Ocean Engineering 110 (2015) 102–112

Contents lists available at ScienceDirect

Ocean Engineering

journal homepage: www.elsevier.com/locate/oceaneng

Barriers to energy efficient and low carbon shipping

Nishatabbas Rehmatulla *, Tristan Smith

UCL Energy Institute, Central House, 14 Upper Woburn Place, London WC1H 0NN, UK

ARTICLE INFO

Article history:
Received 18 January 2015
Accepted 15 September 2015
Available online 9 October 2015

Keywords:
Barriers
Energy efficiency
Modelling
Survey

ABSTRACT

Energy costs represent around 60–70% of operating costs of a ship and with the fuel price soaring to record levels, energy efficiency has become the top priority for many shipping companies. Numerous cost-effective energy efficient options (technologies for new and existing ships and operations) have been identified for improving the energy efficiency of ships. Analysis from industry leading experts and recognised bodies has so far shown substantial unrealised abatement potential using options that often appear to be cost-negative at current fuel prices. Apart from the shortcomings of the analysis, failure to realise this potential could be attributable to various market barriers and failures. This paper discusses non-market failures and market failures in context of shipping and draws on findings of a survey of shipping companies to assess their pervasiveness. The results are compared with analysis undertaken with the global shipping system model (GloTraM). Initial results from these methods suggest the existence of some non-market failures and market failures that have also been discussed in other sectors and industries.

© 2015 The Authors. Published by Elsevier Ltd. This is an open access article under the CC BY license (http://creativecommons.org/licenses/by/4.0/).

1. Introduction

It is suggested that reducing global greenhouse gas (GHG) emissions by fifty to eighty percent below 1990 levels by 2050 is necessary to stabilise the climate and avoid dangerous climate change impacts (IPCC, 2007). To avoid dangerous climate change, all the sectors of the global economy will be required to lower their GHG emissions. The global transport sector emissions represent around thirteen percent of global CO_2 emissions, of which total shipping CO_2 emissions (from international and domestic shipping) accounted for just under three percent (1 Gt) of global CO_2 emissions in 2012 (Smith et al., 2014).'Low carbon shipping' describes a transition from the shipping industry's current levels of emissions and emissions intensity, to lower levels. There is still only limited understanding of exactly what the extent of the transition would need to be and how it could be achieved, but to mitigate risks of dangerous climate change and to align with decarbonisation in other sectors of the economy, a reduction in absolute emissions relative to today's by 30–80% is not inconceivable as a longer term aim (Anderson and Bows, 2011). In light of that level of ambition, this paper aims to consider what barriers might prevent the implementation of such levels of decarbonisation in the shipping industry.

The carbon emissions of transport can be expressed as the product of transport demand (using capacity tonne miles t.nm i.e. tonne nautical miles) and transport supply represented by emissions intensity (gCO_2/t nm i.e. grams of CO_2 emitted per tonne nautical mile). On the transport supply side there are four options available to reduce emissions from shipping (Buhaug et al., 2009) namely, improving energy efficiency i.e. increasing productivity using same amount of energy, using renewable energy sources e.g. solar and wind, using fuels with lower carbon content e.g. liquid natural gas and biofuels and using emission reduction technologies e.g. through chemical conversion, capture and storage. For the purposes of this paper, we will assume that transport demand is out of scope as a 'lever' to reduce emissions. The paper therefore focuses on the transport supply side and improving energy efficiency as a strategy towards low carbon shipping.

1.1. Assessing the decarbonisation potential of a ship

A key component of the shipping system is the individual ships. A number of options exist for either increasing energy efficiency or the abatement of CO_2 from ships. These can be either operational measures, such as speed reduction and weather routing, or technical measures, such as waste heat recovery and air lubrication (Wang et al., 2010), which can be applied to new build ships and in some cases also for retrofit to existing ships. A common method of presenting analysis of the order in which these options might be adopted and the likelihood of investment, particularly for policy work, is the Marginal Abatement Cost Curve (MACC). A MACC is a graph that indicates the marginal cost of emission abatement for varying amounts of emission

* Corresponding author. Tel. +44 020 3108 5965.
E-mail address: n.rehmatulla@ucl.ac.uk (N. Rehmatulla).

http://dx.doi.org/10.1016/j.oceaneng.2015.09.030
0029-8018/© 2015 The Authors. Published by Elsevier Ltd. This is an open access article under the CC BY license (http://creativecommons.org/licenses/by/4.0/).

reduction (Kesicki, 2010). Examples of these for shipping can be found in Faber et al. (2009), Buhaug et al. (2009), Wang et al. (2010), DNV (2009). Besides the inherent shortcomings in MACC analysis (Kesicki, 2010), for shipping it is commonly undertaken with an incomplete representation of costs and little representation of risk (beyond the investment rate of return). The result from the above referenced analyses has so far been the identification of substantial, up to 30% unrealised abatement potential using options that often appear to be cost-negative at current fuel prices.

1.2. Defining barriers and the energy efficiency gap

From the MACCs referenced earlier, it can be observed that there are some options that have a negative cost when implemented. This means they are profitable options since they show a positive net present value, which would mean that the option will save money through reduced fuel expenditure over the investment horizon assumed in the modelling. This could be because the majority of these measures are operational measures, which require less capital outlay compared to technical measures generally featured on the right hand side of the curve. Furthermore, since these options are operational measures, they could in theory also be implemented by charterers with long term time charters. The MACCs however do not show current implementation rates of these options, hence there is a need to gauge the actual implementation rates of these within the industry and sectors. Thereafter, there is a need to understand why some of these measures were implemented and why some had been not taken up, despite their apparent negative cost i.e. identifying the energy efficiency gap (Fig. 1). To assess the actual implementation a survey of shipping companies was conducted and compared with modelled implementation, details of which will be discussed in Section 3.

The term 'energy efficiency gap' refers to the difference between the actual lower levels of implementation of energy efficiency measures and the higher level that would appear to be cost-beneficial or effective from the consumers or firms point of view based on techno-economic analysis (Brown, 2001; Golove and Eto, 1996). Some of the energy efficiency gap can be explained by rational behaviour to market barriers that may not be captured by the techno-economic analysis. If these can be accurately modelled, then the remaining energy efficiency gap can be explained by market failures, as shown in Fig. 1, see also Blumstein et al. (1980), Jaffe and Stavins (1994), Sanstad and Howarth (1994).

A barrier may be defined as a postulated mechanism that inhibits investment in technologies that are both energy efficient and economically efficient (Sorrell et al., 2004). It has been argued that the energy efficiency gap exists due to barriers to energy efficiency (Sorrell et al., 2000; Thollander et al., 2010). These barriers have been broadly categorised as economic, behavioural and organisational (Sorrell et al., 2004) and in practice this taxonomy is not exclusive, each barrier will have economic, behavioural and organisational aspects (Weber, 1997). The focus of this paper is mainly on economic barriers to energy efficiency. Economic barriers to energy efficiency stem from neo-classical economics, which assume individuals and organisations as rational and utility or profit maximising. Thus, economic barriers to energy efficiency can be categorised as market failures and non-market failures. Market failures are flaws in the way the market operates in the context of energy efficiency e.g. lack of information, whereas non-market failures are rational responses of actors to an investment in the context of energy efficiency e.g. capital constraints.

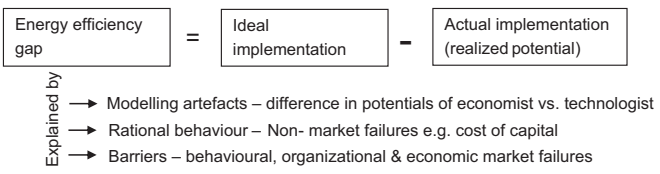

Fig. 1. Explaining the energy efficiency gap.

