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Breaking the Barriers: Operational Measures for the Decarbonization of Shipping

A study on barriers to operational energy efficiency measures

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Abstract

Energy efficiency is a key strategy to address the issue of climate change. Operational measures that increase energy efficiency are widely used in shipping, but there is evidence of a gap between the actual implementation level and what would be optimal. This is dubbed the energy efficiency gap. This paper aims to examine which barriers are responsible for the energy efficiency gap in deep-sea shipping and how policy intervention can mitigate it.

Contributing to the literature on operational energy efficiency measures in shipping, we look to former studies and synthesize former research results to give a comprehensive overview of the subject. Further, we contribute to the literature by analyzing four existing and potential policy regulations and investigating their likely effect on the industry and the energy efficiency gap. This will give a firm foundation for advancing knowledge, facilitating theory development, providing a unifying status check on operational measures, and how policy instruments can affect the uptake of these measures. Our analysis also identifies areas where the current and proposed industry regulations seem insufficient to drive change and where other or stricter policy instruments may be required.

Our findings suggest that split incentives and imperfect information are the main barriers to closing the energy efficiency gap for operational measures in shipping. Policy instruments can help facilitate the uptake of these measures if designed correctly. However, our findings suggest that none of the four regulations addressed in this thesis are likely to solve the problem with a lack of reliable information. Further, MBMs can make monetary savings from reduced emissions more substantial than today and give incentives to reduce emissions. However, contractual clauses and the presence of other market barriers can limit the MBMs effect on vessels' behavior. Consequently, to significantly reduce the emissions from shipping, we argue that the industry should be focusing on finding ways to improve the quality of information about vessels' performance regarding energy efficiency and on exploring new contractual structures.

Keywords – Sustainable shipping, energy efficiency, operational measures, IMO, GHG, operational efficiency.

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1 Introduction

According to the International Maritime Organization's (IMO) 4th GHG study (2020), shipping was responsible for about 2,89% of the world's greenhouse gas (GHG) emissions in 2018. Despite an overall improvement of the global fleet's energy efficiency, the industry's emissions of GHGs have increased by 10% from 2012 to 2018, showing that the industry is moving in the wrong direction (IMO, 2020). The industry is actually expected to increase their share of GHG emissions to around 20-25% by 2050 if no action is taken (Rehmatulla et al., 2017).

Due to its global nature and no specific home, deep-sea shipping is often viewed as an invisible portion of people' lives despite its vital role in global trade and the flow of goods (IMO, 2013). However, during the last few years, the sector's significance has been coming to light, and the importance and urgency concerning the decarbonization of shipping have been recognized by the international community (Lister, 2014). In 2015 176 countries entered into the Paris Agreement in a global response to the threat of climate change. This marked a significant change in the efforts to develop global climate policies (Streck et al., 2016; Mercure et al., 2018). Further, in 2018 the IMO's Marine Environment Protection Committee (MEPC) announced an ambition to reduce the GHGs emissions by 50% by 2050 vis-à-vis 2008 levels (IMO, 2020c). They also sat an ambition to reduce the CO_2 emissions intensity by at least 40% by 2030 and pursuing efforts towards 70% by 2050 (IMO, 2020c). In 2019 the European Green Deal was announced, with the goal of making the EU's economy sustainable and has also set a goal of no net emissions of GHG by 2050 (European Commission, 2019).

One aspect of fulfilling IMOs ambition of reduction of GHGs is the implementation of energy efficiency measures. Energy efficiency is a key strategy to address the issue of climate change (Rehmatulla and Smith, 2015a). By increasing energy efficiency, the amount of energy used to perform a given amount of work will be reduced (Buhaug et al., 2009; Rehmatulla and Smith, 2015a). As fuel costs account for between 60-70% of vessels operating costs, increased energy efficiency can lead to significant reductions in both fuel cost and emissions (Rehmatulla and Smith, 2015a; Adland et al., 2017a). Thus, increased energy efficiency can be a win-win situation (Rehmatulla, 2014; Adland et al., 2017a).

However, despite increasing focus on reducing emissions from shipping and a wide range of measures that are both energy and economically efficient, there is evidence of a gap between the actual level of implementation and what would be optimal given their high energy savings potential and cost-effectiveness (Sorrell et al., 2011; Rehmatulla and Smith, 2015b; Rehmatulla et al., 2017). This problem is dubbed "the energy efficiency gap", and can be explained by barriers inhibiting the uptake of these measures (Blumstein et al., 1980; Sorrell et al., 2004; Rehmatulla, 2014; Rehmatulla and Smith, 2015b,a). Given the existence of an energy efficiency gap and its explanation, it is interesting to look at which barriers are most likely responsible. The purpose of this thesis is to identify these barriers and finding ways to reduce the energy efficiency gap, which is considered as vital in reaching IMOs ambitions.

The contribution of this thesis is threefold. First, we present a comprehensive review of findings in the literature on which economic barriers are most likely to be responsible for the energy efficiency gap for operational measures in shipping. Second, we investigate how policy instruments can be used to reduce the energy efficiency gap. We do this by analyzing four existing and potential policy instruments that aim to reduce emissions from shipping and investigate how these regulations may impact the uptake of operational measures to improve energy efficiency. Analyzing the barriers in light of the current political situation provides new insight into this topic. Third, we evaluate areas where further policy intervention and focus from the industry is required. We look at operational measures because breaking these barriers lead to instant reductions in GHG emission, have a great scope for emissions reduction, represent small investments compared to technical measures, and require little technological changes of the ship structure (Faber et al., 2010a; Rehmatulla, 2014).

The remainder of this thesis is structured as follows. In Chapter 2, we present the methodology of the thesis and the background for our research. Chapter 3 presents a literature review on the topic explaining relevant theory on barriers to energy efficiency and the effect of operational measures. Our findings are presented in Chapter 4, and which barriers are most likely to be responsible for the energy efficiency gap are discussed in Chapter 5. In Chapter 6, we look at the political situation and the effect of policy instruments. Chapter 7 and 8 includes concluding remarks and limitations.

2 Methodology

This thesis is a qualitative systematic literature review, which is an important technique to synthesize research results. This entails a systematic review process to collect articles, and then a qualitative approach is used to assess them (Snyder, 2019). It allows for assessment of the collective evidence of a particular research area as it discusses published information on a particular subject (Snyder, 2019). Literature reviews allow for integrating findings and perspectives from many empirical studies, creating a firm foundation for advancing knowledge and facilitating theory development (Webster and Watson, 2002).

We aim to integrate findings and perspectives from all available studies on barriers to operational energy efficiency measures in shipping. This will synthesize previous research results and give a comprehensive overview of barriers to these measures. Using the same method, we further examine four current and potential policy regulations and investigate how they can affect the uptake of operational energy efficiency measures.

We have had a systematic approach to literature retrieval utilizing the building block search strategy to identify all published articles relevant to our research objective. This search method was used to have a literature search that was planned, documented, and verifiable. Our literature search protocol involved utilizing keywords like "energy efficiency", "operational energy efficiency measures", "environmental regulations in shipping", "decarbonization of shipping", "IMO", and "barriers to energy efficiency". The variety of keywords reflects the nature of this topic.

Our literature search of publication databases identified articles related to our chosen theme. However, only some of the articles met our selection criteria: 1) direct relevance to the topic, 2) credibility based on author, publisher, and validity, and 3) recentness of the work. Our selection is thus not randomly nominated. Our comprehensive overview on the subject of barriers to operational energy efficiency measures include the studies and reports shown in table 2.1 below. There is a variety of the purpose, perspective, and scope of each of the articles. While all these studies looked at barriers to energy efficiency, some articles only deal with individual topics regarding the theme, such as the article by Jia et al. (2017), which investigate "Virtual Arrival". These studies are included because they provide stellar insight into barriers to the operational measure, and in some cases, creates the background for findings in other articles. This, however, may be a source of heterogeneity in our findings.

Table 2.1: Studies and reports included in literature review on policy implications and operational measures,

Type of measure	Articles referenced
Speed reduction	Ronen (1982), Buhaug et al. (2009), Faber et al. (2010a), Cariou (2011), Lindstad et al. (2011), Maddox Consulting (2012), Miola et al. (2011), Wang and Meng (2012), Psaraftis and Kontovas (2013a), Smith et al. (2013), Rehmatulla (2014), Rehmatulla and Smith (2015a), Rehmatulla and Smith (2015b), Assmann et al. (2015), Adland and Jia (2016a), Adland and Jia (2016b), Faber et al. (2017), Hanif et al. (2018), Psaraftis (2018), Adland and Jia (2018), Adland et al. (2019), Poulsen and Sampson (2019), Corbett et al. (2009), GloMEEP (2020), Shell (2020) and Adland et al. (2020).
Virtual Arrival	Buhaug et al. (2009), Rosaeg (2010), Faber et al. (2010a), Miola et al. (2011), Maddox Consulting (2012), Psaraftis and Kontovas (2013a), Lindholm (2014), Knorring and Andersson (2014), Rehmatulla and Smith (2015a), Rehmatulla and Smith (2015b), Jia et al. (2017), Poulsen and Sampson (2019), GloMEEP (2020), IMO (2020b) and Shell (2020)
Weather routing	Padhy et al. (2007), Buhaug et al. (2009), Faber et al. (2010b), Shao et al. (2011), Maddox Consulting (2012), Miola et al. (2011), Rehmatulla (2014), Rehmatulla and Smith (2015a), Rehmatulla and Smith (2015b), Arslan et al. (2015), and GloMEEP (2020)
Trim and draft optimization	Wärtsilä (2008), Buhaug et al. (2009), Faber et al. (2010b), Faber et al. (2010a), Miola et al. (2011), Maddox Consulting (2012), Rehmatulla and Smith (2015a), Rehmatulla and Smith (2015a), Rehmatulla and Smith (2015b) and GloMEEP (2020)

Type of policy	**Articles referenced**
EEXI	Chambers (2019a), Chambers (2019b), IMO (2020c), IMO (2020), BIMCO (2020) and Rutherford et al. (2020a,b).
MBMs	Chupka (2004), Miola et al. (2011), Devanney (2010), Psaraftis (2012), Giziakis and Christodoulou (2012), International Transport Forum (2015), Larkin et al. (2015), Wang et al. (2015), Assmann et al. (2015), Lema et al. (2016), Adland and Jia (2016a), Adland and Jia (2016b), Rehmatulla and Smith (2015a), Kosmas and Acciaro (2017), Jia et al. (2017), Adland et al. (2017b), Adland and Jia (2018), Psaraftis (2018), Adland et al. (2020), European Parliament (2017), Boviatsis and Tselentis (2019), Lagouvardou et al. (2020), IMO (2020c), Trafigura (2020) Shell (2020) and IMO (2020a).
MRV	ECSA (2013), Lister et al. (2015), Adland et al. (2017a), Psaraftis (2018), Adland et al. (2019), European Commission (2020), Poulsen et al. (2020), Psaraftis and Kontovas (2020), Rehmatulla and Smith (2020) and BIMCO (2020).

