THESIS FOR THE DEGREE OF LICENTIATE IN ENGINEERING

Towards Understanding Energy Efficiency in Shipping

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“Of course we run the risk of it being calm tonight,” said Moominpappa. “We could have left immediately after lunch. But on an occasion like this we must wait for sunset. Setting out in the right way is just as important as the opening lines in a book: they determine everything.” He sat in the sand next to Moominmamma. “Look at the boat,” he said.“Look at *The Adventure*. A boat by night is a wonderful sight. This is the way to start a new life, with a hurricane lamp shining at the top of the mast, and the coastline disappearing behind one as the whole world lies sleeping. Making a journey by night is more wonderful than anything in the world.” “Yes, you’re right,” replied Moominmamma. “One makes a trip by day, but by night one sets out on a journey.”

Tove Jansson

Abstract

There is a great interest in increasing energy efficiency in shipping amongst many stakeholders. Shipping companies are looking for ways to reduce costs, and policy-makers—internationally, regionally and nationally—are looking for ways to cut greenhouse gas (GHG) emissions. At first glance, this looks like a win-win situation. Assessments show a large cost-efficient, potential for improvement. However, these also show that even if all cost-effective measures were to be implemented, GHG emissions from shipping will still increase. The continued exponential growth of economies depends on international trade, which in turn will need to be facilitated by an exponentially growing shipping sector.

Moreover, it is puzzling that such a potential could exist at all. What is keeping the shipping industry from harnessing the potential? The same situation has been shown to exist in many sectors and is usually referred to as an energy efficiency gap. It has been attributed to failures and barriers in markets, institutions and organizations. This PhD project is an attempt to understand this gap between reality and what should be cost-effective, through studies of energy management practices in shipping companies. In Paper I, the shipping sector is placed in the context of previous research, based on semi-structured interviews with different stakeholders mainly in the Swedish shipping sector.

The main strategy of this research project was to create a collaborative project together with shipping companies on implementing an energy management systems in their respective organizations. What is it that shipping companies have to be good at in order to improve? A participatory role from academia—an action research approach—was chosen. This was both to gain project acceptance in the companies, and because other researchers have highlighted it when trying to understand change processes. The aim was to publish selected problems as case studies. The first case study, paper II, discusses aspects such as project management abilities, measurements, division of responsibilities, competence and communication in the context of effective energy management.

Policy instruments have already been created as an attempt to increase energy efficiency in shipping. One of these, the Ship Energy Efficiency Management Plan (SEEMP) is aiming at encouraging better practices on board ships. Based on similar instruments and previous research, Paper III discusses gaps in the SEEMP guideline.

This licentiate thesis itself is an attempt to put the results and arguments of the papers in a wider context. It can also be seen as a quest for increasing the author's own understanding of the problem. The role of increased transparency on energy performance is highlighted for improving firm performance, but also for enabling commercial gain in markets for more energy efficient ships and operational practices are highlighted. The role of an energy management organization in a shipping company is also discussed. Finally, the thesis can also be seen as an attempt to entice other researchers to perform further studies in this vast, and for future generations crucial, problem field.

Keywords: shipping, energy efficiency, climate change, energy management systems, action research, phronesis

Appended papers

This thesis is based on the following appended papers:

I **Johnson, H.**, Andersson, K. (2012). Barriers to energy efficiency in shipping. Submitted to *Maritime Policy & Management*.

II **Johnson, H.**, Johansson, M., Andersson, K. (2012). Improving energy efficiency in short sea shipping: a case study. Submitted to *Energy Policy*.

III **Johnson, H.**, Johansson, M., Andersson, K., Södahl, B., (2013). Will the ship energy efficiency management plan reduce CO_2 emissions? A comparison with ISO 50001 and the ISM code. *Maritime Policy & Management*. Vol. 40, No. 2, pp. 177-190.

Related publications (not included in this thesis):

Johnson, H., Andersson, K. (2011). The energy-effiency gap in shipping: barriers to improvement. Presented at the peer-reviewed *2011 International Association of Maritime Economists conference*, Santiago de Chile.

Johnson, H., Johansson, M., Andersson, K. (2012). Barriers to improving energy efficiency in short sea shipping. Presented at the peer-reviewed *2012 International Research Conference in Short Sea Shipping*, Estoril.

Johnson, H., Johansson, M., Andersson, K., Södahl, B., (2012). Will the IMO Ship Energy Efficiency Management plan (SEEMP) lead to reduced CO_2 emissions? A comparison with ISO 50001 and the ISM code. Presented at the peer-reviewed *2012 International Association of Maritime Economists conference*, Taipei.

Styhre, L., **Johnson, H.** (2012). Increased energy efficiency through increased port efficiency. SSPA technical report, EffShip WP7.

Johnson, H., Styhre, L. (2013). Increased energy efficiency through increased port efficiency. Submitted to *Transportation Research Part A - Policy and Practice*.

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Hannes Johnson
Gothenburg, February 2013

Contents

1 Introduction

Discovery commences with the
awareness of anomaly.

Thomas Kuhn

The importance of shipping in today's increasingly globalized world can probably not be understated. The sector is a main facilitator of intra-continental trade, and *the* facilitator of international trade: more than 80% of goods by volume are transported by ship (UNCTAD, 2012b). Due to increased economies of scale, better ports, more efficient cargo handling etc., cost of freight is no longer a major issue when deciding where to produce or market goods (Stopford, 2009). The volume of merchandise trade has grown 5% yearly for decades, which is 2% faster than the growth of the world economy (UN, 2013).

By lowering costs for international trade, shipping is of special importance to developing economies. Their share in world trade increased from 36 percent in 2007 to 42 per cent in 2012, and now make up for half of global import growth (UN, 2013). Developing countries are also expanding their role in the shipping business itself. For example, more than 70% of all ships built in 2010 were built in China and the Republic of Korea (UNCTAD, 2011). More than 70% of all ships are now flagged in a developing country (Kågeson, 2011).

An exponentially growing world economy has thus been going hand-in-hand with an exponentially growing shipping sector. As shipping runs on fossil fuels, this has meant a corresponding exponential increase in CO_2 emissions, as illustrated in Figure 1.1 (IEA,