2. Categorizing barriers to energy efficiency in shipping

As highlighted earlier there exist many opportunities to improve the energy efficiency of new and existing ships through technical and operational measures, some of which at negative costs at current fuel prices. Possible explanations for why these options are not taken up or implemented are that models for analysis are inadequate for representing costs and benefits of low carbon and energy efficiency investment. The data used may be incorrect or other implementation barriers or failures exist which are obstructing the implementation of the measures, such as informational problems, split incentives, access to and cost of capital. This section briefly examines these in the context of shipping, beginning with analysis of each of the non-market failures followed by the market failures.

Non-market failures are obstacles that contribute to the slow diffusion and adoption of energy efficient measures (Brown, 2001) and where the organisation is behaving rationally given their existence (Sorrell et al., 2004). They include heterogeneity, risk, hidden costs and access to capital, which are discussed in turn below in relation to literature in shipping.

2.1. Heterogeneity

Although a technology may be cost-effective on average for a class of users taken in aggregate, the class (e.g. panamax container ships, specific routes and commodities), itself, consists of a distribution of owners and operators: some could economically purchase additional efficiency, while others will find the new level of efficiency not cost-effective (Sweeney, 1993). This will result in overstating the opportunities for a particular option in a particular sector. Wang et al. (2010) in their MACC analysis report that the cost effectiveness and CO_2 emission reduction potential for each option varies widely as a function of ship type, size and age, for example, the potential for emission reduction through speed reductions for containerships is much greater compared to tankers and bulkers, which are relatively slower moving vessels.

2.2. Risk

Technologies are assumed incorrectly to be mature in the techno-economic analysis or a risk is perceived by the firm that performance may be lower than expected, thus risk premiums and depreciation are not adequately included in the model. Early investors may be sceptical about the prospects of a technology and demand a premium on return in order to cover the risks of the investment (Faber et al., 2009). For example, when commissioning newbuilds if depreciation is faster than expected, due to the adoption of technology i.e. diffusion and lower costs due to the learning curve, the solvency of the company may be threatened. So in some cases a shipowner commissioning a new ship would have to compare the risk of having a ship with an innovative design that may depreciate faster than expected with the risk of having a ship with a conventional design but higher operational costs. In such an assessment, the most fuel efficient ship may not always come out best (Faber et al., 2009). According to Sorrell et al. (2000) risk has three dimensions in the context of energy efficiency:

- External risk – includes overall economic trends, fuel price, policy and regulation. This is highly representative of what is being faced by shipping companies, especially the latter two. Fuel costs are paramount in the industry and its expectation can

shape the investment in energy efficiency. It is important to note how the industry copes with its uncertainty. Rehmatulla (2014) shows that on average in the drybulk sector over 50% of the charter market is on time charter where fuel costs are paid for by the charterer, whereas Faber et al. (2009) and Wilson (2010) suggest that almost 70–90% of the fuel costs are passed on. There is also uncertainty in future regulations in shipping which may not be factored in during design but could potentially be implemented in the ships.

- Business risk – includes financing risk and sectoral trends. A major focus for the shipowner is the financing costs of a ship and its repayment (Stopford, 2009). For some shipping markets there are risks that are intertemporal choices, such as development of regional emission control area (ECA's) and use of liquid natural gas (LNG).
- Technical risk – includes technical performance and unreliability of the measure and applies to both newbuild and retrofit technologies for ships.

All of the above dimensions of risks faced by a business can therefore lead to stringent investment criteria, such as high levels of internal rate of return and short payback periods. Anecdotally it has been observed that the payback periods in shipping tend to be very short e.g. 12–18 months (HSH Nordbank, 2014, Lloyds List, 2011) despite the average age of a ship being around twenty five years.

2.3. Hidden costs

Hidden costs are hidden to the analyst (performing the techno-economic modelling) but not the investing firm, resulting in overestimation of the efficiency potential and for shipping perhaps the most cited argument for the efficiency gap (Koomey and Sanstad, 1994; Sorrell et al., 2000). The following costs may not have been included:

Life cycle costs – these are hidden costs relating to the energy efficient option's life cycle cost, which include

- Identification or search costs – these relate to the direct costs incurred as a result of searching for the relevant energy efficiency measure, e.g. through purchased literature, membership access.
- Project appraisal costs – relate to the costs incurred to evaluate a selected measure or technology to the firm's specifics e.g. outsourcing to firms that specialise in data analysis to match the energy efficiency measure with operational profiles of the firm's fleet.
- Commissioning costs – relates to the costs incurred when a measure is selected, meeting with the technology vendor, contracts.
- Additional/specific engineering costs – relates to the costs when the measure is reaching the end of its life, these include increased maintenance costs, decommissioning or removal of the energy efficiency measure.

Transactional costs – transaction costs and other unobserved cost items may render apparently cost-effective measures costly. Smaller ship owners and operators may experience high transaction costs as they cannot spread the costs of for example gathering information over a large number of ships (Faber et al., 2009; Jafarzadeh and Utne, 2014).

Commissioning or disruption costs – some measures to reduce emissions require retrofits that can only be installed by temporarily suspending operations. These measures are costly to implement except at times when operations are halted for other reasons, such as major survey or periodical drydocking. There may therefore be a lag between the time when a measure becomes available and its actual implementation (Faber et al., 2011). Retrofits to existing ships such as the installation of wind power and waste heat recovery systems can only be done cost-effectively when a ship undergoes a major overhaul during a drydock, which causes a time-lag of several years in the implementation of cost-effective measures.

Loss of benefits – reduction in benefits associated with energy efficient option (Nichols, 1994). such as problems with safety, extra maintenance, reliability and service quality. Example of this in shipping are speed reduction and safety, exhaust gas scrubber's reliability and extra maintenance (Acciaro et al., 2013).

2.4. Access and costs of capital

Restricted access to capital markets is often considered to be an important barrier to investing in energy efficiency. Investments may not be profitable because companies also face a high price for capital. As a result, only investments yielding an expected return that exceeds this (high) hurdle rate will be realised (Schleich and Grubber, 2008). Capital rationing is often used within firms as an allocation means for investments (Bhattacharyya, 2011), leading to hurdle rates that are much higher than the cost of capital, especially for small projects (Ross, 1986). This leads to competition between projects within a company and may lead to low priority given to energy efficiency (Bhattacharyya, 2011). If improving energy efficiency comes at the cost of forgoing other more cost-effective opportunities (because of capital or labour constraints or because the projects are mutually exclusive alternatives), it would be rational for the firm to give energy efficiency a low priority (Faber et al., 2009). As an example, a shipowner-operator currently has to decide between investing in a scrubber technology given the regulations around SO_x emissions or improve the energy efficiency of ships given the increasing fuel price.

If the above rational responses can be incorporated and accurately represented in models and still show existence of apparent cost-effective options that were not being employed, it could then be concluded that additional implementation barriers existed. One could then say that there is a gap between the potential reduction achievable and current state, which could be explained by market failures. A market failure occurs when the requirements for efficient or optimal allocation of resources through well-functioning markets are violated, which leads to incomplete markets, imperfect competition, imperfect and asymmetric information. The latter two are more important and relevant in the context of explaining the energy efficiency gap (Sorrell et al., 2000).