2.1 Risk and Bias of Included Studies

In our assessment of the credibility of the studies included in our thesis, we considered both the papers' validity and reliability. Reliability is concerned with the dependability of the study, and it refers to the fact that it should be possible to replicate the study and achieve results of the same nature (Saunders and Thornhill, 2016). In cases where the result can be replicated, the study's reliability is considered to be high. Validity, in context as an evaluation criterion in research, refers to a study's plausibility and relevance (Saunders and Thornhill, 2016). Especially the articles' internal, construct, and external validity was considered. External validity is about whether the research findings can be generalized, internal validity is concerned about the causality of relationships, and construct validity is about whether the concepts are operationalized (Saunders and Thornhill, 2016).

The articles included in our literature review have strong validity and reliability. This thesis is primarily based on research articles. However, we have also included findings from some selected industry reports with emphasis on these concepts, such as Maddox Consulting (2012), Faber et al. (2017) and Shell (2020). Some of these articles have been included because other relevant articles builds on their findings, while others have been included to further strengthen our arguments or to shed light on topics that are not covered by research articles.

3 Literature review

3.1 Operational Energy Efficiency Measures

In total, more than fifty technical and operational measures to improve energy efficiency have been identified (Buhaug et al., 2009; Faber et al., 2010b,a). A selection of these is listed in table 3.1. While improved energy efficiency typically leads to reduced fuel expenditures, there are also other potential benefits connecting economics and sustainable ship operation (Adland et al., 2019). Firstly, vessels with high energy efficiency may obtain higher utilization in the market, leading to improved revenue. Secondly, charterers may be willing to pay a premium for vessels with lower fuel consumption and emissions.

Table 3.1: Types of energy efficiency measures available (Buhaug et al., 2009)

Operational measures	**Technical mesures**
Speed reduction	**Propeller system upgrades**
	Propeller upgrades (winglet, nozzle)
Hull and Propeller maintenance	Propeller boss cap fins
Hull performance monitoring	
Hull coating	**Main engine retrofits/upgrades**
Hull brushing	Main engine tuning
Hull hydroblasting	Common rail upgrade
Dry-dock full blast	Retrofit hull improvements
	Optimization of hull shape
Voyage and operations options	
Shaft power meter	**Air lubrication**
Fuel consumption meter	
Weather routing	**Waste heat recovery**
Autopilot upgrades/adjustment	
Trim and Draft Optimization	
Virtual arrival	

Operational efficiency is defined by Smith et al. (2013) as "the ratio between the actual CO_2 emissions and the actual transport supply". Further, an *operational energy efficiency measure* is defined by Faber et al. (2010b) as measures that do not require physical changes to the ship. Operational measures are viewed by the industry as being important to increase energy efficiency (Faber et al., 2010a). The reasoning behind this is that they have significant potential to reduce CO_2, require little effort for implementation, few technological changes of the ship structure, and require smaller investments compared to technical measures (Faber et al., 2010a).

The operational measures addressed in this thesis are general speed reduction, virtual arrival, weather routing, and trim and draft optimization. These measures have been chosen as they all, according to the literature, meet the following criteria under reasonable circumstances: they are cost-effective, meaning that they are both energy and economically efficient (Sorrell et al., 2004; Faber et al., 2010a), have sizable fuel-saving potential, and several former studies have estimated abatement potential with harmonious results.

General Speed Reduction In a perfectly competitive market where the shipowners are price takers, the optimal speed is settled where the marginal savings from speed reduction equates to the marginal cost of lost revenue due to the reduction in voyages per time unit (Strandenes, 1981; Ronen, 1982), which are determined by fuel prices and freight rates (Maddox Consulting, 2012; Psaraftis and Kontovas, 2013a). By operating at a lower speed, vessels decrease their power requirements, fuel consumption, and cost (Faber et al., 2010a). General speed reduction is considered the measure with the highest impact on energy efficiency (Faber et al., 2010a; Maddox Consulting, 2012; Rehmatulla and Smith, 2015a; IMO, 2020), and is often cited as the best short-term measure to reduce emission (Lindstad et al., 2011; Cariou, 2011; Faber et al., 2017). Several studies investigate the potential savings from speed reduction. According to Corbett et al. (2009), a 50% reduction in speed can result in up to a 70% reduction in emission across a range of containership routes. Further, Psaraftis and Kontovas (2013a) and Smith et al. (2013) argue that slow steaming can be particularly beneficial in a depressed market as it leads to reduced fuel costs and reduced overcapacity in the market, where the latter can cause an increase in the freight rates in the short term.

However, several studies find that shipowners do not adjust speed based on fuel prices and freight rates, as argued in classical maritime economic theory. Assmann et al. (2015) studies average voyage speed for VLCCs and find that the elasticity of speed regarding fuel prices and freight rates is lower than implied by theory. Further, Adland and Jia (2016a) use the average speed from the Capesize market and expand the analysis by using new microeconomic and technical variables. They find that the vessels do not seem to adjust speed according to theory. Similar results were found by Adland and Jia (2016b), who used weekly average speed for VLCC tankers. Further, as pointed out by Psaraftis and Kontovas (2013a), speed reduction can also have negative side effects, such as increased in-transit inventory costs, increased finance costs, and increased maritime transport. It can also lead to modal shifts to land transport associated with increased emissions. Despite its great abatement potential, Rehmatulla and Smith (2015a) finds that speed reduction has an implementation rate of 60%, whereas findings from Rehmatulla (2014) show an implementation rate of 70%.

Speed can be reduced at a technical and operational level. We focus on the latter, where exiting vessels are sailing slower than their design speed (Psaraftis and Kontovas, 2013b). This is known as "slow steaming". There is a rule of thumb saying that the power requirement is related to ship speed by a third power function (Ronen, 1982; Faber et al., 2010a; Rehmatulla, 2014), meaning that a 10% reduction in speed will result in a 27% reduction in power requirements (Faber et al., 2010a; Rehmatulla, 2014). Considering that reduced speed leads to increased trip duration, there is a quadratic relation between speed and fuel consumption per tonne mile, and the net reduction from a 10% reduction in speed is a 19% reduction in power (Faber et al., 2010a). Given this non-linear relationship, speed reduction can lead to dramatic changes in fuel costs (Psaraftis and Kontovas, 2013a). The majority of studies investigating the abatement potential of speed reduction, such as Faber et al. (2017), bases their analysis on the cubic law, thus assuming that the elasticity of fuel consumption with regards to speed equals 3. This assumption usually holds near the design speed of the vessel (Psaraftis and Kontovas, 2013a; IMO, 2014; Adland et al., 2020). However, slow steaming has been prevalent during the last decade (Adland and Jia, 2016a; Cariou et al., 2018), and some studies suggest that the cubic law may not be a good approximation for vessels operating at lower speed (Wang and Meng, 2012; Psaraftis and Kontovas, 2013a). This has been investigated in a newly published study by Adland et al. (2020). They used a dataset of more than 11,000 daily reports from 16 crude oil tankers to investigate the elasticity of fuel consumption regarding speed and show empirically that once weather effects are taken into account, the elasticity depends on the vessel speed itself. Their findings confirm that the cubic law holds near the vessel's design speed. However, at lower speeds, the elasticity can be substantially lower. This indicates that most studies investigating the abatement potential of speed reduction based on the cubic law overestimate the impact of this measure. For example, reducing speed from 15 knots to 12 knots will lead to a 48% reduction in fuel consumption using the cubic law, compared to a 41% reduction using speed-dependent elasticity (Adland et al., 2020). This can also explain why vessels tend to not adjust speed according to theory, as suggested by Assmann et al. (2015), Adland and Jia (2016a) and Adland and Jia (2018).

Since reduced speed is equivalent to reduced transport work per unit of time, more vessels are needed to cover the same transport work (Faber et al., 2010a). Reducing the fleets speed is a trade-off between reduced fuel cost and the cost of additional ships to compensate for the reduced transport work (Faber et al., 2010a). Bunker price and the market capacity are key determinants for the monetary savings caused by speed reduction. The IMO 4th GHG study (2020) estimates the marginal abatement cost (MAC) of speed reduction at different fuel prices and market conditions. The MAC represents the net cost ratio to implement a measure divided by the amount of GHGs it averts (Psaraftis, 2018). The results are summarized in table 3.2, showing that speed reduction has a negative MAC in a depressed market with overcapacity of vessels and when the fuel prices are high.

Table 3.2: Cost efficiency and abatement potential of Speed Reduction by 10%

CO_2 reduction potential	**MAC (USD/tonne)**		
	Fuel price 188 USD/tonne	**Fuel price 375 USD/tonne**	**Fuel price 750 USD/tonne**
Additional ship 0%	-62	-124	-248
Additional ship 50%	79	17	-107
Additional ship 100%	219	157	33

Virtual Arrival Whereas general speed reduction is a trade-off between reduced fuel costs and reduced profit-earning trips per unit of time (Psaraftis and Kontovas, 2013a), efficiency can also be improved within the transport chain without extending transportation times or reduce transport capacity (Faber et al., 2010a; Jia et al., 2017; Poulsen and Sampson, 2019). Demand for port services can fluctuate greatly (Psaraftis and Kontovas, 2013a), and delays and congestions will occur when the demand exceeds the port's capacity. This can be costly for both the shipowner and charterer and may cause negative ramifications downstream the supply chain (Psaraftis and Kontovas, 2013a). Since the most common port system is the First Come First Served system, vessels will have incentives to rush to port, even if there are known congestions (Lindholm, 2014). However, rushing to port only to wait in line is not beneficial from a commercial or environmental perspective as it leads to extra fuel expenditures and emissions (Rosaeg, 2010).

Virtual Arrival is a measure trying to tackle this problem and involves an agreement between the shipowner and the charterer to reduce speed to make the Required Time of Arrival (Jia et al., 2017). Thus, waiting time in port will be turned into extra sailing time, leading to reduced fuel consumption and emissions. The shipowner should be compensated for lost time by referring to the demurrage rate to make the agreement attractive for both parties (Lindholm, 2014). Further, the fuel savings should be split between the shipowner and the charterer. According to Buhaug et al. (2009), virtual arrival is a "sustainable and practical process that rationalizes the transportation chain and provides real benefits such as fuel-saving and thus reduction in vessel emissions, as well as improved safety".

Several studies investigate the abatement potential of speed reduction due to Virtual Arrival. Buhaug et al. (2009) quotes fuel savings of 0-10%, whereas Faber et al. (2010a) quotes fuel savings of up to 27%. Jia et al. (2017) used Automated Identification System (AIS) data to analyze waiting time for VLCC tankers during the period 2013-2015 and found that fuel consumption could be reduced by 7-19% depending on how much of the excess port time can instead be utilized for sailing. Jia et al. (2017) also points at increased transparency, communication, and cooperation between the market participants as other benefits to Virtual Arrival. Further, an analysis by GIA, cited by IMO (2020b), found that if container vessels calling at the Port of Rotterdam in 2018 were given a specific time of unloading 12 hours in advance, 134,000 tonnes of CO_2 could be reduced. This measure's costs are unknown and associated with the costs of more efficient port infrastructure and loading processes (Faber et al., 2010a).

