, the charterer has no saying in initial purchase nor in the innovation that is included in the ship. You can overcome that with, of course, performance-oriented already in the charter contract, now this it is going to be the same problem. They are looking more into these

performance-oriented right agreements. Unfortunately, the shipping industry is so conservative that they are very often not thinking about obvious things, so maybe we need legislation to push them a bit more into this direction" (Regulator, interview 9)

As rightly pointed-out by the regulator (interview 9), it is in the contract aspects of chartering ships that ship-owners can influence how the charter applies eco-efficient practices, and thus improves the environmental performance of even old-technology ships. This seems to be the case of an interviewed owner leading a short and transcontinental shipping liner. When chartering, the firm sets different requirements according to the route. In the case of long distances, the shipping firm requests the 'usual environmental requirements': compliance with IMO rules and port state authority regulations. In the case of short-sea chartering within the European SECA, the shipping firm sets no specific requirements besides low fuel consumption – except when the chartering is extended over time (interview 13).

4.3.2 Business drivers and adoption of environmental technology through voluntary initiatives and partnerships

As described above, the ship owning and leasing characteristics of the industry could be a major barrier for eco-innovation. It can also be seen as an important potential for influencing the development and adoption of environmental technology. An example of a port-driven initiative is the Clean Shipping Project (CSP), initially funded by the Swedish region Västra Götland. CSP launched a web-based interactive index and database. Current members are large cargo owners, who can fill in 20 questions specific for different types of ships. These questions address issues such as SO_X/NO_X emissions, wastewater, bilge water, and anti-fouling technologies. A third party called the Classification Society, verifies the information and the owner then registers at least 20% of their fleet. The database is then shared with carrier or trading companies. The information serves as a decision-making tool to choose the vessel with the lowest environmental impacts. The tool can also serve the shipping authorities in rewarding the best performing vessels. Forwarders and classification societies also benefit from the collected information (Interview 1).

CSP illustrates that some shipping companies invest in SO_X abatement equipment –among others- as part of their self-regulation interest. *Transatlantic* is a Swedish ship-owner with SO_X compliant vessels. The company owns 30 vessels and the fleet's environmental performance information was filled in the CSP database. From a market point of view, *Transatlantic* expects to 'be a part of the increasing of green shipping, it is a win-win situation for all members and they can reach new customers globally' (Ship-owner, Seminar Instruments for the environmental impact of shipping). The case of Transatlantic illustrates how command-and-control regulations, voluntary instruments, and information release may serve similar purposes. From a ship-owner's perspective, CSP is an instrument that improves the company's image and in turn attracts customers (carriers and trading companies). AB Lindex is a Swedish fashion retail company with stores in Sweden and online shopping. Their clothes are manufactured in Asia and transported to Europe. As part of their Corporate Social Responsibility, Lindex committed to reducing their environmental footprint associated with transportation. CSP helped Lindex to find a carrier with the best environmental performing vessels (Cargo owner, Seminar Instruments for the environmental impact of shipping).

Tools like CSP may also bring in benefits to the ship-owners taking part in them. Gothenburg Port proposes differentiating harbour fees based on a vessel's NO_X, SO_X and anti-fouling rating. An in-kind incentive of reduced port fees is given to the first 20 registered vessels. An interviewed expert considered differentiating fees as a relevant aspect of voluntary instrumentation (Interview 9):

> "We know that Gothenburg uses the clean shipping index, Rotterdam does the same. If leading ports are rewarding cleaner ships and therefore indirectly penalising more pollutant ships, you are going to see a huge effect. And there is also talk in some ports to give preferential time slots to clean ships. Now I think this will convince every owner in the end. If you (…) have to wait for the crane, because you are polluting, you are going to try to do something about it, because time is money. So you can trigger the system a bit, through intelligent measures. Of course, it is our job at EU to make sure that if [Port A] does something progressive, then [Port B], which is just [some hundred kilometers distance], is not undermining it and then opening up to polluting ships at preferential fees in order to get the business. That has to be seen, but, of course, there is not a distraction in the market. But I think at the end common sense will prevail. You always have some rogue elements, ships that rarely trade with you or can only come occasionally".