2.5. Information problems

Informational problems taking different forms are the principal source of market failures that account for the energy efficiency gap (Huntington et al., 1994). According to Golove and Eto (1996) this falls into three categories; lack of information, cost of obtaining information and accuracy of information, which are relevant to the barriers faced by shipping companies. Generally the MACC modelling in shipping utilises manufacturer data on costs and savings that may be biased or optimistic, for example Wang et al. (2010) use data derived from an engine manufacturer's brochure. Faber et al. (2011) showed that respondents cited lack of trusted data on measures from an independent third party as an important barrier to implementation. Several initiatives have begun to bring more information, create transparency and decrease the information asymmetry between charterers and shipowners, suppliers and buyers. Accurate and reliable information of energy efficiency measures may be difficult to obtain as those who have information have strategic reasons to manipulate it in order to inflate its value. Sellers advertise and

promote their goods by providing information about their own goods. "Self-interest is an incentive for the provision of misinformation by sellers and the costs of acquiring additional information may be high enough to inhibit acquisition of sufficient unbiased information to overcome well-distributed misinformation" (Golove and Eto, 1996, p. 20). It has been argued that even when information on energy efficiency is signalled through for example labelling, consumers may still be wary because of past experience with advertised misinformation (Stern and Aronson, 1984). The Energy Efficiency Design Index and other indicators of fuel efficiency thus may not increase the transparency in the market and owners of efficient ships may not be able to command higher charter rates (Faber et al., 2009). Staying on the subject of energy efficiency of ships, it should be noted that the ships themselves also lack necessary equipment onboard to provide accurate fuel consumption to both the shipowner and charterer (Jafarzadeh and Utne, 2014). Informational problems do not necessarily arise due to agent opportunism, it may well be that one party may have relevant information on the costs and benefits of an energy efficiency investment, but may find this difficult to convey to the other party (Jaffe and Stavins, 1994, p. 805). In this case if there were no informational problems, the parties would be able to enter into contracts to share the costs and benefits of the investment. However, sometimes this may be outweighed by the transaction costs involved hence investment is likely to be forgone despite potential advantages to both parties (Sorrell et al., 2004). A solution to this would be to standardise energy savings contracts.

2.6. Split incentives

Split incentives refer to the potential difficulties that arise when two parties engaged in a contract have different goals and different levels of information (IEA, 2007). Split incentives occur when the costs and benefits of energy efficiency accrue to different agents (Blumstein et al., 1980; Fisher and Rothkopf, 1989; Howarth and Winslow, 1994). In shipping, split incentives are likely to occur due to the different types of charter (and the divided responsibility for fuel costs) existing between shipowners and charterers. Ship owners who invest in fuel efficiency improving measures cannot, in general, recoup their investment, unless they operate their own ships or have long term agreements with charterers, because neither charter rates nor second hand prices of ships reflect the economic benefit of its fuel efficiency (Faber et al., 2009). Agnolucci et al. (2014) investigate whether energy efficiency is reflected in time charter rates for the drybulk panamax ships (2008–2012) and find that on average only 40% of the fuel savings are recouped by the shipowner-operators through higher time charter rates. The time charter markets not representing fuel efficiency could be due to the variability of actual fuel use and it may be risky for the shipowner to guarantee a low fuel use. In specific market conditions, in the time charter contracts speed may be understated and fuel consumption per day may be overstated (Veenstra and Dalen, 2011). Hence, the fuel efficiency may not be well reflected in the time charter market (Wang et al., 2010) and as a result owners not obtaining premiums for energy efficiency. For a more detailed discussion of split incentives in shipping refer to Rehmatulla (2014) and Rehmatulla and Smith (2015).

Apart from the economic market failures and non-market failures, Sorrell et al. (2000) suggest other barrier categories such as behavioural and organisational, which could also be plausible explanations of the unrealised potential in shipping. Behavioural barriers stem from the behavioural science field and explain the energy efficiency gap, as discussed below.

2.7. Bounded rationality

Orthodox economics assumes that the decision maker will make rational decisions given the available information. Simon (1959) argues that bounded rationality may result in satisfying behaviour using rules of thumb. So, instead of being based on perfect information, decisions are made by rule of thumb (Stern and Aronson, 1984). This is connected to the inability to assess life cycle costs of energy purchasing decisions, the same investment appraisals may be utilised throughout all the different types of investment opportunities including energy efficiency and may also be due to information overlaod (Jafarzadeh and Utne, 2014).

2.8. Inertia

Means that "individuals and organisations are, in part, creatures of habit and established routines, which may make it difficult to create changes to such behaviours and habits" (Thollander et al., 2010, p. 55). People generally do not welcome change in their environments and avoid or ignore problems (Stern and Aronson, 1984). An example of this in shipping is that ship yards may be reluctant to accept ship designs other than the standard ones (Faber et al., 2011; Jafarzadeh and Utne, 2014).

2.9. Values

Implementation of energy efficiency measures is influenced by norms and values in a group or society at large. "Values such as helping others, concern for the environment and a moral commitment to use energy more efficiently are influencing individuals and groups of individuals to adopt energy efficiency measures" (Thollander et al., 2010, p. 55).

2.10. Credibility and trust

This is not only related to the information itself but also the provider of information. As with informational problems, it is also the ability of the provider of information to portray and show these qualities, since the adoption is dependant on the receiver's perceived credibility of and trust in the information provider. The trustworthiness of the information provider is of significant importance. Thollander et al. (2010) cite an example of householders' implementation of measures when information is provided by state versus the same information being supplied by a utility company. The shipping industry is also subject to this issue of trustworthiness of information regarding savings potentials of energy efficiency measures as discussed above.

2.11. Problem statement

Market barriers and failures, particularly the concept of an efficiency gap, appear to be a common feature of a number of markets which could be considered to be similar to shipping. There are indications that the specific structure of the shipping markets could be susceptible to market barriers, but to date there has been little work to quantify the consequence of any failures and to test rigorously for their existence.

Therefore, to develop the knowledge of shipping's low carbon implementation barriers beyond the existing literature, this paper will first examine how different investment parameters might affect the uptake of energy efficiency technology, and then use the results of a survey of shipping stakeholders to investigate the levels of uptake of low carbon initiatives. The results will also be used to discuss differences in uptake between sectors of the shipping markets and to hypothesise about what this might tell us

about the incidence of some of the classical market barriers and failures.

3. Method

3.1. Modelling barriers and implementation

Several different types of bottom–up models, such as optimisation and simulation models have been used to estimate energy demand and emissions for various sector level emissions (e.g. MARKAL, PRIMES). Modelling realistic take up of technology through various assumptions is an important feature of these models. Worrell et al. (2004) identify that most bottom–up models rely on three factors that affect technology adoption; availability, financial costs and operational decision making. Fleiteret al. (2011) find that generally very simplistic assumptions through an aggregated approach are used e.g. adjusted higher discount rates to simulate stronger barriers. Very few models such as PRIMES explicitly integrate barriers into the model, but even these fall short of the large range of barriers identified empirically in the literature (Fleiter et al., 2011) as shown in Table 1.

Source: Adapted from Fleiter et al. (2011)

The model used to analyse the extent to which different market barriers and failures might obstruct energy efficiency in the shipping global fleet is GloTraM, a bottom–up model for estimating the CO_2 emissions trajectories of the shipping industry. The model applies time-domain simulation to calculate evolution over time of the global fleet. The two main drivers of the CO_2 emissions trajectories are:

- The transport demand (e.g. t nm) over time.
- The transport carbon intensity (e.g. gCO_2/t nm) over time.

A more complete description of the method can be found in Smith et al. (2013) and the derivation of the model's baseline input data can be found in Smith et al. (2013). Greater detail on technology modelling can be found in Calleya et al. (2012). The techno-economic evaluation includes a number of assumptions that represent the extent of some of the barriers discussed above. Therefore the model can be used to explore the consequence of some of the classical barriers to the technical specification of ships and the emissions from the sector. Those barriers include:

- Access to capital, as represented by the return on investment period and the WACC (weighted average cost of capital).
- Time window to recoup savings, or return period for investment.
- The principle-agent problem, represented by the proportion of cost-saving associated with fuel-saving, that is passed from the charterer to the owner.