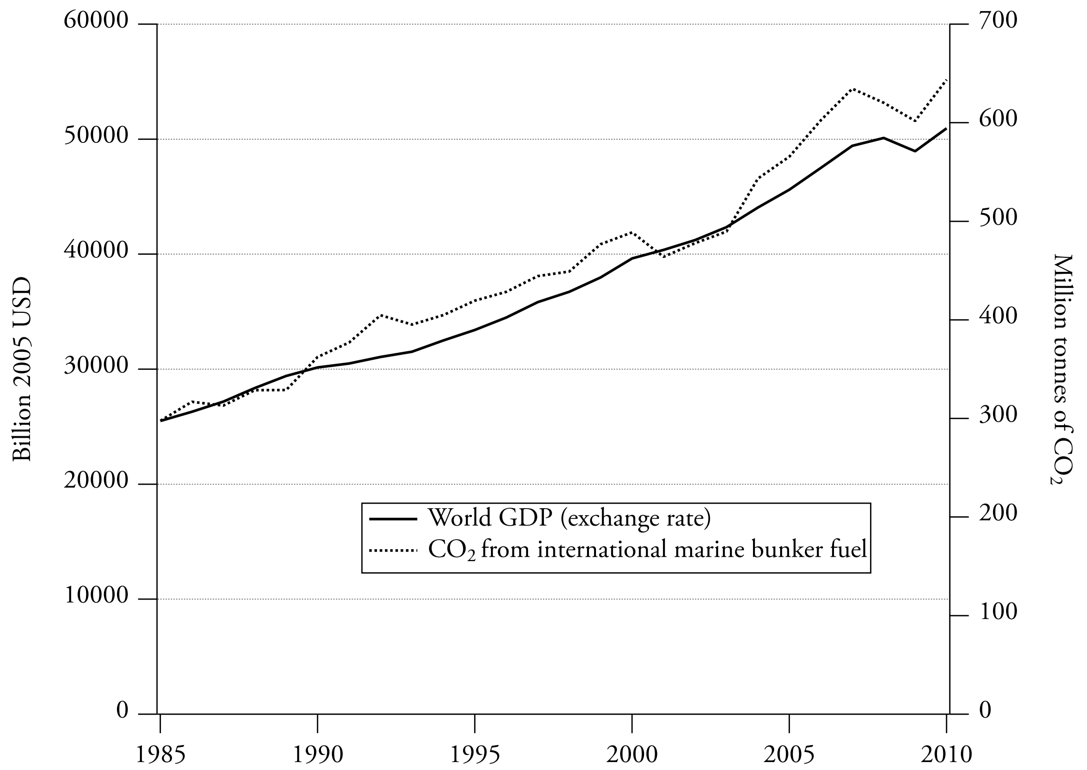


Figure1.1: World GDP by exchange rate (left axis) and CO_2 emissions from international marine bunker fuel (right axis) (IEA, 2012a).

2012a). At the same time, we are living in a carbon-constrained world—our possibilities for future development are bounded by our ability to stabilize greenhouse gas emissions at a level where we can avoid dangerous climate change. This target has politically been set at 2°C warmer than pre-industrial levels. The problem is neither technical nor economical. Rather, a wide range of technical pathways to lowered emissions are possible. Stern (2006) argued that while the investments required for avoiding a dangerous climate change are in the arrears of 1% of global GDP per year, the costs associated with a business as usual scenario range from 5% to 20% or more of global GDP per year. However, the more *cost-efficient* pathways require more or less immediate action. For example, Rogelj et al. (2011) showed how CO_2 emissions will have to peak during this decade and fall below 2010 levels by 2020 in order for us to have a reasonable chance of staying below 2°C. Delayed action is also technically possible, but will be much more costly (Krey and Riahi, 2009; Elzen, Vuuren, and Vliet, 2010). Researchers have even discussed the need for a complete "decarbonization" of the shipping sector by 2050 as a result of a delayed global action (Gilbert and Bows, 2012).

Increased use of fossil energy demanding services such as shipping will thus need to be followed by an even greater increase in efficiency if total emissions are to be reduced. The potential seems to be substantial. Buhaug et al. (2009) estimated that CO_2 efficiency in shipping could be increased some 25 to 75 percent, of which the majority is due to measures that increase *energy* efficiency. Still, reducing *total* emissions will be very difficult. Bazari and Longva (2011) showed that despite regulation recently adopted by the

International Maritime Organization (IMO), emissions will continue to rise. Eide et al. (2011) estimated that even if we were to put a price on carbon on maritime emissions of 100 USD per ton CO_2[1], an impressive 49% reduction from a baseline scenario could be achieved by 2030. Due to the sector growth, this would however still mean that total emissions are rising compared to today. By contrast, the European Union is aiming for 40-50% reduction in emissions by 2050 compared to 2005 (EC, 2011). Shipping and its impact on climate change is the topic of Chapter 2.

To make matters worse, the fact that the main present route towards CO_2 abatement in shipping is through energy efficiency imposes some complicated problems on policy-making. As just mentioned, a significant, cost-effective, potential for improvement has been assessed to be already available. This seems like a paradox. Are the assessments wrong? If measures are cost-effective, why haven't they already been implemented? This phenomenon has been shown to exist in many sectors and is commonly called an "energy efficiency gap" (Jaffe and Stavins, 1994). The gap has been explained through the existence of transaction costs associated with the implementation of measures, as well as to failures and barriers in markets, institutions and organizations, depending on scientific frame of reference. Some of these barriers can possibly be removed cost-effectively, but some might not. The assessments thus show a potential that will never fully be reached. This will be discussed in Chapter 4.

Increased energy conservation and efficiency have been of interest to policy-makers and researchers from a range of scientific backgrounds since the oil crises of the 70's. Actions in the merchant marine as well as the naval sector were taken immediately. Slow-steaming was common practice, perhaps especially in the tanker sector (Artz, 1975). Potential for further improvement was generated by all kinds of measures, but it was still a challenge to convince shipping companies to increase energy efficiency as a way to cut costs, rather than laying off crew (Bertram and Saricks, 1981). Improved operational practices were enabled by advanced ship performance monitoring and analysis systems (Drinkwater, 1967; Reid, 1985). Technical innovations in the form of sails, Flettner rotors, waste heat recovery systems, frequency regulation of pumps and fans, contra-rotating propellers etc. were also being discussed (Bertram, Saricks, and Gregory II, 1983; Morisseau, 1985). Better ships could be designed with new computer models of onboard energy systems (DeTolla and Fleming, 1984). New types of organizational structures and roles were invented in shipping companies, like energy managers (Sweeney, 1980). However, similarly to the rest of the world, interest in energy efficiency faded as oil prices fell, and stayed low for decades. Interest did not seem to arise again until the almost concurrent events of a global debate on global warming and high oil prices. Chapter 3 contains this historical perspective on energy efficiency in shipping.

1.1 A new start

The Department of Shipping and Marine Technology at Chalmers University of Technology initiated two projects in 2009, financed by the Swedish Energy Agency. The first was to make an assessment on what was state-of-the-art in terms of energy efficiency in

[1] As a reference, in the European Emission Trading Scheme, the price of carbon is now on a record low of a handful of dollars.

shipping, to determine where to focus research.[2] The second was to look at how practical efforts with energy efficiency in shipping companies could be improved through the implementation of energy management systems, something which had been a success factor in other industries.

This work attracted the interest of two Swedish shipping companies—Laurin Maritime and Österströms (now part of Rederi AB Transatlantic)—and so a continued effort, which would focus on the implementation of energy management systems in these two companies was initiated. A collaboration project started in September 2010, with financing from the Swedish Energy Agency. To further ensure relevance, the maritime consultancy branch of Det Norske Veritas, already working on energy efficiency for the shipping industry, was included as mentors to the project. From a research perspective, this was to be a multiple-case study project, carried out through an action research design. An overview of the project, including methodology, is provided in Chapter 6.

1.2 Research aims

The existence of a large cost-effective potential for improved energy efficiency entices the mind to ask questions such as *how* and *why* is this so? In the broadest sense, this thesis is directed to understanding this problem.

The priority has been on conducting the joint-industry project such that the performance of the shipping companies with respect to energy efficiency would be enhanced in an effective manner, i.e. that they would be able to increase energy efficiency soon. This is typical of action research (Gummesson, 2000): its value lies in its effect on practice (c.f. Flyvbjerg, 2001). This will be discussed in Chapter 5. The second priority was personal learning on what effective energy management can be. The third priority was generalization of results to the public and the scientific community. Thus, by asking and attempting to answer the more specific question *how can we increase energy efficiency?* from these shipping companies' point-of-view, a new perspective can perhaps be provided on the more general problem of how energy efficiency in the shipping industry can be induced.