Weather Routing Weather conditions influence the power needed to propel a vessel at a given speed over ground (GloMEEP, 2020). The shortest distance between two ports may not always be the fastest or the most cost-effective route due to weather conditions (Arslan et al., 2015). Weather routing is a measure where weather forecasts, vessels characteristics, and sea conditions along the designated voyage are taken into account when deciding the optimal route (Padhy et al., 2007; Shao et al., 2011). This measure should result in reduced travel time or avoiding rough weather, resulting in decreased fuel consumption (Rehmatulla, 2014). Weather routing also aims to increase safety for crew, vessel, and cargo (Rehmatulla, 2014; Arslan et al., 2015). Weather routing is especially important for vessels with long voyages as they normally spend time in unsheltered waters, and they have more route choice flexibility to avoid bad weather conditions (GloMEEP, 2020). There are several services available aiming to help optimize routes, given the corresponding weather conditions (Faber et al., 2010a). The installment cost of these systems is estimated to USD 15 000 per vessel and requires a maintenance cost of an additional USD 3000 per year (GloMEEP, 2020). According to both Buhaug et al. (2009) and Faber et al. (2010b), this measure has an abatement potential of 0,1-4%, whereas StormGEO (2020) argues that container vessels can save up to 10% of fuel consumption due to weather routing. However, as this is a widely used measure today, the current abatement potential is likely lower than estimated by Buhaug et al. (2009) and Faber et al. (2010b).

Trim and Draft Optimization Trim and draft optimization help reduce a vessel's water resistance, and by doing so, reducing its fuel consumption and emissions (GloMEEP, 2020). Optimizing the trim of a vessel can be done by active cargo planning, arranging bunker, or varying the amount of ballast water (Faber et al., 2010b). This measure is applicable for all vessel types and ages but requires additional investments in equipment such as a dedicated trim optimizer, vessel performance monitoring systems in addition to crew training (Faber et al., 2010b; Maddox Consulting, 2012; GloMEEP, 2020). Wärtsilä (2008) notes that these investments usually have a short payback time. Further, this measure is also associated with operational costs caused by collecting and analyzing data with changing trim and ballast. According to Wärtsilä (2008), Faber et al. (2010b) and GloMEEP (2020), trim and draft optimization has the potential to reduce fuel consumption by 0,5% – 3%. However, for ships trading in partial load conditions, such as container or specialized vessels, the reduction potential can be up to 5% (GloMEEP, 2020). This measure is considered to be semi-mature, meaning that the uptake across the industry is limited to date (GloMEEP, 2020). Rehmatulla and Smith (2015a) finds the implementation rate to be 50%.

Table 3.3: Summary of fuel saving potential of operational measures

Operational measure	**Fuel savings potential**
General speed reduction	7,4 - 9 %
Weather routing	0,1 - 10 %
Virtual arrival	0 - 19 %
Trim and draft optimisation	0 - 5 %

3.2 Barriers to Energy Efficiency

Studies across different sectors find that the implementation of measures to improve energy efficiency does not always reflect their substantial abatement potential (Sorrell et al., 2004, 2011; Blumstein et al., 1980), suggesting the existence of barriers inhibiting the adoption of these measures. This is also the case for shipping. Rehmatulla and Smith (2015a) find that the high energy savings potential and cost-effectiveness of energy efficiency measures do not correspond to the rate of implementation observed in the industry. This is supported by Buhaug et al. (2009), Faber et al. (2010a), Agnolucci et al. (2014), Rehmatulla and Smith (2015a) and Adland et al. (2017a). The difference between the actual implementation observed and the level of implementation that would be optimal is defined as the energy efficiency gap, as illustrated by figure 3.1.

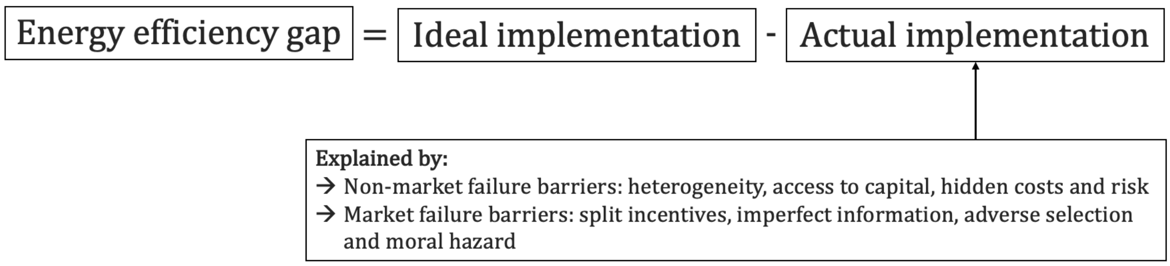

Figure 3.1: Energy efficency gap explained (Sorrell et al., 2004)

Barriers to energy efficiency are a topic that has been widely addressed in literature since 1980. Blumstein et al. (1980) provides one of the earliest looks at barriers to energy efficiency and how they can prevent the "adoption of cost-effective energy conservation measures". The study aimed to look at the reasons why energy efficiency measures were not always an automatic result of market forces. Blumstein et al. (1980) found six classes of barriers to energy efficiency: misplaced incentives, lack of information, regulation, market structure, the availability of financing and custom. This article has been followed by extensive literature on the subject.

Brown (2001) finds that numerous market failures and barriers contribute to the energy efficiency gap. These are conditions of the market that violate the neoclassical assumption of an efficient market. Similarly to Jaffe and Stavins (1996), Brown (2001) find that barriers to energy efficiency can both be barriers created by market failure or non-market failure. Non-market failures are defined by Brown (2001) as market obstacles not caused by market failure but still contributing to the slow diffusion and adoption of energy efficiency measures. On the other hand, market failures are defined as something that occurs when the market operates in a flawed way. Brown (2001) bases its reasons for market failure on Jaffe and Stavins (1996), and cite the causes to be: misplaced incentives, distortionary fiscal and regulatory policies, unpriced costs such as air pollution, unpriced goods such as technological advances or education, and insufficient and incorrect information.

It is pointed out that failing in accounting for such market imperfections in economic models causes an underestimation of benefits from energy efficiency measures. Some of the energy gap is caused by the firms' rational market behavior that cannot be captured by economic models (Rehmatulla and Smith, 2015a). In neoclassical economic modeling, all businesses are assumed to maximize a profit function that arises from a highly stylized set of market and technological conditions (Laitner et al., 2000). It is also assumed that all resources are utilized in an entirely efficient manner. The reliance on overly narrow, unrealistic, and unsubstantiated assumptions about the characteristics of consumers and firms mischaracterize the behavior of the economic agents (Laitner et al., 2000). As a result, benefits from energy efficiency measures are wrongly estimated.

Sorrell et al. (2004) defines barriers to energy efficiency as "a postulated mechanism that inhibits a decision or behavior that appears to be both energy efficient and economically efficient". The article point to three classes of barriers; economic, behavioral, and organizational (Sorrell et al., 2004). The economic barriers can be divided into market failure and non-market failure, which is in correspondence with both Jaffe and Stavins (1996) and Brown (2001). Sorrell et al. (2004) defines market failure as a situation occurring when the requirements for efficient allocation of resources through well-functioning markets are violated. They argue that market failure is caused by principal-agent problems, split incentives, adverse selection, moral hazard, and imperfect or asymmetric information. It is worth noting that there are certain overlaps between several of these barriers. An example of interdependence between potential barriers is the fact that "imperfect information" is listed as a separate barrier, whereas it may cause "split incentives". Further, Sorrell et al. (2004) defines non-market barriers as situations *"where the organization is behaving rationally given the risk adjusted rate of return on an investment in the existing context of energy, capital and unavoidable hidden costs"*. It is emphasized that non-market barriers are real features of the decision-making environment companies face, but that they are difficult to implement in the decision-making models used in the industry (Sorrell et al., 2004). Heterogeneity, hidden cost, access to capital, and risk perception are non-market failure barriers to energy efficiency cited by Sorrell et al. (2004).

Several newer studies on barriers to energy efficiency in shipping uses Sorrell et al. (2004) framework, such as Rehmatulla (2014), Rehmatulla and Smith (2015a,b) and Adland et al. (2017a). Studies by Rehmatulla and Smith (2015b) focus attention on that the implementation gap of operational energy efficiency measures could be explained by the rational behavior of industry players. Economic barriers to energy efficiency stem from neoclassical economics, which assumes individuals and organizations as rational and utility or profit-maximizing (Rehmatulla and Smith, 2015b).

As evidenced by literature, there are numerous ways to classify these barriers, where most of them are linked and overlapping. The taxonomy used in this thesis is based on the Sorrell et al. (2004) framework for economic barriers to energy efficiency. This perspective, according to Sorrell et al. (2004), is the most developed and well-defined. However, it places less emphasis on the regulatory environment as a barrier to energy efficiency. This is by Blumstein et al. (1980) considered to be a significant barrier, of equal importance as those mentioned by Sorrell et al. (2004). Further, barriers to energy efficiency could potentially be resolved through regulatory policy instruments (Faber et al., 2010a). Thus policy intervention can act as a driver for improved energy efficiency. We therefore extend the analysis to lay greater emphasis on how policy intervention can act as a barrier, but also on how it can help to overcome barriers to energy efficiency.

3.2.1 Market Failure Barriers

As Sorrell et al. (2004), we look at market failure and non-market failure barriers. Market failure barriers include split incentives and informational problems. Issues regarding split incentives arise from the principal-agent problem or the agency relationship (Jensen and Meckling, 1976), suggesting that the parties interests are conflicting and that it can be challenging to obtain information about the agent's actions. Hence, split incentives and imperfect information are closely linked (Brown, 2001; Rehmatulla and Smith, 2020).

Split Incentives Improved energy efficiency leads to lower fuel expenditures and emissions

(Smith et al., 2013). However, the economic benefits of energy conservation sometimes accrue to different agents (Blumstein et al., 1980), giving rise to split incentives. Split incentives often occur due to contractual or organizational arrangements (Sorrell et al., 2004), and according to Faber et al. (2010a), it represents one of the most important barriers to energy efficiency.

A vessel can be chartered on two main types of contracts: voyage charter and timecharter (Stopford, 2009; Adland et al., 2017a). The voyage and timecharter allocate responsibility for the vessel's costs between the shipowner and the charterer (Rehmatulla and Smith, 2015a, 2020), which can lead to conflicting interest to minimize their share of costs. Under a voyage charter, all costs are normally borne by the shipowner, whereas the charterer pays the voyage costs under a timecharter contract (Evans and Marlow, 1990).

In the voyage market, the shipowner is usually responsible for selecting the level of operational energy efficiency and is also the one who can pocket any fuel savings (Rehmatulla and Smith, 2015a). In these cases, energy efficiency is in theory already rewarded (Adland et al., 2019), and split incentives should not act as a barrier to implementation of these measures. In a study by Adland et al. (2019), the authors show empirically that operational efficiency seems to be rewarded in the VLCC voyage market. However, several studies argue that vessels in the voyage market do not always optimize speed according to theory (Psaraftis and Kontovas, 2013a; Rehmatulla and Smith, 2015a; Assmann et al., 2015; Adland and Jia, 2016b,a, 2018), and claims that this can be explained by contractual clauses concerning concepts like demurrage, laycan, and speed, which are indicators of split incentives.