3.2. Investment appraisal method

It is not possible to explain all the detail in this paper so only detail on the evaluation of the economic benefit of an intervention is described here. For the example analysed here, it is assumed that there are two stakeholders, one (A) who bears the capital and operating costs of the ship and another (B) who bears the voyage (fuel) costs. This could be considered to be typical of a time charter arrangement but may also be present in the stakeholder chain behind a voyage charter. If everything else remains constant, the consequence of an investment in energy efficiency technology is an increase in A's costs (higher capital and maintenance costs), and a decrease in B's costs (lower fuel costs). The extent to which this cost-saving is passed from B to A is a representation of the extent of a market barrier associated with this principle-agent problem and a key determinant of the investment strategy that A should apply in order to maximise their profits. The cost pass through is quantified in a factor in GloTraM that takes a value between 0 and 1. If the latter, the entire cost-saving is passed from B to A, if 0.5 then 50% of the saving is passed from B to A and 50% retained as B's profit and if 0, 100% is retained as B's profit.

3.3. Scenario specifications

For the purpose of investigating the sensitivity of low carbon shipping to a variety of market barriers, five runs of the model were performed for the period 2010–2025. The evolution of some of the key influences on shipping over the period out to 2025

Table 1
Overview of bottom–up models incorporating barriers.

Models	Not explicitly considered	Simple aggregated approach	Explicitly considered by type of barrier					
			Imperfect information	Hidden costs	Access to capital	Risk and uncertainty	Split incentives	Bounded rationality
Accounting:								
-Mure ii	X							
-MED-PRO	X							
-MEAD	X							
-LEAP	X	(X)						
Optimisation:								
-DNE21+	X							
-MARKAL		X						
-AIM		X						
-PRIMES		X				X		
Simulation								
-CEF-NEMS		X						
-ENUSIM		X						
-SAVE		X		X		X		
-POLES		X						
-ISindustry		X						
-LIEF		X						
-CIMS		X		X				
-GloTraM					X		X	X

cannot be known with certainty. Scenario models can help by exploring the impact of a range of foreseeable inputs to the models, which in turn can demonstrate the sensitivity of outputs to these assumptions.

The following scenario details were held constant for all runs:

- Energy Efficiency Design Index (EEDI) regulation – this regulation entered into force in 2013 and so is assumed as a certainty.
- Compliance with SO*x*, NO*x* regulations as per IMO MARPOL Annex VI regulations for global limits, no application of ECA regulation – similar to EEDI, this is regulation that has been adopted and therefore can be assumed to enter into force according to its prescribed timetable and stringency level.
- No market based measures (MBM) or carbon price are modelled – whilst MBM's were discussed at IMO MEPC during several meetings, the progression of an MBM development was put on hold in 2011 until further notice. The assumption made is that any development of a MBM at IMO will require substantial further work and is therefore unlikely to be entering into force during the time period considered in this work.
- International Energy Outlook (IEO) reference oil price is used to derive fuel prices – a number of oil price forecasts are available, of which IEO's work is one source. The purpose of this scenario exploration is not to understand the range of possible fuel prices (which would require a more thorough investigation of different sources of price scenarios), but to set a reference price and consider variations to investment parameters, hence the selection of IEO's data.
- Long-run averages for time charter prices, held constant in time – charter prices are known to fluctuate, but for simplicity purposes and similar to the focus of this work on only a single fuel price scenario, the scenario exploration is all done with only a single scenario for charter prices and a long-run average ensures that a central price value is used.
- Main engine and fuel choice limited to conventional diesel engines, heavy fuel oil and marine diesel oil – there are alternative fuels becoming available, including LNG and Methanol. However, to create extensive uptake of these fuels, infrastructure for supply of the fuels is needed, along with a significant turnover of the world's fleet to the machinery types required. The timescale (out to 2025) is assumed not to be sufficient for a significant adoption of an alternative fuel and so a simplifying assumption to remove these alternative fuels from the scenarios is considered appropriate.

In all instances, the design speed was held constant and the operating speed of the ship was matched to the design speed. Whilst it is recognised that this may not be reflective of all of the flexibility owners have in choosing the design speed of a ship and that operators have in choosing voyage speeds, these were held constant to control the scenario experiment. The results are therefore a comparison of, ceteris paribus, levels of technology uptake as a function of some key investment parameters. The investment parameters that were varied and their specifications were as shown in Table 2.

Table 2
Values for the investment parameters used in scenarios A– E.

Scenario	Cost savings pass through from operator to owner/%	WACC for owner/%	Return on investment period for owner/years
A	100	10	3
B	100	10	20
C	100	2	20
D	50	10	3
E	25	10	3

There is no publicly available data listing the combination of these investment parameters that best represents different owners and operators in the shipping industry. The values chosen were chosen so that they spanned some of the likely values (for example the cost savings pass through cannot exceed 100% and is unlikely to be less than 25%, the WACC can be guided by long-run interest rates, and the return on investment is unlikely to be more than the expected minimum economic life of a ship (20 years). Perhaps scenario D could be suggested to be closest to reality for operators of ocean going merchant shipping, but all the parameters are likely to vary significantly between firms and the specifics of the contract(s) under which the ship is being operated. Therefore, these should not be considered as definitive of the range of parameters used in the sector, but illustrators of sensitivity.

3.4. Survey

A survey was used to assess the uptake of a number of cost-effective and energy efficient operational measures within the shipping industry. The operational measures were selected from Buhaug et al. (2009), Wang et al. (2010) and Lockley et al. (2011) and are described in greater detail in Rehmatulla (2014). For the flow chart of the survey questions, question formats and survey tools see Fig. 2 and for more details on the wording of the survey questions refer to appendix A in Rehmatulla (2014). The unit of analysis or target population were global shipping companies, which were recruited from Clarksons Shipping Information Network (SIN) database of shipowners. It is thought that this is the most comprehensive list of the target population. However, upon comparison with other online databases such as World Shipping Directory slight under coverage of companies was noted. Every effort was made to merge the frames to cover accurately the target population.

Companies with more than five ships were selected, which consisted of shipowners, shipowner-operators, ship management company and shipping division of major charterers or cargo owners in the wetbulk, drybulk and container sectors only. A cut off of five ships was required due to several reasons. There was a significantly large tail of small companies with less than five ships in their fleet and a large majority of these were single ship companies, which are created to protect the beneficial owner (Stopford, 2009). Cut off samples are common in business surveys because smaller companies are generally difficult to reach (Eurostat, 2008). However, since one part of the target population is deliberately excluded there is a chance to obtain bias in the responses, for example one could be excluding small shipowner-operators offering more energy efficient services. Another reason for the cut off in the sample was because the construction of the sampling frame required merging the databases, filtering companies and entering the required fields, which was a resource intensive task and therefore the cut off was an acceptable trade-off between time and resources expended versus creating a more reflective sampling frame containing over 5000 very small companies. It should also be noted that the sampling frame constructed here is more representative of the respondents compared to most of the empirical studies on barriers to energy efficiency, which used non-representative sampling frames, generally membership frames e.g. Gordon (2008) and Hasanbeigi et al. (2009) resulting in higher non-coverage errors and bias to a select group.