The aim of this project is thus to provide relevant knowledge in the immediate as well as in a long-term context. In the short term, because many shipping companies are now working hard to improve energy efficiency as a way to cut costs. The hope is that the discussions we generate in time propagate beyond the partners of this project. For example, a next step is to develop courses in energy management in shipping for the educational programs at Chalmers. In the longer term policies need to be created that incentivize the shipping industry to be truly great innovators. Knowledge on what companies need to do in this respect—what drivers and barriers are important—could contribute to more effective policy-making. For example, the now mandatory Ship Energy Efficiency Management Plan is discussed in Paper III based on knowledge generated in this project.

1.3 Appended papers

The three papers appended to these thesis are the first to address the shipping industry in the context of the energy efficiency gap-literature:

[2] This later lead to a PhD project in the same department, on the modelling of energy efficient systems on board ships.

- The first, *Barriers to energy efficiency in shipping*, is based on a series of interviews with stakeholders in the Scandinavian shipping cluster. It compares their descriptions of why they find it difficult to work with energy efficiency within their organizations with previous research on energy efficiency in other sectors.

  It has been submitted to the journal *Maritime Policy and Management*. An early draft was presented at the International Association of Maritime Economists (IAME) conference in Santiago de Chile, 2011. The author did the literature review, conducted the interviews, performed the analysis and wrote the paper.

- The second paper, *Improving energy efficiency in short sea shipping - a case study*, details the work of one of the shipping companies in this project.

  The paper has been submitted to the journal *Energy Policy*. It was earlier presented at the International Research Conference on Short Sea Shipping in Lissabon, 2012. The author set up the joint industry project described in the paper, performed the work at the shipping company until joined by consultant Mikael Johansson, and wrote the paper.

- In the third paper, *Will the IMO Ship Energy Efficiency Management Plan (SEEMP) lead to reduced CO2 emissions? A comparison with ISO 50001 and the ISM Code*, we discuss present gaps in regulation on energy management in shipping, based on research on similar instruments.

  This paper was selected for the IAME 2012 Special Issue of *Maritime Policy and Management*. It was presented at the IAME conference in Taipei, 5-8th of September, 2012. The author wrote the paper after discussions with the co-authors.

1.4 Thesis structure

This is not traditional disciplinary research, but is ultimately rather an attempt to sketch and understand a problem formulation. In order to appreciate how science in a meaningful way can contribute, a broad range of topics will need to be covered. As a consequence, the outline of this thesis is perhaps a bit unorthodox. In summary, it has the following structure: this introductory chapter is followed by a chapter on climate change and consequences for shipping. This is necessary to understand the challenge posed by anthropogenic climate change, the challenge which policy-instruments now are being created to meet. Chapter 3 contains an overview of energy efficiency measures, starting from the oil crises. Chapter 4 discusses the gap between the apparent cost-effective potential and reality from various research frameworks present in literature. Chapter 5 deals with how science can contribute in these kinds of problems. Chapter 6 contains a description of the joint-industry project and how it was managed in terms of research methodology and design. Also included is a summary and synthesis of the appended papers. A discussion takes place in Chapter 7. Chapter 8 concludes.

2 Shipping and climate change

A new scientific truth does not triumph by convincing its opponents and making them see the light, but rather because its opponents eventually die, and a new generation grows up that is familiar with it.

Max Planck

GIVEN that global emissions of GHGs will have to start decreasing, what contribution is necessary from the shipping sector? How great a challenge is it facing? The answer to these questions depends on a great deal of things: the timing of global regulation; the resulting contribution of other sectors, in magnitude and time; the emissions from the shipping sector today and its projection into the future based on likely demand for transportation; available potential for improvement and associated costs, etc. Research has been directed towards understanding the shipping sector and the rest of the world separately and no proper synthesis has yet been made.

What has been shown is that if the shipping sector is requested to perform reductions in *total* emissions, radical changes are necessary (Buhaug et al., 2009). These include "an abrupt decoupling between seaborne trade and economic growth; very low global economic growth; extreme shortage of fossil energy; and, introduction of unexpected technologies" (p. 149). Conceivable measures are not enough to counter the expected growth of the sector (Buhaug et al., 2009; Faber et al., 2009; Eide et al., 2011). The timing of global action might have great consequences also for the shipping sector. Gilbert and Bows (2012) mentioned "a need for complete decarbonisation of the shipping sector by or soon after 2050." (p. 614) if action is delayed beyond this decade. This is not the topic of this thesis, but there is a great need for better understanding this challenge.

Increasing energy efficiency—delivering the same service using less energy, and as a consequence, emitting less—is often pointed out as a main route towards mitigating the climate impact of shipping (as opposed to, for example, a switch of fuels). To understand the role of energy efficiency in today's and the coming century's shipping markets, we need therefore to first make a brief survey of the science and politics of climate change.

2.1 A very short introduction to climate change science

The climate is unequivocally warming (IPCC, 2007): temperatures are increasing, sea levels are rising, the Arctic sea ice is decreasing its coverage. That an increase of the concentration of CO_2 emissions in the atmosphere would lead to an increase in global mean temperature was predicted by Arrhenius in the late 19th century (Arrhenius, 1896). Climate change science has of course evolved since Arrhenius, but his general indication has been further supported by research. Not only CO_2 has this effect, and the term "greenhouse gases" (GHGs) now denotes a range of substances that contribute similarly, namely in the way that they affect radiative forcing: a measure of the total effect a substance has on the energy flow through the outer bounds of the atmosphere. In their latest review of climate change science, the International Panel on Climate Change (IPCC)[1] has asserted that there is an "extreme likelihood" ($> 95\%$) that mankind has since 1750 "exerted a substantial warming influence on climate." (IPCC, 2007, p.671) Moreover, since 1950, it is "exceptionally unlikely" ($< 1\%$) that natural processes have had an influence comparable to that attributable to those that are anthropogenic (Forster et al., 2007, p. 131). This change in CO_2 emissions during the last 10000 years can be appreciated in Figure 2.1.

The most significant GHGs are CO_2 mainly from energy use and deforestation; methane (CH_4) mainly from agriculture, waste and energy use; and nitrous oxide (N_2O) mainly from agriculture, as seen in Figure 2.2. There used to be a large difference between what we denote developing countries and developed countries in terms of energy use and CO2 emissions. Per capita emissions are still very skewed (Raupach et al., 2007), but developing countries have now overtaken developed in terms of total emissions (Peters et al., 2011). Despite the economic downturn of 2009, the increase of CO_2 emissions from combustion of fossil fuels was the largest ever recorded: emissions fell in developed (Annex I) countries but increased in developing (non-Annex I).[2] Peters et al. (2011) demonstrated how CO_2 emissions from combustion of fossil fuels and cement production in 2010 more than offset the reduction in 2009, in the highest total annual growth since 2003. Particularly this is due to growth in emerging economies.

In comparison to other forms of adverse impacts humans have on the environment, like acidification and eutrophication, CO_2 and other GHGs have a very long-term effect. Even if societies were to rapidly decrease or even stop emitting CO_2, the concentration in the atmosphere is reduced very slowly. Increase in temperature, changes in precipita-

[1] The International Panel for Climate Change (IPCC) was created in 1988 by the United Nations Environment Programme (UNEP) and the World Meteorological Organization (WMO). Its purpose was to regularly review climate change science and produce review reports (Oberthür and Ott, 1999).