The positive experience from CSP has motivated interest in replicating voluntary initiatives of this type. The Danish EcoCouncil also proposes a voluntary labelling scheme to be used in Danish harbours (Press-Kristensen and Ege, 2011). However, despite the positive environmental effects of CSI and other voluntary initiatives, ship-owners associations are cautious about having different kinds of indexes in each port. A Scandinavian National Association's fleet will have some advantages if they participate in this label scheme: for example, having innovative technology on board. Yet this association pinpoints challenges when using label schemes: particularly, the risk that several evaluation indexes co-exist in different ports (Interview 4).

5 Discussion

The author analyzed the question: *How do new air pollution regulations interact with other eco-innovation drivers in the adoption of environmental technologies in the shipping industry?* With this purpose, the author carried out a case study with a focus on the short sea shipping industry within the North European SECAs. The case study focused around two main issues:

- How is sulphur content in marine fuels being regulated within the Emission Control Areas and how it influences eco-innovation in short-sea shipping?
- How does air pollution regulation influence eco-innovation through interaction with other drivers?

The case study used Rennings (2000) and Rubik's (2005) model as the theoretical point of departure. This section discusses the case study by summarizing the main findings and upgrading the conceptual framework. The revised model stresses the interaction and complements among the different drivers. The new proposed model was adapted to short sea shipping and possible variations or adaptations that could take place in other industries and sectors (Figure 2).

Although not as important as regulations, market pull is expected to increasingly motivate the adoption of marine environmental technology as a result of the voluntary initiatives of carriers – e.g. participation in clean shipping indexes.

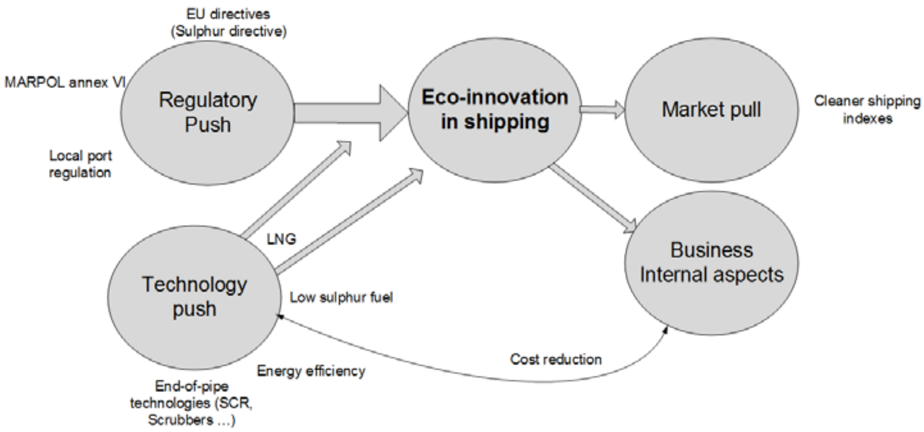

Figure 2 Drivers of environmental technology adoption in the maritime industry- a revised framework.

The first major finding was that air pollution from ships is regulated globally through IMO, continentally through EU regulations, and locally through port and state standards. In EU waters, one regulation is the subject of concern by ship-owners: the limits to the sulphur content in marine fuels. As the case presented, different technological alternatives are available and encouraged by the EU for vessels to comply with the sulphur standards (low sulphur fuel, LNG, or scrubbers). This first finding suggests that the sulphur directive and MARPOL Annex VI may stimulate the diffusion of end-of-pipe technology while process change technology needs more time to be implemented. One of the discussed process-change technologies is the use of "cleaner" fuels such as LNG and low sulphur fuels such as MGO. In the case of LNG, the major barriers are a lack of bunkering infrastructure and the increase in space needed on board of the ship to install the LNG tanks (Bengtsson et al., 2011). In the case of MGO or similar low sulphur fuels, the major constraints are the possibility of bunker costs fluctuation (Notteboom and Vernimmen 2009).