A stratified sampling approach was taken so as to represent the different variables of interest to the survey. The majority of the companies are headquartered in European Union region and the Far East, altogether representing nearly 90% of the census population as shown in Table 3. A company with 90% of its fleet belonging to a sector would be placed in the respective sector

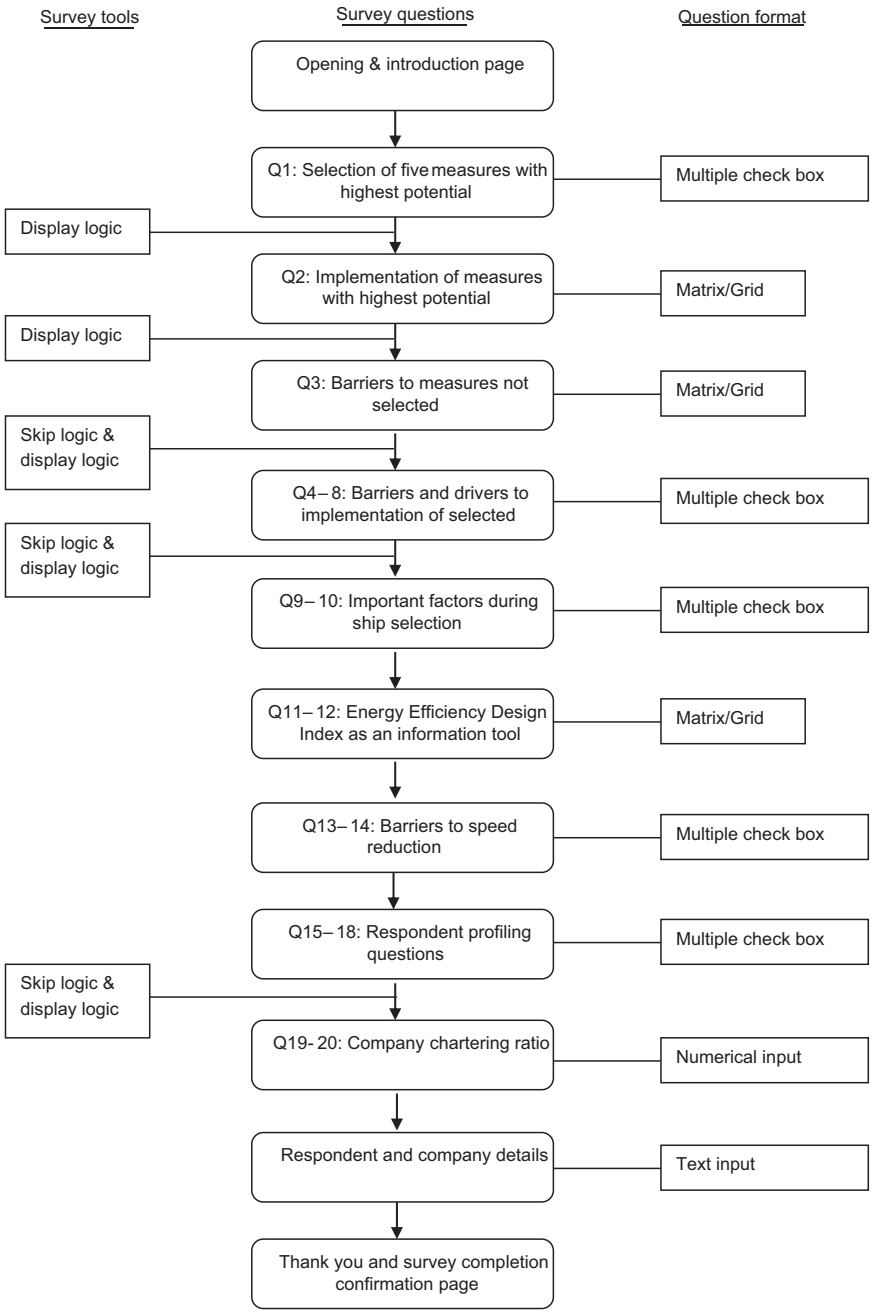

Fig. 2. Flow chart of survey questions, software tools and question formats used.

category and when the fleet composition falls below 90% for one sector, the company is placed under the mixed sector category. The total number of companies that responded was 170, which consisted of 120 almost complete (90% item response) responses and 50 partially completed responses. In order to be representative and to make generalisations i.e. reach statistically overall significant results with a confidence level of 90% and margin of error interval of $+/-15\%$ or $+/-20\%$, each stratum required a minimum number of responses, presented in Rehmatulla (2012).

Table 3
Population divided according to major geographic regions, sector and size.

		EU	West	Asia SC	Far East	Total
Wetbulk	**Large**	9	6	2	10	27 (5%)
	Medium	88	6	14	33	141 (24%)
Drybulk	**Large**	4	3	1	10	18 (3%)
	Medium	75	11	6	49	141 (24%)
Container	**Large**	13	0	0	11	24 (4%)
	Medium	37	4	2	14	57 (10%)
Mixed	**Large**	23	1	4	21	49 (8%)
	Medium	80	1	8	54	143 (24%)
		329 (55%)	32 (5%)	37 (6%)	202 (34%)	600 (100%)

4. Results & discussion

The results from the scenarios specified in Table 2 can be seen inFig. 3. Only two examples are presented, corresponding to a large tanker (VLCC) and a large containership. The results presented show the model estimated forecast of the attained EEDI by newbuild designs from 2010 to 2025. The trends are approximately similar for all ship sizes, but because of variations in revenue, capital costs, operating costs

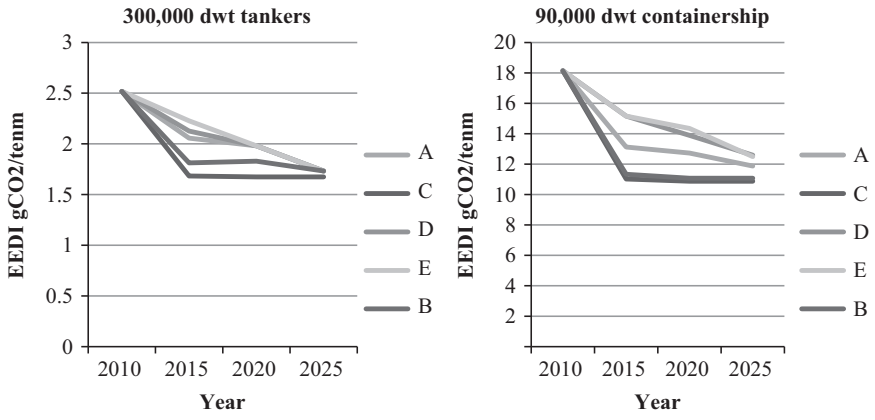

Fig. 3. Results from scenario runs for newbuild EEDI in each year.