[2] The United Nations Framework Convention on Climate Change (UNFCCC) is the basis for international negotiations on climate change (Oberthür and Ott, 1999). In Annex I to the FCCC, countries that have some kind of obligations to reduce GHG emissions are listed. These are the European Community and all countries that were "industrialized" in 1992. Countries that were excluded from this list are referred to as non-Annex I countries and were "developing countries" in 1992.

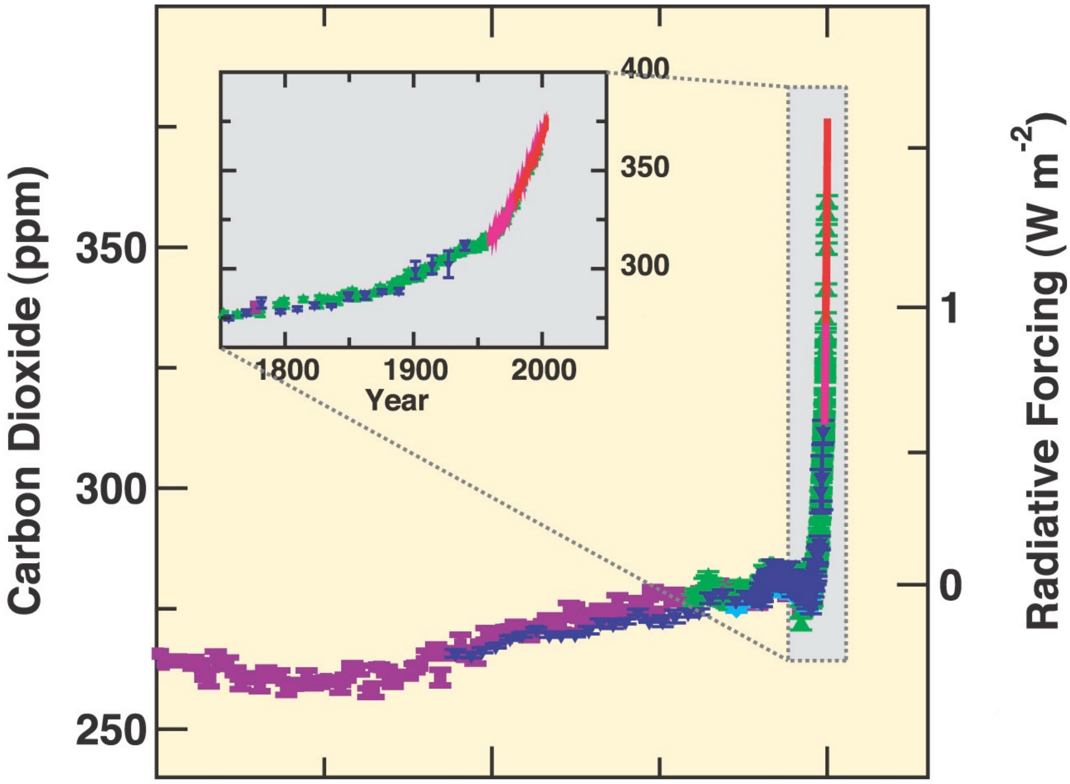


Figure2.1: GHG emissions since 10000 years (large panel), and since 1750 (inset panel) (IPCC, 2007).

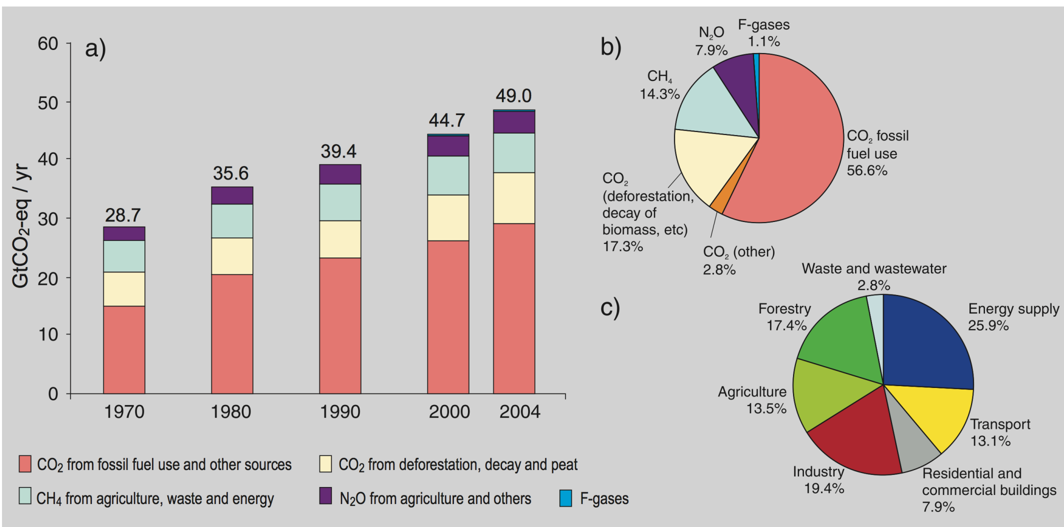


Figure2.2: GHG emissions from various sectors (a), share of different GHGs in 2004 (b), contributions from different sectors to global GHGs in 2004 (c) (IPCC, 2007).

tion, and rising sea levels, are expected to be irreversible, at least the coming 1000 years (Solomon et al., 2009).

The global mean temperature is now 5°C warmer than during the last ice age. An equally large temperature change would be devastating (Schellnhuber et al., 2012). Even a 2°C warming, the goal nations set in the Copenhagen Accord[3] will have a profound effect. For example, Frieler et al. (2012) showed how the temperature increase needed to be limited to 1.5°C in order to preserve more than 10% of global coral reefs. Now, almost 1°C degree warmer than pre-industrial levels, the effects of climate change are visible, for example in the form of shrinking glaciers, melting permafrost and costal erosion, as well as in changes of biological systems (Rosenzweig et al., 2008). Some processes are faster than earlier predictions: the arctic is melting faster than forecasted in the latest report of the IPCC (Stroeve et al., 2007), and might be ice free in summertime already in 30 years (Wang and Overland, 2009).

The maritime environment is also being affected. Decreased ocean productivity, altered food web dynamics, and a greater incidence of disease has already been observed (Hoegh-Guldberg and Bruno, 2010). Larger effects are expected in oceans in polar regions and in the tropics, due to decrease of ice-levels and perturbations in coral ecosystems (Doney et al., 2012). Increased acidity, due to the deposition of atmospheric CO_2 in the ocean, combined with higher temperatures (Doney et al., 2009), will force marine ecosystems into conditions in which they have not been for hundreds of millions of years, if ever. Such changes have previously been associated with mass-extinction events (Honisch et al., 2012).