At first glance, this situation appears to conform to what the literature reports on the side of benefits of “strong” environmental standards: the possibility to motivate eco-innovation (Ashford and Hall, 2011). However, it is not clear to what extent this “strong” environmental regulation will encourage eco-innovation. Ship-owners are concerned with the high costs of cleaner technology associated with low sulphur emissions. Such an attitude implies a resistance to innovating technologies, which could bring the emissions to lower levels than those required by the regulation as proposed by Ekins (2010). Meanwhile, other drivers in addition to regulation and technology push could come into play in motivating eco-innovations, which could provide additional environmental benefits beyond the legal requirements and their associated costs. These drivers are analyzed next.

The case study also presented the relationship between market pull and self-regulation as drivers for eco-innovation. One of the findings was that the current market situation of the shipping business provides challenges to environmental technologies. In particular, ship-owners will not have enough motivation to install environmental technologies, if this is not required by law. An exception was to participate in voluntary programs designed to share information with business-to-business customers on the environmental performance of vessels (i.e. Clean Shipping Index). The expectation with this type of voluntary initiative is that business to business customers create incentives for the installation of environmentally friendly technology (Horbach et al., 2012). Kesidou and Derimel (2012) claim that voluntary participation in these programs does not necessarily mean investments on environmental technology. In this case, we could not assess whether voluntary programs have implied investments or not. The case study unfortunately could not assess an individual firm in terms of their internal business aspects. In the theoretical framework, we claimed that knowledge generation is linked to this driver of eco-innovation. We have provided examples of business’ activities, which could increase eco-innovation capacity.

One of the examples was inter-organizational work (Fjeldstad et al., 2012) and the other was EMS (Horbach et al., 2012). Voluntary programs as the ones presented in this case, could serve to address one of the challenges of adopting environmental technology: knowledge and information problems (Kemp et al., 1992). Therefore, one proxy to assess internal business aspects is to look into the participation levels in these kinds of programs. The relations between market pull drivers and internal business aspects are sketched in Figure 2. In the meantime, internal business cost reduction also influences the need to look for technologies which can reduce operating costs.

6 Conclusions

The purpose of the case study was to understand how sulphur content regulation on marine fuels interacts with other drivers for the adoption of environmental technologies. First, a literature review was presented based on definitions of eco-innovation and two categories of environmental technology: end-of-pipe and clean tech. At the same time, this review provided a conceptual framework about drivers influencing eco-innovation in the shipping industry. The case study then analyzed how these drivers interact in the short-sea shipping industry within the North European SECAs.

The firs sub-question focused on *How the Sulphur content in marine fuels is being regulated within the emission control areas and how it influences eco-innovation in short-sea shipping?* The analysis showed that environmental regulations influenced the development of eco-innovations, mainly motivated by the increasing costs of the use of conventional technologies like low sulphur fuels. One implication of this involves policy-makers for national or European authorities, who promote marine eco-innovation through public-private partnerships or through public subsidies. In order to ensure compliance with the EU directive on sulphur content in fuels, it is not enough currently to propose a short list of possible compliance technologies. Instead, a target-based regulation will be able to aid shipping firms in finding cost-effective solutions based on their own situation. An inspiration could be the current international ballast water convention, in which many different types of technologies are available for ship-owners, and many different kinds of technological combinations are possible. Several supplier companies are interested in creating their own innovations and have begun the procedures to get approvals in order to be able to sell them to the market.

The second sub-question was *How does air pollution regulation influence eco-innovation through interaction with other drivers?* The case study at this point was centered on the interaction among market pull, internal business aspects, and regulation as drivers for eco-innovations. Inspired by the general eco-innovation model, a specific model for the maritime industry is presented. In the context specific model, market pull and internal business aspects are closely overlapping, while internal business aspects relate to the technological push by cost-reduction. In the case study, market pull and internal business aspects were exemplified with voluntary programs. In these kinds of initiatives, market pull interacts with internal business aspects by allowing stakeholders to share knowledge and information about environmental technologies.