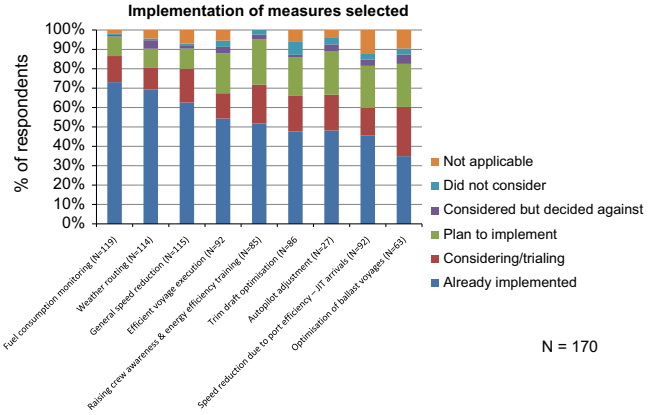

Fig. 4. Implementation of operational measures believed to have highest potential.

and performance and cost data between ships of different size and type, the results are not exactly the same. In all cases, the upper limit of the EEDI trajectories is represented by the EEDI regulation's required EEDI value in each of the years (it progresses from 10% baseline reduction in 2015 to 30% baseline reduction in 2025). The constraints on design speed and machinery specification mean that the only source of energy efficiency improvement is technology. The range of technology options available are not all compatible with each other and the maximum feasible improvement of EEDI is 40%. This sets a lower bound on the curves, which is reached in both instances in 2015 for the most favourable investment parameter scenario

Scenario D (estimated to be Business As Usual, BAU) is shown to follow the required EEDI values closely for both the ship types studied. There is little discrepancy between E and D – perhaps more would be seen if the constraint on achieving a maximum EEDI were relaxed. Scenario A shows a significant departure to D and E for the case of the container ship, but the greatest discrepancy is shown when the return on investment period is significantly extended. There is little discrepancy between scenarios B and C which differentiate from each other solely on cost of capital. That discrepancy is more marked in the instance of tankers, which is consistent with the general trend in the results that imply that in A, B and C, a greater amount of decarbonisation is achievable for the containership than the tanker given the same set of investment parameters.

The results from the survey showed that fuel consumption monitoring, general speed reduction and weather routing were cited as measures that have the highest potential. The follow up question asked whether they have considered or implemented the measure they believed had the highest potential. Fig. 4 shows that even measures that were cited as having the highest potential have actual implementation rate of around 70%.[1] On average across all the measures the implementation rate decreases to around 50%. This clearly shows that despite the negative costs, ease of implementation (Acciaro et al., 2013) and short payback period of most operational measures (Wang et al., 2010), some measures still do not see 90–100% implementation. Many MACC studies assume that measures with negative costs would have been fully implemented or will be implemented under a certain fuel price. A discussion of the non-market failures and market failures that could be contributing to this gap between the potential and actual is discussed below.

4.1. Non-market failures

Some of the gap in the implementation could be explained by rational behaviour of the firms. We apply the concept of heterogeneity (a particular technology may be cost-effective on average, but not in all cases) and see how size of the firm and the sector it operates in affects the implementation of measures. Figs. 5 and 6 show that there is a difference between the overall implementation rates for each of the sizes and sectors. For some measures there is a positive relationship between the size of the firm and the implementation and for some measures a negative correlation can be observed. The relationship between sector and implementation of a measure does not show clear relationship in almost all cases.

Since the survey uses nominal level data, chi square based coefficients are used, which assess how the actual frequencies in the crosstabulation differ from the expected frequency i.e. when there is no association[2] (Field, 2005). The raw chi square figure is converted into a correlation index using the Cramer's *V*. The Cramer's *V* statistic is used because one or both of the variables have more than two categories (Field, 2005) e.g. size has three categories, small, medium and large and implementation has two categories, implemented and not implemented. To interpret the Cramer's *V*, Cohen's (1988) widely accepted interpretation of effect sizes is used; 0.1 is a small effect size, 0.3 is medium or moderate effect size and 0.5 is a large effect size. To make inferences from the sample to the larger population and as a rule of thumb for small samples it is suggested to use 0.05 as the critical point (de Vaus, 1995). Table 4 shows the zero order (without controlling for other variables) bivariate relationships or crosstabulations between each measure's implementation and its association with sector and

[1] – Efficient voyage execution includes voyage planning and DWT utilisation.
– Speed reduction due to port efficiency includes Just In Time arrivals.
– Optimisation of ballast voyages includes ballast speed reduction.

[2] Crosstabulations analysis only reveal the strength of the relationship between the independent and dependant variables, direction and linearity of relationships are not possible for nominal level data.

size. In contrast to Figs. 5 and 6 the results show the sector in which a firm operates has more of a relationship with the implementation of the measures compared to the size of the firm. In general, however a weak to moderate relationship between the two variables is observed which cannot be generalised to the larger population. Similarly, multivariate regression analysis shows that neither of the variables (sector and size) are good at explaining the implementation of the measures.

Hidden costs, access to capital and risk perception are cogent reasons for why some shipping companies do not implement measures and these can be easily misrepresented in techno-economic modelling approaches, resulting in overestimation of savings potential. The respondents were asked why they believed the measures they had not selected initially had lower potential for fuel savings. Lack of access to capital and additional costs related to the measures fared very low in the responses to this question (Rehmatulla, 2012), although, lack of access to capital and additional costs had perfectly negative correlation with size of the company.

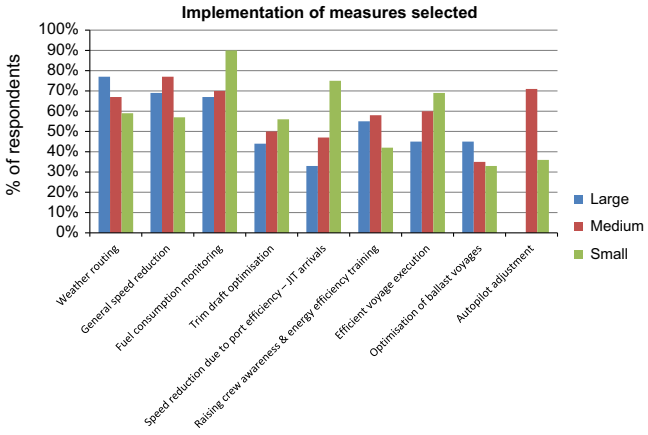

Fig. 5. Implementation of measures by company size.

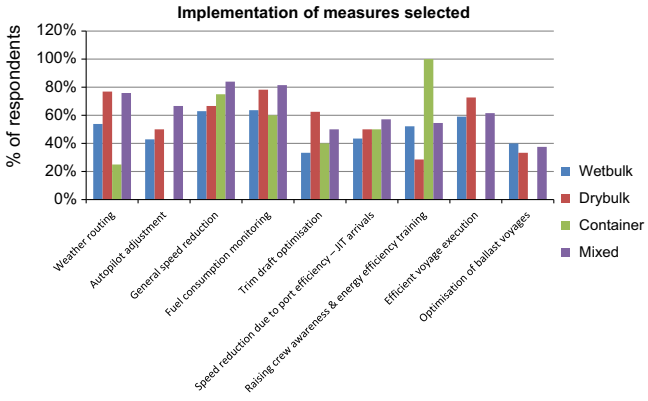

Fig. 6. Implementation of measures by sector.

4.2. Market failures

In general the most pertinent barrier across all measures that were not selected i.e. seemed to have lower fuel-saving potential, were; 'lack of reliable information on cost and savings', 'difficultly in implementing under some types of charter', 'lack of direct control over operations' and 'materiality of savings', i.e. measures may be ignored by decision-makers due to their limited impact (Kollamthodi et al., 2008). These barriers represented on average 50% of barriers cited for any given measure. Analysing this in greater detail, it can be seen that there were specific barriers for each of the measures. Lack of reliable information on cost and savings affects the potential for weather routing, autopilot adjustment, trim/draft optimisation and raising crew awareness and training. Weather routing and autopilot adjustment are mature technologies (Wang et al., 2010) for which it would be expected that such information is readily and reliably available. For a breakdown of most cited barriers per measure refer to Rehmatulla and Smith (2015). There was not a clear relationship between informational problems cited and size of the firm. For the survey, indicators of split incentives were; the chartering ratio of the company and the perception of the barrier. To assess the chartering ratio respondents were asked about the percentage of the fleet that is owned, chartered in and out under the different types of charter. The perception of the split incentive barrier was gauged through three choice categories; 'savings cannot be fully recouped', 'difficult to implement under some types of charter' and 'lack of direct control over operations'. For the chartering ratio, the companies were divided into six groups to reflect company structure and chartering ratio e.g. group 1 is a company that owns majority ($>50\%$) of the fleet and charters out majority ($>50\%$) of the fleet in spot market. Controlling for the sector, results in much larger effect size but at the same time significance values increase, because of the smaller sample after controlling. As an example the general speed reduction and chartering group correlation is 0.627 almost doubling after controlling for sector with p value of .215. Table 5 shows the zero order relationships between implementation of measures and chartering group is relatively higher compared to that of size and sector. This suggests that the split incentives and thus market failures could have a higher influence on the implementation of the energy efficiency measures, though this cannot be generalised beyond the survey sample.