Under a voyage charter, fuel costs are borne by the shipowner (Evans and Marlow, 1990). According to classical maritime economic theory, the party paying for the fuel may want to optimize speed as a function of fuel prices and freight rates (Strandenes, 1981; Ronen, 1982; Psaraftis and Kontovas, 2013a). Thus, in a depressed market, the shipowner will normally benefit from slow steaming. However, speed clauses are included in most charterparties, which demands the vessel to sail at "utmost speed" (Rosaeg, 2010; Jia et al., 2017). The charterer seeks to minimize investments in in-transit inventory and does not pay directly for fuel costs (Rosaeg, 2010; Psaraftis and Kontovas, 2013a). Consequently, the charterer does normally not benefit from slow steaming. This is because slow steaming leads to higher inventory costs, and the speed stipulated in the charterparty is seldom the most energy-efficient one (Rehmatulla, 2014). Thus, speed optimization can be in breach of the terms of the charterparty, which can be costly for the shipowner (Rehmatulla and Smith, 2015a). However, this failure's positive side effect is that it gives the shipowner incentive to implement other cost-effective measures to retain the same margins.

Contractual clauses concerning demurrage and laycan can also lead to a sub-optimal high speed (Faber et al., 2010a; Adland and Jia, 2018). According to Faber et al. (2010a), the opportunity to save fuel by reducing speed and arrive at the port when it is ready for the vessel is lost in the current system due to demurrage and laycan. A shipowners profit from a voyage is given by the equation below (Adland and Jia, 2018):

$$\textit{Profit} = \textit{Freight revenue} + \textit{demurrage payable - fuel costs}$$

The shipowner is responsible for delivering the vessel to the port within the laycan (Lindholm, 2014), and risks to lose the contract if the vessel is not present to load within this time window (Adland and Jia, 2018). In a declining market, the shipowner can have an incentive to cancel a contract if the vessel does not show up within the laycan, as it may have the opportunity to replace the original vessel with a vessel at a lower rate (Adland and Jia, 2018). However, cancellation will normally lead to reduced profit for the shipowner, thus giving the incentive to increase speed to minimize the risk of cancellation. The incentive to increase speed will be further reinforced if the demurrage rate is higher than the daily earnings from sailing (Adland and Jia, 2018). Demurrage is a daily penalty the charterer has to pay in case of exceeded laytime (Faber et al., 2010a; Adland and Jia, 2018), and is considered an important revenue for shipowners in a depressed market (Poulsen and Sampson, 2019). When the earnings obtained from sailing is higher than the demurrage rate, a shipowner can maximize profit by minimizing time spent in port and maximize time spent sailing as the value of sailing exceeds the value of waiting (Adland and Jia, 2018). However, in a depressed market where the demurrage rate is higher than revenues obtained from sailing, a profit-maximizing shipowner will seek to maximize demurrage, which is done by arriving at the first layday (Adland and Jia, 2018; Poulsen and Sampson, 2019). The relationship between income from sailing and demurrage has been studied by Adland and Jia (2018). They used timecharter equivalent spot freight rates and demurrage rates for Aframax crude oil tankers for 2015-2016 to illustrate the economic effects of demurrage on vessel earnings and optimal speed. They show that when the demurrage rate is higher than the daily income obtained from sailing, which is normal in a depressed market, the optimal speed for a profit-maximizing shipowner will be substantially higher than without demurrage, as increased speed will lead to higher demurrage payable.

Split incentives is a well-known hinder for the uptake of technical measures to improved energy efficiency in the timecharter market, as the shipowner can invest in improved energy efficiency, yet the savings in fuel expenditures accrue to the charterers (Agnolucci et al., 2014; International Transport Forum, 2015; Rehmatulla and Smith, 2015b; Rehmatulla et al., 2017; Adland et al., 2017a). However, in the timecharter market, the charterer has the operational control over the vessel (Rehmatulla and Smith, 2015a) and get to decide whether or not to implement a wide range of operational measures, such as speed and virtual arrival (Rehmatulla, 2014). Since it is also the charterer who pays for the corresponding fuel costs, conflicting interest to minimize costs should not occur (Rehmatulla, 2014). This is supported by Faber et al. (2010a), Smith et al. (2013) and Rehmatulla and Smith (2015a), who finds that operational measures involving speed have a higher implementation rate in the timecharter market than in the voyage market, which can partly be explained by the timecharterers having the operational control as well as the incentive to save fuel costs.

Although the charterer can implement most operational measures under a timecharter contract, some measures are still primarily implemented by the shipowner (Rehmatulla, 2014), such as weather routing. Whereas the implementation of these measures will be beneficial for the charterer, it will imply an extra cost for the shipowner (Rehmatulla and Smith, 2015b), thus giving rise to split incentives. The incentives could be realigned if the charterer passed some of the savings back to the shipowner in terms of a premium (Rehmatulla, 2014; Adland et al., 2017a), or if it leads to other benefits such as higher utilization resulting in higher overall revenues (Adland et al., 2019). The size of the premium relative to the saving represents the extent of a market barrier associated with split incentives (Rehmatulla and Smith, 2015b). This allocation is a key determinant for the shipowner's profit (Agnolucci et al., 2014; Adland et al., 2017a), and according to Jaffe and Stavins (1996), measures will only be implemented if the shipowner believes that it will lead to higher profits.

Several studies are investigating whether or not energy efficiency is rewarded in the timecharter market through premiums. However, most of them are looking at the implementation of technical measures, which usually imply a higher cost than most operational measures (Rehmatulla, 2014). These findings can still be relevant, as they can give the shipowners indications of whether or not the market reward energy efficiency. In a study of the timecharter rates for drybulk vessels in the period 2008-2011, Agnolucci et al. (2014) found that 40% of the savings from improvements in energy efficiency were allocated to shipowners. A similar study by Adland et al. (2017a) which expanded the time horizon and drybulk vessel sizes, found that only 14-27% of the fuel savings were reflected in higher rates during normal market conditions. This indicates that the findings by Agnolucci et al. (2014) are not robust when expanding the sample throughout a full market cycle (Adland et al., 2017a). Further, during market booms, Adland et al. (2017a) found that energy inefficient vessels received a premium, as the value of time and carrying capacity will exceed the value of fuel savings when freight rates are high (Adland et al., 2017a). The study concludes that there is a meager reward for investment in energy efficiency during normal market conditions and that fuel-efficient vessels will even be penalized during market booms. These finding suggests that market failure exists. Further, split incentives market failure for technical measures has also been analyzes in a newly published study by Rehmatulla and Smith (2020). They find that firms with the majority of their vessels on timecharter contracts have a higher implementation of energy efficiency technologies than firms mainly operating in the voyage market. In contrast to both Agnolucci et al. (2014) and (Adland et al., 2017a), their findings suggest that the split incentives problem is to some extent being correcting for in the market.

Imperfect Information Vessels with high energy efficiency can obtain several benefits, including reduced fuel expenditures, higher utilization in the market, and higher freight rates (Adland et al., 2019). According to Jaffe and Stavins (1996) and Adland et al. (2019), the ability to collect these benefits is crucial for the incentive to implement measures to improve energy efficiency. However, imperfect or asymmetric information can make it challenging for shipowners to obtain these benefits, as it reduces the ability to identify and reward the most energy-efficient vessels (Rehmatulla, 2014; Rehmatulla and Smith, 2015a; Adland et al., 2019). Several studies point to this as one of the most important reasons behind the energy efficiency gap in shipping (Faber et al., 2010a; Rehmatulla, 2014; Rehmatulla and Smith, 2015b; Adland et al., 2017a; Shell, 2020).

Economists generally classify goods into three categories with regards to information about their quality (Sorrell et al., 2011):

- Search goods: the consumer can determine quality with certainty before buying the product;
- Experience goods: the consumers can only determine quality after buying the product;
- Credence goods: when it is challenging for the consumer to determine the quality of the product even after they have started using the product

According to Sorrell et al. (2011), the ability to identify a goods quality will impact its vulnerability to information market failure. To measure a vessel's performance regarding energy efficiency in real operating conditions can be challenging as fuel consumption is influenced by several "difficult-to-observe variables", such as weather conditions (Rehmatulla, 2014; Adland and Jia, 2016b,a; Rehmatulla et al., 2017). Thus, identifying the most energy-efficient vessels, which can lead to higher utilization and higher rates in the timecharter market, can be difficult. This also makes it hard to estimate the monetary savings caused by a measure aiming to improve energy efficiency. Based on this, the vessel's energy efficiency may therefore be categorized as a credence good. Adland et al. (2019) claims that only improved quality of information can lead to fairer pricing of energy efficiency and sustainable operation in the markets in the short term. Further, both Agnolucci et al. (2014) and Adland et al. (2017a) argue that lack of information is one of the most important reasons for sub-optimal allocations of savings in the timecharter market and that it is reasonable that the charterers are not willing to pay a full premium when they do not have full information about corresponding costs and savings. This view seems to be shared among the market participants. Several studies point to a lack of reliable information about costs and savings as one of the most important barriers for the uptake of operational measures (Rehmatulla, 2014; Rehmatulla and Smith, 2015b; Shell, 2020).

In other cases, the supplier of a good holds relevant information but are unable or unwilling to share this information with the prospective buyer (Sorrell et al., 2011). This type of asymmetric information arises in shipping when the charterer has less information than the shipowner about a vessels technical or operational quality (Strandenes, 2000). Before entering into a timecharter contract, the shipowner must provide the charterer with information about estimated fuel consumption under different circumstances (Rehmatulla et al., 2017). If high energy efficiency can lead to higher rates, the shipowner might be tempted to misrepresent a vessels energy efficiency (Veenstra and van Dalen, 2011; Rehmatulla, 2014). However, if the charterer can provide evidence that the vessel was incapable of achieving the promised speed and fuel consumption, a performance claim can be made by the charterer to compensate for the loss of productivity due to reduced speed or higher fuel costs due to higher fuel consumption (Williamson, 2012; Rehmatulla et al., 2017; Rehmatulla and Smith, 2020). Thus, there is a trade-off between getting high timecharter rates and being claimed for providing wrongful information about energy efficiency. However, it can be challenging, time-consuming, and costly for the charterer to monitor the vessels' fuel consumption and shipowners' actions (Rehmatulla, 2014). If the charterer does not monitor fuel consumption, it has limited power to claim that the shipowner has provided wrongful information about the vessels fuel consumption (Rehmatulla et al., 2017). Further, it can also lead to adverse selection (Sorrell et al., 2011). Adverse selection occurs when vessels performing above the average standard withdraw from the market because they are not sufficiently paid to deliver high-quality (Strandenes, 2000).

In an industry report published by Shell (2020), lack of transparency regarding emissions is identified as an important obstacle for decision-making and that transparency is required for customers, investors, and financiers to identify top performers and verify commitments. The report argues that there is a lack of publicly available data, as emission reporting is only conducted for regulatory reasons. This is supported by Agnolucci et al. (2014). Further, Smith et al. (2013) and Rehmatulla et al. (2017) argue that the information about fuel consumption can be difficult to verify due to the lack of any universal and international labeling system of vessels' environmental performance.

3.2.2 Non-market Failure Barriers

Heterogeneity, hidden cost, access to capital, and risk perception are non-market failure barriers to energy efficiency cited by literature (Sorrell et al., 2004; Rehmatulla, 2014; Rehmatulla and Smith, 2015b). All these represent important barriers to implementing energy efficiency in the shipping industry. They all are easily misrepresented in economic modeling approaches, which results in a faulty representation of the energy efficiency measure's savings potential. This section examines these in the context of shipping.