This case study focused on short-sea shipping and on-going environmental regulations which press the industry to tackle several environmental problems. Other environmental aspects are currently in the process of being regulated and there is a possibility of the creation of stepping stones for possible new eco-innovations. This includes climate change, energy efficiency in ships, black carbon, and ballast water, among others. The third question focused on *What could be future directions in the combination of regulation with other drivers for eco-innovation in the shipping industry*? The case showed that market pull will continue to interact closely whenever ship-owners consider environmental regulations as expenses rather than investments. The case also showed that since technological push interacts closely to regulatory push, lobbying by environmental technology suppliers will continue to be strong in order to have certain technologies included in future regulations (e.g. scrubbers in the case of recent amendments to the sulphur directive).

The results should however consider the limitations of the research design; case studies are often criticized due to the findings being very specific to a certain context, which jeopardizes replicability in other contexts. This paper considered the SECA in Northern Europe as a geographical delimitation and the key actors related to the short-sea shipping industry in the empirical data collection phase. One limitation was that the SO_X problem is only one problem associated with shipping. It is often portrayed as independent to other issues such as ballast water, global warming, and other air pollution problems.

Of interest for further research are research questions around R&D initiatives in maritime firms, by assessing through structural equation modelling the interactions suggested in this paper. Some Nordic countries have set in place innovation programs and archival data around publically financed maritime innovation initiatives which can be a good source of data for this type of research.

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7 Appendix A. Information sources

Table A. 1 In-depth interviews

#	Organisation	Type	Location
1	Clean Shipping index	NGO	Gothenburg
2	Danish Environmental Protection Agency -Environmental technology	Government Agency	Copenhagen
3	Danish Environmental Protection Agency-Eco-innovation project shipping	Government Agency	Copenhagen
4	Danish Shipowners Association	Shipowners Association	Copenhagen
5	Community of European Ship-yards association	Branch Association	Telephone
6	Danish Maritime Authority	Government Agency	Copenhagen
7	Danish Eco-council	Environmental NGO	Copenhagen
8	European Shipowners Association	Shipowners association	Brussels
9	DG-MARE European Commission	Regulators	Brussels
10	DG-ENVI European Commission	Regulators	Brussels
11	Danish Shipowners Association	National ship-owners association	Brussels
12	EU Parliament	Envi-Commission	Brussels
13		Shipping and logistic incumbent firm	Telephone
14		Marine equipment manufacturer	Aalborg

Table A. 2 Observation: sources of data

Event	Date	Role
Seminar ‘Business opportunities by clean shipping index’	February 2011	Participant
Seminar ‘Instruments for the environmental impact of shipping’, Gothenburg	April 2011	Participant
MARKIS (Maritime Innovation in Kattegat and Skagerrak – Interreg IVB project) Yearly Conference	November / December 2011	Presenter
MARCOD/MARKIS Maritime Conference on Business Opportunities in the wake of the new maritime environmental regulations for shipping, Frederikshavn, Denmark	April 2012	Presenter

8 Appendix B. Data analysis

Table B. 1 - Emerging categories and themes used to built-up the article

Themes	Categories	Relevant codes
Regulations	Institutions role in shipping air pollution enforcement	IMO, commission_role, port
	Sulphur directive	SOx, expansion_SOx, amendments
	Emerging trends in air pollution regulation	Future regulations, NECA, NOx regulations
Innovation	Contextual influences on innovation	Fuel prices, technical explanations
	Technical solutions to comply	Scrubbers, LNG
Regulation+innovation+market dynamics	Voluntary programmes	Market based, technology driven

	Why innovation may be hindered?	Compliance, postponing, challenges cleantech