Table 5
Results of correlation by group of different operational measures.

Measure	Chartering Group		Multivariate analysis	
	Cramer's *V*	Significance	R^2	Significance
Weather routing	.287	.394	.08	.42
General speed reduction	.363	.154	.13	.15
Fuel consumption monitoring	.284	.369	.08	.38
Raising crew awareness	.485	.086	.23	.08

Table 4
Results from the statistical testing of homogeneity in the survey respondents.

Measure	Sector		Size		Multivariate analysis	
	Cramers *V*	Significance	Cramers *V*	Significance	R^2	Significance
Weather routing	0.305	0.151	0.117	0.557	0.1	0.3
General speed reduction	0.283	0.24	0.178	0.266	0.11	0.25
Fuel consumption monitoring	0.213	0.536	0.189	0.208	0.08	0.45

5. Concluding remarks

This paper attempts to take a broad perspective on the subject of the implementation barriers that could impede shipping's transition to a lower carbon modus operandi. Given the extensive evidence for an efficiency gap that is presented for other sectors of the economy, it seems hard to imagine that a gap is not also present in the shipping industry. Indeed the results of the survey presented show implementation of around 70% for measures with high fuel saving potential and an average implementation rate across all the operational measures examined to be 50%, under the assumption that most of the operational measures could be considered by classical analysis to be termed “cost-effective”. This supports the hypothesis that an efficiency gap might exist for shipping too.

In order to address the question: if an efficiency gap exists and what might its significance be, a study was undertaken using GloTraM. This quantified the energy efficiency of newbuild ships over the period 2010 to 2025 under a range of assumptions for the investment parameters used as input parameters to the model. The study showed that under certain investment circumstances, a maximum impact on energy efficiency (in this instance a reduction of EEDI by approximately 40%) could be reached in 2015, whereas with several of the range of scenarios considered, the newbuild's energy efficiency would be ‘pegged’ to the level defined in the EEDI reduction trajectories.

Given the evidence for the existence of an efficiency gap, the next challenge is to estimate which market barriers or failures might be most likely to be responsible. Detailed analysis of the survey data can provide some insight to this. The fact that a greater implementation percentage is attributable to the measures perceived to have the highest fuel saving implies either that agents were behaving rationally or that there may be barriers that result in the lack of uptake, i.e. it appears to refute the hypothesis that there are modelling artefacts that exist that have not been taken into account. The statistical analysis found that non-market failures were not obvious explanations for the patterns of uptake of individual operational measures for the population studied. However, extrapolating this conclusion to the whole fleet could not be fully justified due to the size of the sample. On the other hand, market failures were found to be correlated to the implementation of individual measures, which supports the hypothesis that they are a plausible explanation for the efficiency gap.

Further work is clearly beneficial in a number of areas. GloTraM could be used to consider the retrofit as well as the newbuild sectors of the shipping industry. Results from such analysis could then be combined in order to explore the impacts of different levels of market barriers on the emissions of the sector and not just the specifications of the fleet. The survey that has been conducted to understand the implementation scale and behaviours around operational measures could be extended to include technical measures, smaller firms (with one to four ships in the fleet) and could also be increased in its sample size to improve statistical control values. Further work could also delve further into more granular details of the implementation of energy efficiency measures within a firm, for example investigating the drivers of implementation and how the implementation permeates through the entire fleet of the company. Some attempt has been made within the industry to assess the diffusion of operational and technical measures, however these have been brief and subjective. Further research could focus on a few key technologies’ ‘adoption’ at company level and ‘diffusion’ at the economy or industry level.

Acknowledgements

This paper is based on work undertaken for the project “Low Carbon Shipping – a Systems Approach” EP/H020012/1 and the authors would like to thank RCUK Energy, Rolls Royce, Shell, Lloyd's Register and BMT who have funded and supported the research, as well as the academic, industry, NGO and government members of the consortium that support the research with in-kind effort and data. The authors would also like to thank all the participants to the survey and the two anonymous referees whose comments have improved the quality of the paper.

References

Acciaro, M., Hoffmann, P., Eide, M., 2013. The energy efficiency gap in maritime transport. J. Shipp. Ocean Eng. 3 (12), 1–10.

Agnolucci, P., Smith, T., Rehmatulla, N., 2014. Energy efficiency and time charter rates: Some evidence quantifying the extent of split incentive problem in the panamax drybulk market. Transp. Res. Part A: Policy Pract. 66, 173–184.

Anderson, K., Bows, A., 2011. Beyond 'dangerous' climate change: emission scenarios for a new world. Philos. Trans. R. Soc. A 369, 20–44.

Bhattacharyya, S., 2011. Energy Economics. Springer, London.

Blumstein, C., Krieg, B., Schipper, L., York, C., 1980. Overcoming social and institutional barriers to energy conservation. Energy 5, 355–371.

Brown, M., 2001. Market failures and barriers as a basis for clean energy policies. Energy Policy 29, 1197–1207.

Buhaug, Ø., Eyring, V., Corbett, J., Faber, J., Hanayama, S., Lee, S., Lee, D., Linstad, H., Markowska, A., Mjelde, A., Nelissen, D., Nilsen, J., Palsson, C., Wanquing, W., Winebrake, J., Yoshida, K., 2009. Second imo GHG study-update of the 2000 IMO GHG study, viewed 06 November 2012. ⟨http://www.imo.org/blast/blastDataHelper.asp?data_id=27795&filename=GHGStudyFINAL.pdf⟩.

Calleya, J., Pawling, R., Smith, T., Greig, A., 2012. Ship design and evaluation for a GHG constrained future, in: Proceedings of the Environmentally Friendly Ship Conference, Royal Institution of Naval Architects, UK, London., 28–29 February 2012.

Cohen, J., 1988. Statistical Power Analysis for the Behavioural Sciences. Lawrence Erlbaum Associates, New Jersey.

de Vaus, D., 1995. Surveys in Social Research. Allen & Unwin, North Sydney.

DNV, 2009. Pathways to Low Carbon Shipping, Abatement Potential Towards 2030. Det Norske Veritas ⟨http://www.dnv.com/binaries/pathways%20to%20low%20carbon%20shipping%202030_tcm4-400655.pdf⟩.

Eurostat, 2008. Survey sampling reference guidel ines: introduction to sample design and estimation techniques, .viewed 25 July 2011 ⟨http://epp.eurostat.ec.europa.eu/portal/page/portal/product_details/publication?p_product_code=KS-RA-08-003⟩.

Faber, J., Behrends, B., Nelissen, D., 2011. Analysis of marginal abatement cost curves. viewed 05 December 2011 ⟨http://www.cedelft.eu/publicatie/analysis_of_ghg_marginal_abatement_cost_curves/1155?PHPSESSID=9ec0891a1418473f9020106cba2e3441⟩.