From a technical and an economical point of view, it is possible to avoid larger climate changes. Azar and Schneider (2002) showed how even conservative (high) estimates for costs of CO_2 abatement necessary for a stabilisation below 550 ppm in the atmosphere – in the order of trillion USD – would be negligible in the context of the large timescale involved. Instead of being ten times richer in 2100, the world would reach the same situation in 2102, as the investments would be spread out and the economy would still be growing exponentially. The Stern Review estimated the cost of stabilizing at 550 ppm CO_2e to range from -1% to 3.5% of GDP by 2050, acknowledging that many improvements (typically energy efficiency measures) could come at negative costs. Ignoring investments to abate emissions early would equally lead to large costs: it is important to act quickly. Rogelj et al. (2011) showed how emissions need to peak in this decade and fall below 2010 levels in 2020, in order to have a greater than 66% chance of staying below a 2 degree warming. The pledges made under the Copenhagen accord are not enough for this purpose, and might even lead us to a 3 degree warming (Rogelj et al., 2010). The International Energy Agency (IEA) showed how all available emissions for a 2°C scenario (450 ppm) would be accounted for by existing infrastructure like power plants and buildings already by 2017 (IEA, 2012b). In a scenario of rapid diffusion of energy efficiency measures, the IEA assessed that the window before "complete lock-in" is open longer, until 2022 (pp. 269-383).

[3]The Copenhagen Accord is a non legally binding document presented and taken note of at the 15th meeting of the Conference of The Parties (COP) to the Framework Convention on Climate Change (FCCC) in Copenhagen, 2006.

2.2 Methods to assess the present contribution of the shipping sector

In the Second IMO GHG study, Buhaug et al. (2009) estimate GHG emissions from shipping through exhaust gas from main engines, auxiliary engines and boilers; refrigerants from storage of cargo and provisions, air-conditioning, and from ship scrapping; and cargo emissions due to leakage. Total CO_2 emissions, the dominant GHG from shipping, from international and domestic shipping was estimated to have ranged from roughly 870 to 1250 million tonnes , or 2.7% to 3.6% (p. 27). The effect of these emissions in terms of total radiative forcing is complex: for example, it is positive through its emissions of CO_2, negative through its emissions of sulphur, and both positive and negative through its emissions of NO_x (Lund et al., 2012). On a net basis, shipping has through the combination of these mechanisms been assessed to contribute to radiative forcing negatively (Eyring et al., 2010; Lund et al., 2012).

There are two main ways of determining GHG emissions from shipping: 'bottom-up', using data on the technical composition and actual movements of the world fleet, or 'top-down', using statistics on the amount of bunker fuel sold (see Miola, Marra, and Ciuffo (2011) for a literature review). Buhaug et al. (2009) concluded that the latter approach produces results that are always lower than the former, and that the former method provides more accurate measures.

An overview of recent estimations have been reproduced in Figure 2.3. The International Energy Agency estimated that the amount of CO2 from international marine bunker sales attributed to developing (Non-Annex I) countries had risen in 2009 by 3.1% from 2007, but fell by 14.5% in developed (Annex I) countries, leading to a net reduction of 5.2% (IEA, 2012a). In 2010, however, total emissions have rebounded past pre-crisis levels (increasing 7% from 2009 to 2010). As can also be seen in Figure 2.3, sales of bunker have increased constantly in non-Annex I countries since the last decade, and has for years surpassed Annex I countries.[4]

2.3 Methods to assess the future

Niels Bohr is often attributed as having said that prediction is very difficult, especially about the future. In order to understand something as complex as the contribution of the shipping sector to global GHG emissions in the coming decades, simplifications must be made. It is easily appreciated that the relationship between ship emissions and the world economy can be understood through the following equation:

[4]The impact of the economic crisis was recently a main argument for a decision (MEPC 64/WP.1, p. 40) in the IMO to conduct a new GHG study: "the current estimate does not take account of the economic downturn experienced globally since 2009" (MEPC 64/5/5, Annex, p. 1). While the financial crisis had little impact on global CO_2 emissions, it might be different for the shipping industry. Trade collapsed in 2009—trade volumes fell 17.5% between September 2008 and January 2009 (Gregory et al., 2010)—but has now recovered to pre-crisis levels. It is uneven, however; developing countries have exceeded these levels, particularly China and East Asia, though developed countries which saw the greatest drop in trade have still to catch up in terms of trade volume(UNCTAD, 2012a). From the perspective of many investors, ship owners, ship operators and other stakeholders, this is much less than expected. A record delivery of new ships in 2010 (ordered in good times, well before the crisis), resulting in a 8.6 percent growth of the world fleet that year, ensured that there is still an overcapacity of ships compared to transport demand (UNCTAD, 2011). In total, the world fleet had by January 2012 grown by 37% in four years (UNCTAD, 2012b). In this author's opinion, what this means for total CO_2 emissions does not seem entirely trivial.

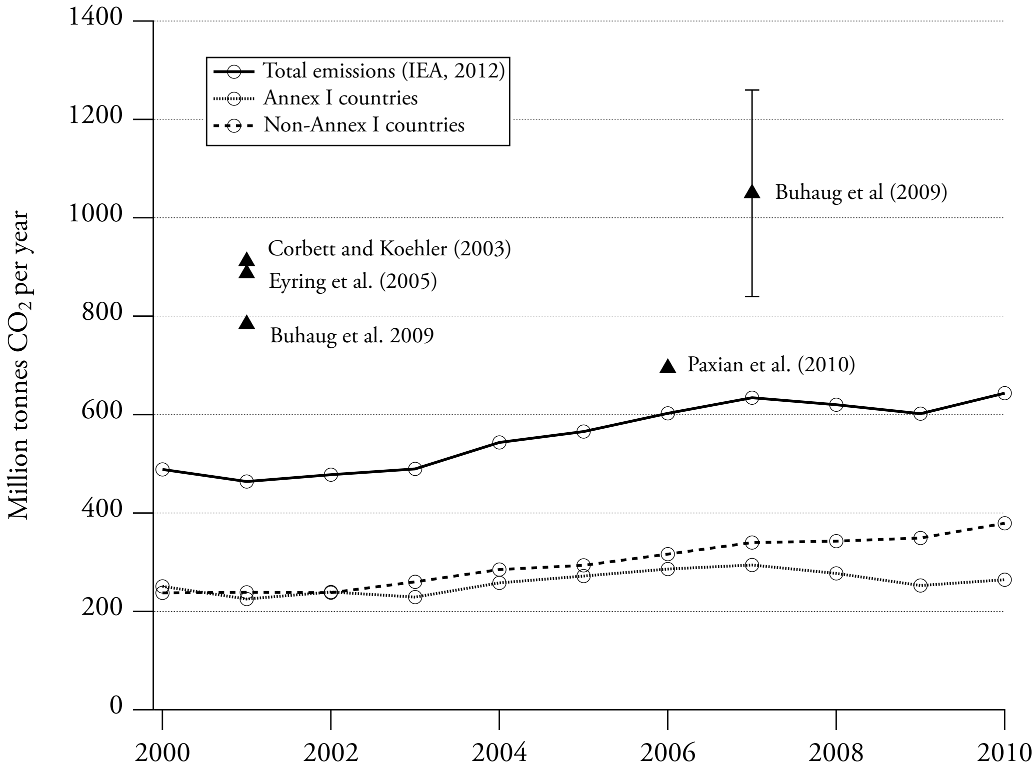


Figure2.3: Different estimates of CO_2 emissions from international shipping. The solid lines represent bunker sales as reported to the IEA, also divided into Annex I countries and non-Annex I countries in the dashed lines. Buhaug (2009) contained an upper and lower bound of their final estimate, depicted as error bars in the graph.

$$Total\ CO_2\ emissions = GDP \cdot \frac{Transport\ work}{GDP} \cdot \frac{Energy}{Transport\ work} \cdot \frac{CO_2\ emissions}{Energy}, \quad (2.1)$$

where GDP is the size of the world economy, the second term is the amount of cargo transported a certain distance (for example *tonne · nautical mile*) necessary to maintain that GDP (the transport intensity of the economy), the third is the energy required to perform that transport work (energy efficiency), and the final term is the amount of CO_2 associated with each unit of energy used. Increased transport work by the shipping sector and increased GDP has been seen to have a good correlation, and is used to project ship emissions into the future.[5] With accompanying assumptions on future mixes of energy carriers and their respective CO_2 emissions as well as on possible increases in energy efficiency, plausible scenarios can be made.