Heterogeneity refers to that one technology can have different profitability and potential for reducing emissions depending on the vessel characteristics, route, and cargo (Longarela-Ares et al., 2020). All estimates of a particular measure's cost-effectiveness to energy efficiency are based on an average (Sorrell et al., 2004). This implies that their potential may not reflect the actual emission reduction of a measure. Sorrell et al. (2004) further quotes heterogeneity as a possible explanation for the non-adoption of some of the operational measures available to vessels. The discrepancies from the baseline emission reductions specified earlier depend on the distribution of characteristics within the class (Sorrell et al., 2004). Further, some energy efficiency measures may be mutually exclusive or only applicable to a specific type of vessel (Longarela-Ares et al., 2020).

Across the deep-sea leg of shipping, there is a wide variety of the characteristics of vessel attributes, size, and age. This is emphasized by Faber et al. (2010b), who account that the emission reduction potential for each operational measure varies as a function of ship size, type, and age. Rehmatulla (2014) also points to this fact. Vessel age is especially of interest considering the investment in energy efficiency measures because older ships tend to have a lower margin of recovery of investment (Longarela-Ares et al., 2020). Heterogeneity in shipping is also discussed in a study by Adland et al. (2016). This study helps explain that despite shipping being considered close to a perfect market on an aggregated level and thus vessels being a homogeneous commodity, the situation is different from a micro perspective. Vessels' attributes, their owners, and the difference in charterers needs mean that none of the market participants can be perceived as identical.

Hidden Costs are costs that are hidden to the analyst performing the economic modeling but not to the firm investing in the energy efficiency measure (Sorrell et al., 2004;

Rehmatulla and Smith, 2015b). The problem of hidden costs is quoted as one of the most vital arguments for the efficiency gap and implies that measures are overestimated in energy efficiency potential (Sorrell et al., 2004). Hidden costs act as a barrier for energy efficiency measures when they outweigh the benefits of adopting a measure (Longarela-Ares et al., 2020). They typically include life cycle, transaction, commissioning or disruption cost, and loss of benefits.

Life cycle costs are cost concerning to the energy efficiency measures life cycle (Rehmatulla and Smith, 2015b). They include:

- Identification and search cost related to the direct cost of searching for a relevant energy efficiency measure.
- Project appraisal costs are costs incurred in evaluating a measure in concerning the firm's specific needs.
- Commissioning cost relates to implementing a selected measure, i.e., meeting with relevant vendors and contracting.
- Additional engineering costs, which are costs related to maintenance, decommissioning, or removal.

Transaction cost can often make cost-effective measures costly. This is especially relevant for smaller shipowners and operators because the cost of, i.e. information gathering per ship becomes very high. (Rehmatulla and Smith, 2015b).

Commissioning or disruption cost are cost incurred because some measures require a temporary suspension in operations, and therefore creates a time lag between when a measure becomes available and its actual implementation (Faber et al., 2010a; Rehmatulla and Smith, 2015b).

Loss of benefits is when the implementation of energy efficiency measures is associated with a reduction in benefits (Rehmatulla and Smith, 2015b).

Access to Capital For industry players in deep-sea shipping, capital constraints are caused by either restrictions to overall borrowing or how available financing is allocated to projects. The latter is the most relevant for operational measures. Both Sorrell et al. (2004) and Faber et al. (2010a) argue that investment in energy efficiency has been of low priority and that the internal allocation of capital constitutes a significant barrier for energy efficiency. This is exemplified by Faber et al. (2009). At the time, many of their interviewees indicated that energy efficiency measures had low priority because of the low cost of bunker fuel. As a result, the focus had been on reducing crew costs rather than costs related to fuel. Since internal funding is always restricted, the bar of investment is often higher than the actual cost of capital (Ross, 1986). This is especially true for small investment projects, for which the implementation of operational measures often is comparably low to other investment decisions. Investing in energy efficiency can come at the cost of forgoing other more cost-effective opportunities, and therefore it has been rational for firms not to prioritize energy efficiency (Faber et al., 2010a; Rehmatulla, 2014).

For restrictions to overall borrowing, the poor economic conditions after the financial crisis of 2009 have led to low, unstable growth and constraints on liquidity (KPMG, 2015; Norwegian Shipowners' Association, 2019). This has affected shipowners' access to capital greatly in a negative sense (Norwegian Shipowners' Association, 2019). In a report by the Norwegian Shipowners' Association (2019) it is stated that a shipowners access to capital has gradually weakened in the period from 2014 to 2017 and that this tightening capital access is expected to continue into 2020. However, it is important to note that there are large variations between segments regarding the perception of access to capital (Norwegian Shipowners' Association, 2019). Nevertheless, in total, access to capital is considered to be tighter than before. The change in access to capital is also caused by increased sustainability focus in CSR strategies and the consumer-driven pressure on financial institutions (International Transport Forum, 2015; Shell, 2020). Several significant shipping banks such as Citibank, BNP Paribas, Amsterdam Trade Bank, DNB, Credit Suisse, ING, DanskeBank and Société Générale have joined the Poseidon Principles, a framework for assessing the climate disclosing and alignment of ship finance portfolios with regards to IMO guidelines (Poseidon Principles, 2020).

Risk is an important barrier to energy efficiency and can cause discount rate premiums on energy efficiency investments or rejection of energy efficiency technologies (Sorrell et al., 2004). Similarly to Sorrell et al. (2004), this paper distinguishes between three dimensions of risk in the context of energy efficiency; external, business, and technical risk.

External risk includes all overall economic trends, fuel price, policy, and regulation (Sorrell et al., 2004; Rehmatulla and Smith, 2015a). This is highly representative of the risks faced by deep-sea shipping companies. Bunker price is paramount in the industry, and the cost of fuel constitute up to 70% of vessels operating costs (Rehmatulla and Smith, 2015a; Adland et al., 2017a). Changes in fuel prices fluctuate greatly, which can cause dramatic changes in the economics of a measure (Maddox Consulting, 2012). Bunker volatility, therefore, imposes an external risk to all operational measures, which can act as a barrier to the implementation of operational measures to improve energy efficiency (Maddox Consulting, 2012).

Policy risk is connected to changes in rules and regulations and how these can affect the monetary savings caused by measures to improve energy efficiency. There is an increasing chance of policy changes that can benefit vessels with a low GHG footprint (Adland et al., 2019). Being precautionary and having a fleet that can tackle changes in the industry's regulatory framework can represent sustainable competitiveness (Adland et al., 2019). However, uncertainty regarding future regulations can also hinder investments aiming to reduce emissions, as some companies may find it safer to wait and see which regulations are being enforced before putting money into environmental upgrades. This is particularly relevant for measures with high investment costs. Policy implications will be further discussed in chapter 6.

Business risk includes risk associated with financing and sectoral trends (Rehmatulla and Smith, 2015b). As Rehmatulla and Smith (2015b) points out, an important risk focus area for a shipowner is financing costs of a ship and its repayment (Stopford, 2009).

Technical risk is here associated with specific risk in particular technologies (Sorrell et al., 2004). As Sorrell et al. (2004) points out, many operational energy efficiency measures are well proven and apparently low risk. However, the fact that the energy efficiency measures addressed in this thesis are categorized as semi-mature and mature makes it unlikely that technical risk will often provide a reason for limited uptake.

4 Findings

This section present our findings on which barriers that represent the largest contributor to the energy efficiency gap. The different studies on energy efficiency barriers largely agree on which barrier is the most prominent for each operational measure. Faber et al. (2010a) and Maddox Consulting (2012) represent the most noteworthy exception. Faber et al. (2010a) cites no significant barriers to weather routing, and Maddox Consulting (2012) argues similarly for speed reduction.

4.1 Barriers to Speed Reduction

There is a consensus among several studies that split incentives is the most important barrier to speed reduction (Maddox Consulting, 2012; Rehmatulla and Smith, 2015a; Adland and Jia, 2016a, 2018; Shell, 2020). This problem may occur when the shipowner can maximize profit by reducing speed. However, this can lead to increased investments in in-transit inventory for the charterer. Most charterparties include a speed clause, which reduces the risk of increased costs for the charterer. Thus, this reduces the shipowner's flexibility to optimize speed according to economic theory. Further, contractual clauses concerning concepts like laycan and demurrage can also be categorized as split incentives problems. These arrangements can give the shipowners perverse incentives to increase speed only to wait at anchorage to collect demurrage (Adland et al., 2019), thus increasing emissions and fuel costs.

Several studies find that vessels do not seem to adjust speed according to theory (Assmann et al., 2015; Adland and Jia, 2016a,b), and Adland and Jia (2016a) suggest that contractual structures and clauses are obstacles for speed reduction. In a survey performed by Rehmatulla and Smith (2015a), almost 60% of the respondents pointed to contractual arrangements as the most important obstacle for speed reduction. Similar results were also found in a survey performed by Hanif et al. (2018). Psaraftis and Kontovas (2013a) argues that a predetermined speed set in the charterparty will hinder speed reduction. Industry sources also acknowledged this problem in a newly published report by Shell (2020). Faber et al. (2010a) also address split incentive problems in speed reduction and argues that the ability to reduce emission and fuel expenditures by reducing the speed is lost in the voyage market due to contractual concepts such as demurrage and laycan. This is supported by Adland and Jia (2018), who found that in a depressed market where the demurrage rate is higher than the freight rate, the concept of demurrage will lead to a substantial increase in the optimal speed for a profit-maximizing shipowner, thus increasing emissions. This problem has also been addressed by several other studies, including Corbett et al. (2009), Faber et al. (2010a), Maddox Consulting (2012), Rehmatulla and Smith (2015a) and Poulsen and Sampson (2019).

Despite several sources identifying multiple barriers to speed reduction, Maddox Consulting (2012) argues that there are no significant barriers. The high implementation rate evidence this. However, Maddox Consulting (2012) acknowledges that split incentives can be a barrier to achieve a higher implementation rate of speed reduction.

Interestingly the literature primarily focuses on split incentives as a barrier to speed reduction in the voyage market, suggesting that this is not a problem faced by the timecharter market. This seems reasonable since the charterer controls speed, the fuel bill, and economic consequences in case of delays under this type of contract (Buhaug et al., 2009). Therefore, we can expect a speed reduction to have a higher uptake rate in the timecharter market than in the voyage market. This is supported by Rehmatulla and Smith (2015a) who find indications of higher implementation levels of speed reduction in the time charter market than in the voyage market. IMO (2020b) and Maddox Consulting (2012) further argues that vessels operating in the timecharter market will experience less contractual barriers with regards to speed reduction than those under voyage charters.

4.2 Barriers to Virtual Arrival

Similarly to speed, decisions about port time arrivals are often dictated by charter party agreements Shell (2020). In a report published by Shell (2020), several interviewees argue that this is inflexible, and disincentives improvements. As one of the shipowners interviewed stated "We could get a 10% CO_2 reduction and fuel-cost savings by optimizing arrival times like airlines. But contracts mean we would not get the benefits". However, as Faber et al. (2010a) points out, agreeing on a Virtual Arrival contract policy will mitigate this problem as it stipulates the allocations of the monetary savings.