Faber, J., Markowska, A., Nelissen, D., Davidson, M., Eyring, V., Cionni, I., Selstad, E., Kågeson, P., Lee, D., Buhaug, Ø., Lindtsad, H., 2009. Technical support for European action to reducing greenhouse gas emissions from international maritime transport. CE Delft, viewed 19 January 2010. ⟨http://ec.europa.eu/clima/policies/transport/shipping/docs/ghg_ships_report_en.pdf⟩..

Field, A., 2005. Discovering Statistics Using SPSS, 2nd ed. Sage, London.

Fisher, A., Rothkopf, M., 1989. Market failure and energy policy. Energy Policy 17 (4), 397–406.

Fleiter, T., Worrell, E., Eichhammer, W., 2011. Barriers to energy efficiency in industrial bottom-up energy demand models: a review. Renew. Sustain. Energy Rev. 15, 3099–3111.

Golove, W., Eto, J., 1996. Market barriers to energy efficiency: a critical reappraisal of the rationale for public policies to promote energy efficiency. Lawrence Berkeley National Laboratory, University of California, Berkeley, viewed 12 October 2011.⟨http://emp.lbl.gov/sites/all/files/lbnl-38059.pdf⟩..

Gordon, S., 2008. Steering towards change: Overcoming barriers to energy efficiency in merchant ships (unpublished MSc dissertation). Environmental Change Institute, University of Oxford, UK, Oxford.

Hasanbeigi, A., Menke, C., du Pont, P., 2009. Barriers to energy efficiency improvement and decision-making behaviour in Thai industry. Energy Effic., vol online first

Howarth, R., Winslow, M., 1994. Energy use and CO_2 emission reduction: integrating pricing and regulatory policies. Energy 19 (8), 855–867.

Nordbank, H.S.H., 2014. Ship energy efficiency: a bank's perspective, viewed 15 October 2014, ⟨https://drive.google.com/folderview?id=0B4dXMTiEqjYUUHp2T1N2SDRtNVU&usp=sharing&tid=0B4dXMTiEqjYUSTRYNV9aLUNhT2M⟩.

Editors introduction. In: Huntington, H., Schipper, L., Sanstad, H. (Eds.), Energy Policy, 22; 1994, pp. 795–797.

IEA, 2007. Mind the Gap: Quantifying Principal-Agent Problems in Energy Efficiency, viewed 15th October 2011, ⟨http://www.iea.org/publications/freepublications/publication/mind_the_gap.pdf⟩.
IPCC, 2007. Climate change 2007: Synthesis Report, ⟨http://www.ipcc.ch/pdf/assessment-report/ar4/syr/ar4_syr.pdf⟩.
Jafarzadeh, S., Utne, I., 2014. A framework to bridge the energy efficiency gap in shipping. Energy, 1–10.
Jaffe, A., Stavins, R., 1994. The energy-efficiency gap What does it mean? Energy Policy 22 (10), 804–810.
Kesicki, F., 2010. Marginal Abatement Cost Curves For Policy Making – Expert-based vs. Model-derived Curves. UCL Energy Institute.
Kollamthodi, S., Braniggan, C., Harfoot, M., Skinner, I., Whall, C., Lavric, L., Noden, R., Lee, D., Buhaug, O., Martinussen, K., Skejic, R., Valberg, I., Brembo, J., Eyring, V., Faber, J., 2008. Greenhouse gas emissions from shipping: trends, projections and abatement potential. AEA Energy & Environ., viewed 09 March 2010. ⟨http://archive.theccc.org.uk/aws3/AEA%20shipping%20report%20for%20the%20CCC.pdf⟩
Koomey, J., Sanstad, A., 1994. Technical evidence for assessing the performance of markets affecting energy efficiency. Energy Policy 22 (10), 826–832.
Lloyds List, 2011. Owners urged to think long term on investment payback, viewed 07 June 2011, ⟨http://www.lloydslist.com/ll/sector/ship-operations/article372257.ece⟩.
Lockley, P., Jarabo-Martin, A., Sharma, K., Hill, J., 2011. Ship Efficiency: The Guide. Fathom..
Nichols, A., 1994. Demand-side management: overcoming market barriers or obscuring real costs? Energy Policy 22 (10), 840–847.
Rehmatulla, N., 2012. Barriers to Uptake of Energy Efficient Operational Measures: Survey Report. Energy Institute, UCL.
Rehmatulla, N., 2014. Market Failures and Barriers Affecting Energy Efficient Operations in Shipping (unpublished PhD thesis). UCL Energy Institute, University College London (UCL), London.
Rehmatulla, N., Smith, T., 2015. Barriers to energy efficiency in shipping: a triangulated approach to investigate the principal agent problem in shipping. Energy Policy 84, 44–57.
Ross, M., 1986. The capital budgeting practices of 12 large manufacturing firms. Financ. Mangement 15 (4), 15–22.
Sanstad, A., Howarth, R., 1994. Normal markets, market imperfections and energy efficiency. Energy Policy 22 (10), 811–818.
Schleich, J., Grubber, E., 2008. Beyond case studies: barriers to energy efficiency in commerce and the services sector. Energy Econ. 30 (2), 449–464.
Smith, T., Jalkanen, J., Anderson, B., Corbett, J., Faber, J., Hanayam, S., O'Keefe, E., Parker, S., Johansson, L., Aldous, L., Raucci, C., Traut, M., Ettinger, S., Nelissen, D., Lee, D., Ng, S., Agarwal, A., Winebrake, J., Hoen, M., Chesworth, S., et al. 2014. Third IMO GHG Study 2014; International Maritime Organisation (IMO), viewed 15 September 2014. ⟨http://www.lowcarbonshipping.co.uk/files/ucl_admin/MEPC_67-INF_3_-_Third_IMO_GHG_Study_2014_-_Final_Report_Secretariat.pdf⟩.
Smith, T., O'Keefe, E., Haji, S., 2013. GloTraM Method,. UCL Energy Institute, London.
Smith, T., O'Keefe, E., Haji, S., Agnolucci, P., 2013. GloTram External Factors. UCL Energy Institue, London.
Sorrell, S., O'Malley, E., Schleich, J., Scott, S., 2004. The Economics of Energy Efficiency: Barriers to Cost-effective Investment. Edward Elgar, UK.
Sorrell, S., Schleich, J., O'Mallye, E., Trace, F., Boede, U., Ostertag, K., Radgen, P., 2000. Barriers to energy efficiency in public and private organization, SPRU – Science and Technology Policy Research. University of Sussex, Brighton.
Stern, P., Aronson, E., 1984. Energy Use: The Human Dimension. W.H. Freeman and Company, New York.
Stopford, M., 2009. Maritime economics, 3rd ed. Routledge, London.
Sweeney, J.,1993. Comments on energy efficiency and human activity: lessons from the past, importance for the future, vol unpublished draft.
Thollander, P., Palm, J., Rohdin, P., 2010. Categorizing barriers to energy efficiency: an interdisciplinary perspective. Chapter in Energy Efficiency by Palm, J., Sciyo Publications.
Veenstra, A., Dalen, J., 2011. Ship speed and fuel consumption quotation in ocean shipping time charter contracts. J. Transp. Econ. Policy 45 (1), 41–61.
Wang, H., Faber, J., Nelissen, D., Russel, B., St Amand, D., 2010. Marginal abatement costs and cost-effectiveness of energy efficiency measures, Submitted to IMO MEPC, 61st Session, 23rd July 2010.
Weber, L., 1997. Some reflections on barriers to the efficient use of energy. Energy Policy 25 (10), 833–835.
Wilson, J., 2010. Carriage of Goods by Sea, 7th ed. Longman, London.
Worrell, E., Ramesohl, S., Boyd, G., 2004. Advances in energy forecasting models based on engineering economics. Annu. Rev. Environ. Technol. 29, 345–381.