[5]The correlation between GDP growth and the growth of demand for shipping has been found to be “good” for at least the period of 1985-2001 (Eyring et al., 2005). This was also shown in Figure 1.1. The use, extraction and transportation of materials is indeed inherent to our economic system (Steinberger, Krausmann, and Eisenmenger, 2010). We increased material use 8 times during the last century, slightly slower than economic development but faster than population growth (Krausmann et al., 2009). While developed regions adopt strategies for dematerialisation—to use less materials for the same economic output—developing regions of the world still have a need for raw material to construct roads, buildings, ports, railways and other forms of infrastructure, and a growing number of middle class citizens will buy more goods. Per

When we approach the middle of the century, the small share of the contribution of shipping today is expected to have grown substantially in a business as usual scenario. Buhaug et al. (2009) estimated a 150% to 250% growth by 2050, following global GDP growth: in total 1.5-2.5 GT CO_2 a year. Future scenarios for total global emissions vary widely depending on the required certainty of the projection with respect to increase in temperature, and also with the assumed point in time at which the world reaches a peak in emissions. Meinshausen et al. (2009) showed how the probability of not exceeding a 2°C warming ranged from 85% to 36% when emissions ranged from the equivalent[6] of 10 Gt CO_2 per year to 36 Gt CO_2 eq per year by the year 2050. In the scenario with a high probability of not exceeding 2°C, shipping could thus constitute 15-25% of the available global budget in 2050.

Many of these scenarios assume that a peak in emissions will come very soon. Rogelj et al. (2011) demonstrated a cost-effective scenario, where emissions peak this decade and with 2020 level below 2010 levels, which enable a 66% chance of a warming under 2°C. Later peaks will need to be accompanied by sharper reductions in emissions. Such a development would be much more expensive. Shipping may need to play a larger role in scenarios with delayed action. Gilbert and Bows (2012) argued that CO_2 emissions for shipping could even be larger than total global emissions by 2050 in scenarios "that have realistic peaking dates and the highest probability of not exceeding 2°C" (p.614).

Efforts have been made to produce scenarios for future emissions from shipping, using a set of scenarios developed by the IPCC[7] (e.g. Eyring et al., 2005; OPRF, 2008; Buhaug et al., 2009). Recognizing that the economic (GDP) growth and the growth of international trade has historically had a good correlation, Eyring et al. (2005) as well as Buhaug et al. (2009), used the development of economic growth from the different IPCC scenarios as the only input to their scenarios for shipping. OPRF (2008) took a different approach. They used available projections also on world energy consumption, population, etc., and treated the growth of various cargos differently. For example, crop transportation growth is assessed in tandem with data from the Food and Agriculture Organization of the UN (FAO). For the growth of the container sector, they used the same historical relationship between GDP growth and demand for transportation. All in all, this different approach produces a demand for transport in terms of tonnes-miles per year that is *half* of what is estimated by the correlation of GDP and transport demand. To acknowledge the difference, Buhaug et al. (2009) used in the final analysis the mean values of the OPRF study and a GDP correlation approach. Low and high bounds were chosen that encapsulated the results of both studies.

capita material and energy use is 5-10 times higher in developing regions than developed, and it has been forecasted that energy and material use will grow with a factor of 2-3 the coming decades as agrarian regions become industrial (Krausmann et al., 2008).

[6]As indicated previously, different GHGs contribute to radiative forcing differently. The CO_2 *equivalent* is a normalized unit to discuss the impact of all GHGs, i.e. the total contribution if all gasses had been CO_2.

[7]In order to provide basis for assessing impacts of future climate change, the IPCC developed various scenarios in an attempt to capture different possible world pathways. The main factors driving GHG emission growth were shown to be attributed to demographic and socio-economic development, and rate and direction of technological change. The resulting scenarios are regarded by the IPCC as "alternative images of how the future might unfold and are an appropriate tool with which to analyse how driving forces may influence future emission outcomes and to assess the associated uncertainties" (Nakicenovic et al., 2000, p. 4). No single scenario should be regarded as being most likely. Rather, policymakers and researchers are recommended to use a range of scenarios in their analysis.

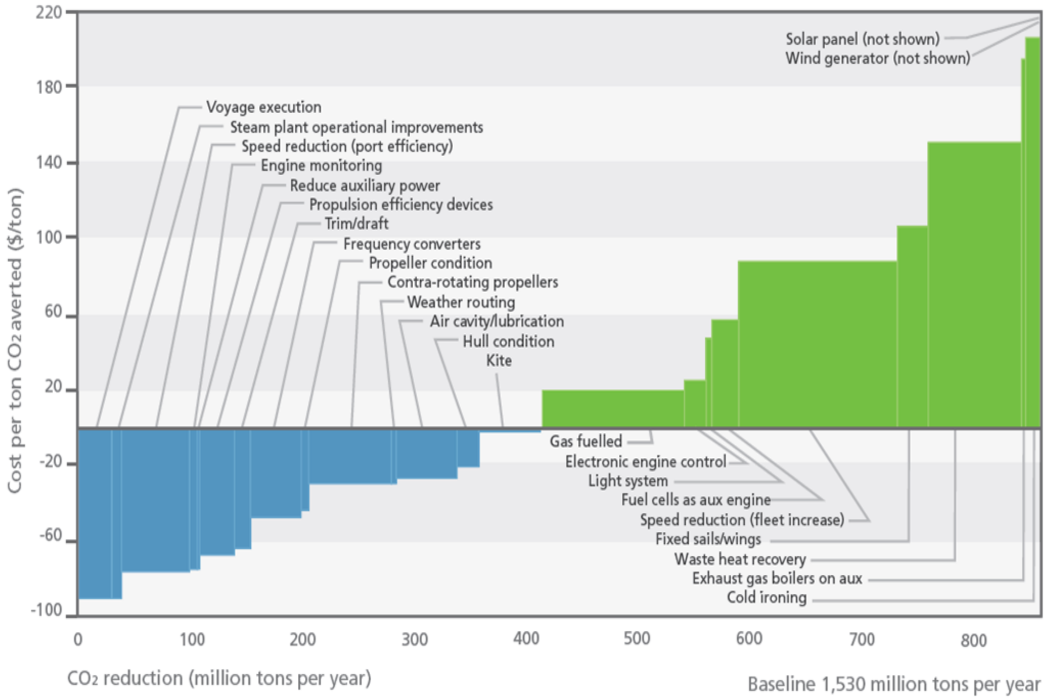


Figure2.4: Marginal abatement cost curve from DNV (2010)

These projections thus produce Business-As-Usual scenarios: they do not include assumptions on switches in energy carriers, or increases in energy efficiency. In order to understand the technical and economical potential of abating CO_2 emissions in projections, *marginal abatement cost* (MAC) curves have been developed. An example can be seen in Figure 2.4. On the horizontal axis, the abatement potential in tonnes of CO_2 for a number of measures are given; on the vertical axis, the cost of each measure can be found. The figure shows a large potential for abatement at below zero cost. As mentioned in the introduction, this could signal additional transaction costs[8] associated with the measures that add to MAC estimates. For this reason the use of these curves as decision-support for policy-making has been criticized (Kesicki and Strachan, 2011; Kesicki and Ekins, 2012). This will be discussed further in Chapter 4.