Findings from both Rehmatulla and Smith (2015a) and Rehmatulla (2014) point to lack of reliable information about costs and savings from Virtual Arrival as the most important barrier to implementation. This problem is also addressed in findings from interviews performed by Poulsen and Sampson (2019). As pointed out by Jia et al. (2017), a set of calculations and analysis must be performed to assess a Virtual Arrival policy implementation, and the parties have to agree on how to allocate the monetary savings caused by the speed reduction. However, estimating the reduction in fuel consumption that can be addressed to Virtual Arrival can be challenging as fuel consumption will be influenced by speed and other factors such as weather conditions, trim and hull fouling conditions (Rehmatulla et al., 2017; Adland et al., 2020). Thus, none of the parties can know for certain what the fuel consumption would have been without the Virtual Arrival policy, and agreeing on this benchmark can be challenging as the shipowner and charterer will have conflicting interests to maximize their share of the monetary savings. The highest saving potential from Virtual Arrival is expected to be where economic considerations favor inefficient operational arrival (Buhaug et al., 2009).

Several studies argue that Virtual Arrival requires additional administrative work and cooperation between the shipowner, charterer, and the port (Intertanko, 2011; Rehmatulla, 2014; Poulsen and Sampson, 2019; IMO, 2020b; Shell, 2020). This can be both time consuming and costly, and can negatively impact the parties' incentives to implement a Virtual Arrival policy. IMO (2020b) has acknowledged the need for better cooperation between ports and vessels to facilitate the reduction of GHG emissions. They encourage member states to support the industry's collective efforts to improve data quality and availability allowing for reliable and efficient data exchanges (IMO, 2020b). Knorring and Andersson (2014) and Maddox Consulting (2012) suggest that the issue with lack of information about savings and trust between the shipowner and the charterer can be solved by letting an independent third party calculate the savings from Virtual Arrival.

Virtual Arrival is considered as a promising measure to reduce emissions from the shipping industry (Buhaug et al., 2009; Faber et al., 2010a; Rehmatulla, 2014; Rehmatulla and Smith, 2015a; Jia et al., 2017). However, Poulsen and Sampson (2019) argues that the theoretical potential is improbable to be achieved as the charterer may have commercial considerations that outweigh the benefits from Virtual Arrival. Most commodities' prices can fluctuate greatly, and their value often outweighs the cost of freight and fuel by many orders magnitude. If the charterer believes that their commodity price will rise, it can be commercially rational for the charterer to ask the vessel to wait at anchor as the cargo's value is significantly greater than demurrage rates. Poulsen and Sampson (2019) argues that this can also be beneficial for the shipowner as the crew gets to catch up on maintenance and sleep while earning demurrage.

4.3 Barriers to Weather Routing

The literature seems to have conflicting views on which barriers are the most important for the implementation of weather routing. Whereas Faber et al. (2010a) argues that there are no significant barriers to weather routing, Traut et al. (2015) finds that lack of information is the most important obstacle. 24% of the respondents in their survey pointed at the lack of reliable information on cost and savings as the most vital barrier to implementation. Rehmatulla (2014) find that split incentives barriers are not problematic concerning weather routing in timecharter contracts because the charterer is responsible for the implementation of the measure and has an incentive to save fuel as it is on their account. Despite this, 16% of survey respondents in Rehmatulla and Smith (2015a) cited that contractual arrangements can be be a barrier to weather routing. Further, the view of Rehmatulla (2014) is also in contrast to findings from Maddox Consulting (2012), who argue that the cost of weather routing is borne by the shipowner in the timecharter market, whereas the charterer will receive the benefits in terms of reduced fuel costs. Maddox Consulting (2012) argues that split incentives are the most important barrier to weather routing in the timecharter market. Additionally, Buhaug et al. (2009) argue that skilled and motivated crew are essential for optimal voyage performance and that the highest savings can be expected where contractual arrangements reward efficient sailing. Buhaug et al. (2009) suggest that incentive schemes where the crew gets rewarded for efficient operation can be an effective measure to motivate the crew.

4.4 Barrier to Trim and Draft Optimization

Several studies argue that split incentives and imperfect information are the most important barriers to trim and draft optimization. According to Rehmatulla (2014), the most pertinent barrier is the lack of reliable information on cost and savings, which can be categorized as a market failure problem. Similar results have been found by Rehmatulla and Smith (2015b). Such informational problems can reduce the shipowners' ability to retain potential benefits from improved energy efficiency, thus leading to lower uptake rates (Jaffe and Stavins, 1996; Adland et al., 2019). The focus on lack of reliable information on cost and savings is also partly explained by this operational measure's more technical nature. Maddox Consulting (2012) finds that there is some technical risk regarding uncertainty over the optimal fuel consumption in ballast conditions, affecting the measure's efficiency. This, is in contrast with the perception of trim and draft optimization being a mature technology (Rehmatulla, 2014; GloMEEP, 2020). Faber et al. (2010a) finds no barriers to the implementation of this measure.

Difficulties with implementing the measure under some types of charter contracts are also cited as a relevant barrier (Rehmatulla, 2014). Trim and draft optimization is a measure that is implemented by the shipowner in both the voyage and timecharter market (Rehmatulla, 2014). Since implementation would reduce fuel expenditure for the shipowner in the voyage market, split incentives should not be a barrier to implementation. However, the shipowner might hesitate due to the investment cost, even though it has a short payback time (Faber et al., 2010a).

Whereas most operational measures have a higher implementation rate in the timecharter market than in the voyage market, Rehmatulla (2014) finds that trim and draft optimization have a higher uptake rate in the voyage market. Rehmatulla (2014) suggest that this can be explained by conflicting interests arising in the timecharter market. Cargo intake, which is decided by the charterer, will impact the draft. However, the system used to optimize trim will, in most cases, be paid by the shipowner, whereas the charterer receives the benefits. Split incentives may therefore arise. This is supported by Rehmatulla and Smith (2015a), where the participants argued that trim and draft optimization could be difficult to implement under some types of charter. Similarly, Maddox Consulting (2012) also argue that the cost of installing can lead to split incentives in the timecharter market. The charterer receives the direct benefit of the implementation in terms of reduced fuel costs, meanwhile the additional costs are incurred on the shipowner. Consequently, the shipowner's incentives and the charterer's have to be realigned, which can be achieved by the charterer compensating the shipowner in terms of a premium.

5 Barriers to energy efficiency

This section discusses which barriers represent the largest contributor to the energy efficiency gap, in light of our findings.

5.1 Market Failure Barriers

Split incentives and imperfect information seem to be the most prominent and most frequently mentioned barriers across the studies. Although they vary in importance depending on the measure, these are the most prevailing barriers for all measures.

Split Incentives Our findings suggest that the prevalence of split incentives depends on the contractual agreements between charterer and shipowner. In the timecharter market where the charterer has operational control over the vessel, conflicting interests to minimize costs should not occur. This is supported by Faber et al. (2010a), Maddox Consulting (2012), Rehmatulla (2014), Smith et al. (2013) and Rehmatulla and Smith (2015a) who all find a higher implementation of speed-related measures in this market compared to the voyage charter market. However, some operational measures, such as weather routing, are usually implemented by shipowners. Since these measures are beneficial for the charterer but impose an extra cost for the shipowner, split incentives may still be a barrier to some operational measures (Maddox Consulting, 2012; Smith et al., 2013).

Energy efficiency in the voyage market is, in theory, already rewarded as it is the shipowner who receives the benefits of improved energy efficiency (Adland et al., 2019). However, contractual clauses regarding concepts like speed, demurrage, and laycan can give rise to split incentives. For instance, speed is typically stipulated by the charterer who aims to minimize investments in in-transit inventory (Maddox Consulting, 2012). As Rehmatulla (2014) points to, since the charterer does not pay the fuel cost directly, the stipulated speed is seldom the most energy-efficient one but rather selected to minimize the charterers costs. Thus, as found by Rehmatulla and Smith (2015a), voyage charter contracts and their structure and clauses can make operational measures more difficult to implement.

The difference in barriers to energy efficiency caused by contractual agreements is supported by the findings of Rehmatulla and Smith (2015a). It is found that the average implementation rate of speed-related measures seems to be higher in the timecharter market than in the voyage market. This is rational since the charterer has operational control in the timecharter market and an incentive to save fuel, thus removing the problem with conflicting interests. Further, these findings indicate that split incentives may represent a greater barrier to implementing technical rather than operational measures to improve energy efficiency. However, split incentives may still act as a barrier to operational measures in the voyage market and those operational measures decided by the shipowner in the timecharter market.

The length of a timecharter contract will also influence the implementation rate of operational measures. Under these contracts, the charterer controls the implementation of several operational measures. Consequently, the operational or investment cost associated with the measure affects the economics of implementation. These operational measures can represent a sizeable cost to the charterer with short term contracts and be deemed unprofitable despite the theoretical cost and emission savings.

Imperfect Information Imperfect information can make it challenging for the shipowner to obtain benefits from energy efficiency measures, as it can reduce the ability to identify and reward the most energy-efficient vessels (Rehmatulla, 2014; Rehmatulla and Smith, 2015a; Adland et al., 2019). Our findings suggest that both lack and reliability of the information is an issue. All fuel-saving potential, and thus emission-reducing potential, is based on an average that does not necessarily reflect the characteristics of the vessel implementing it. Savings from the different measures can be wrongly estimated, causing uncertainty about its actual profitability. Challenges regarding verification of fuel savings caused by a measure can negatively affect the shipowner's ability to retain the benefits of high energy efficiency(Rehmatulla, 2014; Rehmatulla and Smith, 2015a).

From the industry interviews conducted by Shell (2020), it is also suggested that a lack of transparency regarding emissions hinders the implementation of measures aiming to reduce emissions. The study finds that there needs to be greater transparency of emissions across the industry to enable decarbonization activity. Without transparency, it will be impossible for stakeholders to identify more energy-efficient ships (Shell, 2020), causing difficulties with deciding on the commercial value of implementing operational measures.

The issue of imperfect information is also addressed by Adland et al. (2019), who stresses the need for better information. Uncertainty surrounding the monetary gains from an energy-efficient operation is a serious barrier to implementing energy efficiency measures, and it is crucial to reduce the ambiguity of such measures' effects. This is vital, because as Adland et al. (2019) points out: "In the short term, it is only improved quality of information that can contribute to fairer pricing of energy efficiency and environmentally friendly operation in the markets".

The uncertainty hindering the uptake of operational energy efficiency measures is also caused by the lack of an industry standard for collecting and comparing data (Shell, 2020). There is no uniformly accepted calculation standard, which makes comparing emissions profiles and performance data difficult. Shipowners can have an incentive to misrepresent a vessel's energy efficiency if there are problems with monitoring energy efficiency performance. This creates an environment of mistrust between the charterer and shipowner, which will negatively influence charterers' willingness to pay a premium for and investing in energy efficiency, further hindering the uptake of operational measures.

5.2 Non-market Failure Barriers

The majority of studies claim that the types of barriers categorized as market failures are the best plausible explanation for the energy efficiency gap, but non-market barriers should not be cited as unimportant. Faber et al. (2010a), brings more focus to barriers that can be categorized as non-market failures. They cite a lack of prioritizing the operational measures, access to capital, and heterogeneity as main barriers.

Implementing operational energy efficiency measures is a business decision at large, and one that is influenced by the assumptions and limitations of economic modeling. Investments in operational energy efficiency measures have been foregone by other more profitable or cost-effective measures because this was the rational choice from a business perspective. This is also supported by Rehmatulla (2014) and Rehmatulla and Smith (2015b), who also discussed the often low priority of smaller energy efficiency investments. The focus on reducing GHG emissions, and the positive rewards from this, is not large enough to sufficiently engage the industry on its own. In the absence of regulation forcing action and lack of profitability, pure commercial considerations rule.

Shell (2020) points to the value of establishing investments in operational energy efficiency measures as key to decreasing emission. A solid business case can help drive change in how contracts are structured and lead to extended contract duration and increased benefit-sharing schemes (Shell, 2020). However, as Poulsen and Sampson (2019) points out, charterers' commercial considerations often outweigh the benefits from energy efficiency measures in practice. This is an issue also brought forward by Adland et al. (2019), who argue that “if more energy-efficient vessels are not rewarded through better utilization, higher freight rates, and improved asset values compared to less environmentally friendly designs, the incentive to develop and operate such vessels will not be present”.

Implementation of operational measures is also affected by non-market failure barriers such as fuel price, heterogeneity, and hidden cost. All factors indirectly help determine the supposed cost-effectiveness of an operational measure. No economic modeling decision will realistically include all possible hidden cost faced by the firm making the investment decision based on the fact that they by definition are "cost hidden to the firm investing in the energy efficiency measure" (Sorrell et al., 2004; Rehmatulla and Smith, 2015b). Despite how careful a firm is in considering all possible costs related to the implementation of an operational measure, it will be challenging to include everything, and thus the possibility of overestimation remains. The same issue is true for heterogeneity, where the estimates of the cost-effectiveness of a particular measure will be based on an average of ships, which is not necessarily homogeneous. The risk of volatility in fuel prices is also difficult to fully consider and will affect the potential savings from implementing measures.

6 Policy implications

In the previous section, we have identified split incentives and imperfect information as the most important barriers to improve operational energy efficiency. These barriers can potentially be solved through policy instruments (Faber et al., 2010a), which aims to create conditions that can help make these win-win solutions feasible in a cost-effective way (Psaraftis, 2019; Lagouvardou et al., 2020). It is expected that there will be new rules and regulations coming into force during the next decade and that these will make a significant impact on the shipping industry. Being precautionary and able to tackle these changes can represent sustainable competitiveness for shipping companies (Adland et al., 2019). However, policy intervention is also a potential source of external risk (Sorrell et al., 2004; Blumstein et al., 1980). This section examines four current and proposed policy instruments that we believe provide a robust representation and reflection of the current political situation and investigate their potential impact on the energy efficiency gap in shipping. Next, we look at areas where further policy intervention may be required.

6.1 IMO

IMO is responsible for the international regulation of safety and environmental protection in international shipping and is committed to reducing emission from the industry (IMO, 2018; Poulsen et al., 2020). The organization has the opportunity to impose global regulations that can facilitate significant emission reductions from the global fleet while creating a level playing field. A level playing field globally is particularly important for deep-sea shipping and is considered being vital to drive change. Decarbonization is one of the most important topics on IMOs agenda (Psaraftis, 2018), and it has initiated several important regulations during the last decade (IMO, 2018). In 2018, IMO adopted the Initial IMO GHG Strategy representing the industry's response to reduce emissions consistent with the Paris Agreement temperature goals (IMO, 2018; Psaraftis, 2019; IMO, 2020c). This strategy includes a vision, ambitions, guiding principles, candidate measures, and follow up actions (Psaraftis, 2019; IMO, 2020c). A revised strategy including agreements on targets, measures, and an implementation plan will be adopted in 2023 (IMO, 2018; Psaraftis, 2018; Lagouvardou et al., 2020).

The initial strategy includes several candidate short-term, mid-term, and long-term measures to fulfill IMO's ambition to reduce GHG emissions. The majority of the candidate short-term measures aim to improve the operational efficiency of existing vessels (Lagouvardou et al., 2020), which is considered vital to fulfilling IMO's ambition to reduce carbon intensity by at least 40% by 2030 (DNV GL, 2020). Further, Market Based Measures (MBMs), which have been abandoned by IMO since 2013 (Asariotis et al., 2013), are now listed as a candidate mid-term measure (IMO, 2020c; Lagouvardou et al., 2020). The long-term measures are primarily focusing on zero carbon and fossil-free fuels (IMO, 2020c; Lagouvardou et al., 2020).

EEXI At the 75th session of the IMO's Marine Environment Protection Committee (MEPC 75) held in November 2020, two new regulations were approved, the Energy Efficiency Existing Ship Index (EEXI) and the Carbon Intensity Indicator rating (CII) (IMO, 2020c). These short-term measures aim to address both technical and operational measures to reduce emissions from vessels (IMO, 2020), which is in line with IMO's 2030 ambition (IMO, 2020). The EEXI builds upon the existing Energy Efficiency Design Index (EEDI), which applies to new vessels, by applying energy efficiency standards to the existing fleet (Chambers, 2019a; IMO, 2020). Vessels that do not meet the requirements have several different compliance options (Chambers, 2019b; Rutherford et al., 2020b). According to both Chambers (2019b) and Rutherford et al. (2020b), an engine power limitation (EPL), which limit the vessel's maximum speed, is likely to be the cheapest option and therefor favored.

The EEXI has received some positive traction from the industry and has been backed by CIMAC and BIMCO (Chambers, 2019a; BIMCO, 2020). It has also been met with criticism. EEXI's potential to reduce fuel and emissions has been analyzed by Rutherford et al. (2020a,b). Due to the prevalence of slow steaming, they argue that this regulation would have to be aggressive to reduce emissions. However, according to Rutherford et al. (2020a) the EEXI, as proposed, will only lead to a reduction in CO_2 by 0.7% to 1.3%. Rutherford et al. (2020b) state that the EPL would have to be above 50% to reduce emissions modestly (Rutherford et al., 2020b). Chambers (2019a) argues that EEXI regulates efficiency on paper, but will have limited impact on real-world emissions and fuel consumption.

Split incentives and contractual clauses are identified as the most important barriers to speed reduction. Since the EPL reduces the vessel's maximum speed, the speed set in charterparties and the vessel's ability to increase speed to receive demurrage will be reduced accordingly. Consequently, we argue that the EEXI can reduce the energy efficiency gap for speed reduction, but that its effect will depend on the prevalence of slow steaming and its level of ambitions.

Bunker Levy The initial strategy opens up for MBMs as potential mid-term measures to reduce emissions (IMO, 2020c). MBMs are based on the "polluter pays" principle and can help reduce negative externalities by internalizing the cost of emissions (International Transport Forum, 2015; Lagouvardou et al., 2020). Several studies argue that MBMs are important instruments to reduce emissions from shipping (Larkin et al., 2015; Lema et al., 2016; Kosmas and Acciaro, 2017; Psaraftis, 2018; Lagouvardou et al., 2020).

An MBM that has received positive traction from the academic community is a global bunker levy scheme (Giziakis and Christodoulou, 2012; Psaraftis, 2018). Under this scheme, all vessels could be subject to a levy established at a given cost level per ton of fuel bunkered (Giziakis and Christodoulou, 2012). The levy makes the monetary savings caused by improved energy efficiency and the use of alternative fuels more substantial than today. According to economic theory, this should result in higher uptake of these measures (Chupka, 2004; Jia et al., 2017). The levy could be channeled to an international fund, which could be used to foster research and technology deployment, and ease the financial burden on shipping companies investing in green technologies (Lagouvardou et al., 2020; Kosmas and Acciaro, 2017; Trafigura, 2020). This is similar to the Norwegian NOx Fund, which is considered a success (Kosmas and Acciaro, 2017).

The academic community seems to agree that a bunker levy can lead to reduced emissions. Gu et al. (2019) argues that a bunker levy is the only cost-efficient way to reduce emission without governmental intervention. Further, according to Psaraftis (2012), a bunker levy would provide price certainty, which may enable shipowners to act proactively to reduce their emissions. Several industry players also seem to favor this scheme. In a white paper by Trafigura (2020), one of the world's largest ship charterers, the company encourages IMO to introduce a significant bunker levy, as they state that this is the only way to make a significant impact on the emissions from the shipping industry.

However, the actual result of a bunker levy relies on several factors. Kosmas and Acciaro (2017) argue that the effect of a levy depends on its size, market conditions, fuel prices, and freight rates. Whereas economic theory suggests that increased fuel prices should lead to reduced speed, findings from several studies indicate that it has a limited effect on vessel's behavior (Assmann et al., 2015; Adland and Jia, 2016a,b; Adland et al., 2017b). Based on nearly 7000 boundary crossings, Adland et al. (2017b) have empirically investigated how increased fuel prices inside the Emission Control Areas (ECAs) affect speed. Their findings suggest that this regulation has not contributed to the intended changes in vessels' behavior (Adland et al., 2017b). These findings indicate that a bunker levy is unlikely to contribute to the expected changes in vessels' behavior, and that the main problem is likely to be contractual structures (Adland and Jia, 2016a). This is in line with Rehmatulla and Smith (2015a), who argues that the presence of market failures indicates that MBMs would not be cost-effective to drive change and that the market is unlikely to respond efficiently to a bunker levy. They state that command and control regulations such as EEXI may be a better fit. Similarly, Adland and Jia (2018) argues that if contractual structures are hindering improved energy efficiency, a levy will have less impact than if economic incentives and regulations were aligned.

Psaraftis (2018) and Trafigura (2020) argue that the levy's size has to be significant to make an impact. Devanney (2010) investigate the impact of a levy based on fuel prices of 465 USD/tonne. He finds that a bunker levy of 50 USD/tonne can reduce VLCC emissions by 6% over a market cycle, whereas a 150 USD/tonne levy can lead to a reduction of 11.5%. Further, Adland et al. (2020) suggest that the true elasticity of fuel consumption with regards to speed can be lower than 3. These arguments question the benefits of slow steaming and the effects of bunker levies. The authors illustrate this by showing the impact of a levy on 200 USD/tonne of fuel as a function of elasticity using characteristics from a representative Aframax vessel. Their findings are summarized in table 6.1. Here we see that the estimated reduction in emissions is significantly reduced when changing the elasticity from three. Hence, a levy's impact on speed-related measures may be less substantial than estimated by most studies and challenges the view that higher fuel prices will force vessels to reduce speed and, thus, emissions. These findings can also explain why changes in freight rates and bunker prices seem to have a limited effect on speed, as found by Assmann et al. (2015), Adland and Jia (2016a,b) and Adland and Jia (2018).

Table 6.1: Impact of a bunker levy as a function of elasticity. Source: Adland et al. (2020)

Outcomes	Bunker price 400 USD/tonne		Bunker price 600 USD/tonne	
	Elasticity = 3	**Elasticity = Variable**	**Elasticity = 3**	**Elasticity = Variable**
Optimal speed (knots)	10,.4	10.5	8.9	9.8
Profit/day (USD)	26,267	24,704	23,707	20,561
Emissions/day (tonne)	18.3	23.9	11.7	20.5

Based on these findings, we argue that a levy gives economic incentives to improve energy efficiency. Still, our findings suggest that contractual clauses can hinder the levy's impact on speed-related measures. Further, it does not contribute to overcome the problem of imperfect information, which is considered as the most important barrier to Virtual Arrival, weather routing, and trim and draft optimization.