The projections that have been made that included abatement measures, have shown that even assuming high costs of CO_2 (assuming such a cost is imposed also on ship emissions), the magnitude of measures thus made 'cost-efficient' would not lead to any reduction in total emissions (Buhaug et al., 2009; Faber et al., 2009; Eide et al., 2011).

2.4 Shipping and global climate policy

The work in the IMO on climate change is very much shaped by the Kyoto Protocol to the FCCC.[9] Assigning the task of reducing GHG emissions from shipping to the IMO was a compromise solution, as countries could not agree on how to apportion emissions

[8] A simple way of explaining transaction costs is that these are the costs of "running the economic system" (Arrow, 1969), i.e. costs for searching for information, for establishing and monitoring contracts, for setting up and running internal organizations etc. In orthodox (neo-classical) economic theory, transaction costs are assumed to be zero. For an engineer such as myself, Furubotn and Richter (2005) was a great introduction.

from either aviation or shipping to individual countries (Oberthür and Ott, 1999). It was done through the following text:

> The Parties included in Annex I shall pursue limitation or reduction of emissions of greenhouse gases not controlled by the Montreal Protocol from aviation and marine bunker fuels, working through the International Civil Aviation Organization and the International Maritime Organization, respectively.
>
> (article 2.2, Kyoto Protocol)

The implications of 'pursue' and 'work through' have been extensively discussed in IMO meetings ever since. Diplomatic discussions between countries are in a "dead-lock", due to disagreement between the interpretation of two basic concepts underlying the IMO and the Kyoto protocol (Kågeson, 2011). The first, the concept of Common But Differentiated Responsibilities (CBDR) is a fundamental part of UNFCCC:

> The Parties should protect the climate system for the benefit of present and future generations of humankind, on the basis of equity and *in accordance with their common but differentiated responsibilities* and respective capabilities. Accordingly, the developed country Parties *should take the lead in* combating climate change and the adverse effects thereof. (my emphasis) (article 2, FCCC)

In IMO regulation, on the other hand, the concept of No More Favourable Treatment (NMFT) is universally used: a port state can apply IMO legislation to any ship entering its waters or ports. The IMO secretariat itself has made it clear that they have "not identified any potential treaty law conflict between the Kyoto Protocol and the provisions that may be developed by the Committee on GHG emissions from the combustion of marine bunker fuels".[10] Among other reasons, they state that "[...] 'pursue limitation' [...] is not the same as limiting the outcome of IMO's decision-making process to application to Annex I countries exclusively". Finally, it is concluded that shipping regulation must both as a principle and for practical matters be global in scope:

> [I]t is due to the complexities of the international shipping trade (i.e. the interaction of private and public law in connection with registration; the right and obligation to fly a flag; and the further interaction between flag, port and coastal State jurisdiction) that IMO shipping regulations are, as a matter of principle, and must be, as a practical matter, global in nature and applicable to all commercial ships, with appropriate differences, if any, to be based on factors such as their type, structure, manning and operational features, irrespective of the flag they are flying or the degree of industrial development of the flag State or the State of nationality of the owner or the operator. (GHG-WG 3/3/9)

A compromise solution is likely necessary. Applying solely the NMFT principle may weaken the negotiating position of developing countries in global climate discussions (Hackmann, 2012). Several ways have been proposed to reconcile these principles.

[9]However, GHG emissions appeared on IMO's table already in 1991. It was argued by the UK delegation that "consideration should be given to accurate monitoring and forecasting of carbon dioxide emissions from shipping and the difficulty of allocating responsibilities to individual states" (report from the BCH-subcommittee, MEPC 32/12, quoted in Strong (2011)).

[10]In: *Review of proposed market-based measures: relation to relevant conventions and rules. The organization's work on GHG emissions and the United Nations Framework Convention on Climate Change and its Kyoto Protocol.* Submitted by the IMO secretariat to the Third Intersessional Meeting of the Working Group on GHG Emissions from Ships, 2011. Document no: GHG-WG 3/3/9.

Kågeson (2011) argued for two: either to apply an instrument globally, with economic compensation to non-Annex I countries, or that the application is limited to passages to Annex I countries, with or without compensation to other parties.

Representatives have discussed various proposals in the International Maritime Organization for measures that would deal with GHG emissions, two of which have now been implemented: the Energy Efficiency Design Index (EEDI) and the Ship Energy Efficiency Management Plan (SEEMP). The first attempts to set a design standard for new ships, while the second is directed to encouraging better management practices on energy efficiency onboard ships. Further measures, mainly market-based in the form of e.g. a tax on bunker or an emissions trading scheme, have been stalled due to the CBDR conflict (Kågeson, 2011). A critical review of these instruments is difficult to make as peer-reviewed papers on them are very scarce.[11] While the EEDI has spawned hundreds of submissions to IMO meetings, only one paper (Devanney, 2011) has been published in a peer-reviewed journal (and that paper is very critical to the EEDI concept). The only paper on the SEEMP is written by the author of this thesis.

Market based measures are covered to a slightly larger extent. Miola, Marra, and Ciuffo (2011) discussed different market based measures for shipping, including a global emissions trading scheme, and concluded that a global market-based system would overcome challenges present in regional regimes, such as carbon leakage and how to apportion emissions. The number of market based measures actually on the IMO table are increasing. Psaraftis (2012) reviewed several submissions to the MEPC on the topic. He mentions a problem of insufficient transparency in the IMO process to review market based measures: they are based on MAC curves, containing assumptions on costs and effectiveness which are not fully disclosed.

2.5 Sub-global policy

The Kyoto protocol does not in any way hinder countries from including marine bunker fuel in their national emission inventories. Oberthür and Ott (1999) noted soon after Kyoto that doing this might provide countries with further motivation to take action themselves and increase pressure on the IMO process (pp.111-113). Indeed, the slow progress in the IMO has now spurred discussions for at least a decade on the possibilities for regional and even domestic policies. For example, the European Commission threatened to introduce measures of its own by 2013 unless the IMO reached an internationally binding agreement (Faber et al., 2009). A range of measures have been discussed, for example the inclusion of shipping into the European Emission Trading Scheme (ETS) (Miola, Marra, and Ciuffo, 2011). Based partly on workshops with various stakeholders in shipping, Gilbert and Bows (2012) reviewed abatement measures and the respective potential for influence by nations, reproduced here in Table 2.1. The rationale is that while stakeholders often argue that global measures are needed for e.g. ship design, there are other areas where nations and regions might have more influence than the IMO.