IMO Criticism Even though decarbonization of shipping is one of the most important topics on the IMO's agenda, the organization has received criticism for moving too slowly and setting weak ambitions to reduce emissions (Larkin et al., 2015; Lister et al., 2015; International Transport Forum, 2015; Psaraftis, 2018; Psaraftis and Kontovas, 2020). The organization's structure can partly explain this. IMO usually practice consensus-based decision-making (IMO, 2020; Psaraftis and Kontovas, 2020). The rationale behind this is that a measure adopted by the organization needs as much support as possible to create a level playing field (IMO, 2020), meaning that all shipping companies are subject to the same circumstances concerning legislation, taxes, and subsidies (Appelman et al., 2003). According to IMO (2020), member states that do not support a treaty would not ratify it and may rather adopt alternative treaties of their own. However, the need for consensus has caused some convention ratification processes to last for more than a decade (Lister et al., 2015), while other submissions are rejected even if the majority of member states are positive to the proposal.

Psaraftis and Kontovas (2020) criticize the Initial IMO Strategy for being full of compromises. For instance, the strategy includes two principles, (a) non-discrimination and (b) Common But Differentiated Responsibilities and Respective Capabilities (CBDR-RC), which are in direct conflict with each other. The same view is taken by Traut et al. (2018). The principle of CBDR-RC has been an obstacle to several proposed regulations and is considered the main reason why MBMs were suspended from IMO in 2013 as a group of member states argued that MBMs were not compatible with this principle (Psaraftis, 2018;

Psaraftis and Kontovas, 2020). Psaraftis (2018) and Psaraftis and Kontovas (2020) argue that CBDR-RC is the most significant obstacle to any progress on maritime emission reduction and state that a way to circumvent this principle is needed to be found if any serious progress is to be made. Thus, they argue that regulations such as a "correctly sized" global bunker levy will be hard to implement as it will be met by criticism. Recently, IMO member states agreed to consider establishing a research and development (R&D) fund trough a 2 USD/tonne levy on marine fuel (Corbett, 2020). While the size of the levy is probably way too small to reduce emissions, it can raise important money for R&D. Further, this could also be discussed as a short-term measure while waiting for a "correctly sized" levy to be imposed and can be a way to build confidence in implementation. The proposal received support, even though some member states were concerned about the governance and oversight of the fund (Corbett, 2020). Keeping this in mind, a "correctly sized" levy will likely receive massive reactions from these countries.

6.2 Regional Regulations and Private Initiatives

EU ETS In response to slow IMO processes, regions and organizations are now acting unilaterally (Lister et al., 2015; Psaraftis and Kontovas, 2020). In 2017 the European Parliament voted to include shipping in the EU Emission Trading System (EU ETS) as of 2023, in case no global agreement is reached by 2021 (European Parliament, 2017; Psaraftis, 2018). This MBM makes it more expensive to pollute and give shipowners and charterers incentive to reduce pollution to save costs. However, this scheme will also face the same challenges as the bunker levy scheme.

The EU ETS scheme has reached massive criticism from the industry (Miola et al., 2011; Wang et al., 2015; Psaraftis, 2018; Lagouvardou et al., 2020; Shell, 2020). Shipping is an international industry, which, according to IMO (2020a), only operates effectively if the regulations and standards are agreed, adopted, and implemented internationally. Both the industry and the academic community argues that regional regulations may create significant distortions and obstacles for efficient trade across the continents (Miola et al., 2011; Wang et al., 2015; Psaraftis, 2018; Shell, 2020). Miola et al. (2011) and Psaraftis (2018) argue that including shipping in the EU ETS can increase GHG emissions from shipping. They also point to a loss of competitiveness of the European economy, and especially for European maritime transport companies, as possible consequences. Vessels are easily mobile, and a likely effect of the EU ETS is that vessels choose to sail longer distances to avoid European ports and seas as much as possible. Thus, it can be relatively easy for the shipping companies to avoid the EU ETS (Miola et al., 2011; Wang et al., 2015; Psaraftis, 2018). Further, Miola et al. (2011) argues that the inclusion of shipping in the EU ETS can cause high transactions costs. This problem can, in particular, be significant for smaller vessels and result in increased cost of European shipping.

MRV Lack of reliable information about vessel's energy efficiency is identified as one of the most important contributors to the energy efficiency gap for operational measures (Agnolucci et al., 2014; Adland et al., 2017a, 2019). In 2018, the European Commission implemented a mandatory monitoring, reporting, and verification (MRV) scheme for CO_2 emission for ships calling at European Ports (Psaraftis, 2018; European Commission, 2020). This regulation aims to provide information about fuel consumption and help shipowners save fuel and reduce emissions (ECSA, 2013; Poulsen et al., 2020). According to ECSA (2013) and Rehmatulla and Smith (2020) the MRV regulation can help overcome market barriers related to lack of information if designed correctly. However, Rehmatulla and Smith (2020) argue that the regulation is sub-optimal as is. The publicly available MRV data disclose information about fuel usage associated with GHG emissions (Poulsen et al., 2020) but does not provide information about operating conditions and factors attributing to an increase in CO_2 intensity (ECSA, 2013; BIMCO, 2020). Thus, an observer would not be able to identify a vessels energy efficiency based on MRV data (Poulsen et al., 2020). Consequently, the regulation does not provide the information needed to contribute to the higher implementation of measures such as Virtual Arrival, weather routing, and trim and draft optimization.

Poulsen et al. (2020) have investigated the MRV's impact on the tanker market. They argue that the MRV regulation is unlikely to lead to any significant reduction in emissions in the tanker market as it does not address the complexity of power relations along the supply chain and how different agents influence emissions. They state that this regulation can provide incentives to shipowners to reduce emissions, but it does not have the same impact on charterers and oil majors who can influence ship operations to a great extent. Poulsen et al. (2020) stated that regulations aiming to reduce GHG emissions should expand their focus beyond the behavior of producers of goods and services to also focus on the incentive structures and demands placed on them by global buyers.

Despite its weakness, the MRV regulation has also received positive feedback as it increases focus on fuel consumption and raises awareness on potential savings of fuel reduction ECSA (2013). Further, Psaraftis (2018) states that data from ships must be collected and reported to track global energy efficiency gains.

Private Initiatives Lack of reliable information about vessels' performance with regards to energy efficiency is a problem that private initiatives like the Clean Shipping Index, Sea Cargo Charter, and Clean Cargo have tried to solve. However, as Lister and Dauvergne (2013) points out, the growing prevalence of these NGOs and private initiatives can be problematic. The number and variance of rating schemes can confuse the market because data and green claims may not be comparable (Lister, 2014). As stated in the same article, "a company receiving a green ship award from one program may not necessarily qualify under another rating scheme as the metrics and methodologies differ". This is vital, because as Zacher and Sutton (1996) state, "uniformity is an essential precondition for a growing maritime industry because it promotes both certainty of costs and factor mobility".

6.3 Policy Implication

Our findings suggest that non of these regulations and initiatives will be sufficient to overcome the problem regarding lack of information about vessels' energy efficiency. We argue that improved quality of information is crucial to increase uptake of measures such as Virtual Arrival, weather routing, and trim and draft optimization. Consequently, we assert the need for a standardized and mandatory system to monitor vessels' performance in real operating conditions to reduce industry emissions. This system should be uniform and apply to all vessels, above a certain size, across the globe.

Further, we see that contractual structure can hinder the effect of MBMs, and that command and control mechanisms may have a greater impact on the energy efficiency gap where split incentives is an issue. We argue that the industry should explore alternative contractual clauses to align the shipowner's and charterer's incentives.

Both the industry and the academic community seem to agree that IMO is the preferred policymaker as it has the opportunity to impose global regulations and create a level playing field. However, our findings suggest that IMO builds on fundamental principles that hinder significant progress in reducing emissions. In the absence of actions taken within the IMO, the door for regional regulations and private initiatives are wide open. However, the findings from our literature review suggest that regional regulations can cause unwanted distortions. Despite this, it can also have positive effects. As stated by Lister et al. (2015), Boviatsis and Tselentis (2019) and Psaraftis and Kontovas (2020), both the EU ETS and the MRV scheme put pressure on IMO and force them to act, which may be exactly what the IMO needs.

7 Conclusion

This thesis presents a comprehensive literature review on barriers to energy efficiency and the implications of policy intervention. The object of this thesis was to investigate several topics that are of crucial interest and represent gaps in the literature. We examined which barriers that are most likely to be responsible for the energy efficiency gap for operational measures in shipping. Further, we analyzed how policy instruments can be used to reduce this gap and which areas should be focused on in order to drive change.

We conclude that split incentives and imperfect information represents the most important barriers to improved operational energy efficiency in shipping. Further, we find that the prevalence of these barriers is closely linked to the contractual structure and the allocation of costs and savings. While these barriers are created by market failure, the contribution of non-market failure barriers to the energy efficiency gap must not be ignored.

From the literature review on policy implications, our findings suggest that none of the discussed regulations are sufficient to overcome the identified barriers. MBMs can be efficient instruments to stimulate innovations, the uptake of new technology, and reduce the energy efficiency gap for the operational measures. However, the prevalence of contractual clauses and other market barriers suggest that MBMs are unlikely to make any significant changes in vessel's behaviour. Further, the EEXI could stimulate to increased uptake of speed-related measures if designed correctly. However, as proposed, this regulation is unlikely to reduce emissions notably. The MRV scheme aims to provide information about vessel's performance concerning energy efficiency. However, we concluded that this scheme does not provide the information needed to identify a vessel's real energy efficiency.

Based on our findings, we argue that improved quality of information is crucial to increase the uptake of measures such as Virtual Arrival, weather routing, and trim and draft optimization. We therefore argue that a standardized and mandatory system to monitor vessels' performance in real operating conditions is needed and that such a system could be imposed by organizations such as IMO or the EU. Further, we conclude that the industry should explore new contractual clauses to align shipowners' and charters' incentives, which is necessary to make progress in reducing emissions from the shipping industry.

8 Limitations

We acknowledge that this thesis has certain weaknesses that influence its validity and reliability. First, some of the research articles are not recently published and may include information that does not provide an accurate representation of the current circumstances. For instance, we have chosen to include papers such as Faber et al. (2010a), since several of the other articles cited in this thesis rely on findings from this paper. Nevertheless, as we have been mindful of this, the implication of using these papers should not have a significant impact on our conclusion.

Second, several of the studies included in this thesis have a limited scope, which may impact their ability to be generalized across the population. For instance, some studies only consider one type of vessels, such as Jia et al. (2017), which analyzes the effect of Virtual Arrival for VLCC tankers. Since vessels differ in terms of design and on the operational level, we could expect other results for other types of vessels. Similarly, Adland et al. (2017b) examine the speed dynamics of vessels crossing in and out of the North Sea ECA, whereas the result could be different in the North America ECA where stricter enforcement is in place. However, we argue that their conclusions and implications for the energy efficiency gaps still are able to be generalized beyond their limited scope.

Third, some of the studies we have looked at are not scientific papers, but reports made by consulting firms and organizations. This may entail some biases in these sources, and result in weaker reliability for the paper, because they do not follow the strict research ethics considerations.

Fourth, some of the topics addressed in this thesis, such as bunker levy and speed reduction, are widely discussed by the research community. However, it has been challenging to find relevant literature on other topics, such as the EEXI and weather routing. Consequently, this may affect the topics external validity.

Fifth, there are numerous different regulations currently being discussed both within the IMO, EU, and private organizations. This thesis only examines four regulations, and we can not be certain that the same result would have been provided if we investigated other or several regulations. However, we believe that the regulations we chose provide a robust representation and reflection of the current political situation.

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