[11] Is the epistemic community working on these instruments too small to give room for a critical discussion also in peer-reviewed literature? In article on energy "inefficiency" in the building industry, Biggart and Lutzenhiser (2007) argued that "[f]ailures to adopt more forceful energy codes and standards can be traced to aggressive industry opposition, general governmental disinterest, and the absence of powerful actors from the debates. Codes and standards do not necessarily represent what is technically possible, socially desirable or even best practice. They are negotiated rules established by professional societies, industries, and governmental agencies." (p.1081).

Table2.1: A gauge of influence of nations on CO_2 emission from shipping (from Gilbert and Bows (2012).

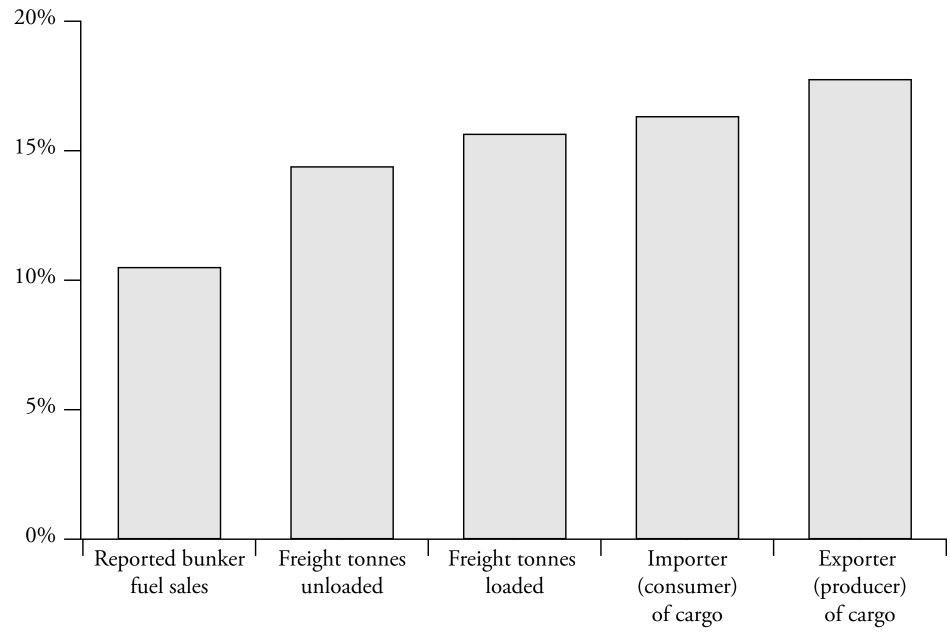
Aspect of shipping system	Potential for national policies to influence this aspect		
	Strong	Medium	Weak
Main engine fuel type		✓	
Auxiliary engine fuel type	✓		
Quantity of fuel sold			✓
New ship designs using alternative fuel sources or propulsion			✓
Fuel efficiency of main engine			✓
Fuel efficiency of auxiliary engine			✓
Efficient ship design			✓
Efficient ship retrofit		✓	
Efficient ship building process		✓	
Efficient ship routing/driving		✓	
Efficient operations in national waters	✓		
Efficient port operations	✓		
Efficient use of journey/ship (e.g. high load factor)		✓	
Flag of vessel			✓
Vessel owner			✓
Vessel operator			✓
Efficient crew management			✓
Number of journeys	✓		
Quantity of freight imported/exported	✓		
Value of freight imported/exported	✓		
Ultimate destination or origin of imports/exports	✓		
Freight owner		✓	

Individual countries have made efforts to mitigate CO_2 emissions, especially the UK, who, as described earlier, was also the first to draw attention to the issue in the IMO. Any apportionment scheme for a nation or region needs to be sufficiently accurate to capture the implementation of abatement measures, and also to be directed to those aspects that are within the sphere of influence of the same entity. Heitmann and Khalilian (2011) reviewed apportioning regimes and concluded that while no single option can be regarded as "fair", allocation on the basis of the nationality of the commercial operator is most fair, as operators "have the most control over the emission levels of their ships by regulating speeds and routes". Gilbert and Bows (2012) showed how CO_2 emissions for international shipping could be apportioned to the UK so that it would range from 7.05 Mt CO_2 (bunker sold) to 42.05 Mt CO_2 (apportioned to the nation importing freight) per year, corresponding to 1.25% and 5.02%, respectively, of global emissions from shipping. In Box 2.1, these apportionment methods are applied to Sweden.

2.6 Rebound effects

No overview of the role of energy efficiency as a strategy to abate GHG emissions is complete without at least mentioning the discussion of rebound effects. Rebound effects is a broad concept, covering mechanisms presumed to follow greater energy efficiency, that enable additional energy use so that the net effect is uncertain, and possibly much lower. The problem was first formulated by Jevons (1865), who argued that increased

Box2.1: Shipping GHG apportionment methods—the case of Sweden



Sweden is, in terms of exports and imports, almost an island. A large part of our trade leaves and enters our borders by ship. In the above figure, the result of applying the various apportionment regimes as described by Gilbert and Bows (2012) to Sweden is displayed. Data on exported and imported cargo (trade in USD) is found in UN Comtrade (2012) and data on freight tonnes loaded and unloaded in Swedish ports is found in EUROSTAT (2012) and UNCTAD (2008). If CO_2 emissions from shipping as attributed to Sweden in 2007 (i.e. the date of the latest IMO estimate, in Buhaug et al. (2009)) are added to Swedish GHG emissions for the same year, shipping's share ranges from roughly 11 to 18%. Apportionment based on sales of bunker fuels is easy to assess, as it has been submitted to the IEA since many years. In Sweden, the Swedish Energy Agency has been gathering data on domestic and international bunker sales since 2003: domestic and international bunker sales have accounted for roughly 11% of total GHG emissions during the last decade.

Total shipping emissions calculated as bunker fuel sales in Sweden rose by roughly 20% from 2003 to 2010. If Sweden is to meet its goal of reducing CO_2 emissions by 40% of 1990 levels by 2020, assuming shipping emissions is constant at 2007 levels, the sector will contribute to between than 27-50% of the available budget of roughly 28 million tonnes of CO_2, depending on method of apportioning.

energy efficiency would even lead to a net increase of energy use, a process which is often referred to as Jevons' paradox (Alcott, 2005; Sorrell, 2009). This subject has received little treatment in either scientific or policy discussions on shipping and climate change. Two examples from everyday life introduces the problem well:

- If a family decides to insulate their house, install a more energy efficient heating system etc., in a cost-efficient manner, what will they do with this increased capacity? This family can now enjoy increased indoor temperature at a lower cost. This is called a *direct* rebound effect: an increase in energy efficiency leads to more consumption of the same good.
- If a family were to reduce energy costs at home, and now have more money over for other things: what is the net energy consumption if they decide to use their new spare funds for a family trip to Thailand? This is known as an *indirect* rebound effect.

Moreover, economy-wide rebound effects have also been discussed: if energy demand is reduced, this would lead to reduced energy prices, which could again lead to a rebounding demand. Sorrell (2009) exemplify the complexity of these mechanisms through Jevons (1865) and Ayres (2002):

> According to Jevons, the early Savory engine for pumping floodwater out of coal mines 'consumed no coal because its rate of consumption was too high.' It was only with the subsequent improvements by Watt and others that steam engines became widespread in coal mines, facilitating greater production of lower- cost coal which in turn was used by comparable steam engines in a host of applications. One important application was to pump air into blast furnaces, thereby increasing the blast temperatures, reducing the quantity of coal needed to make iron and reducing the cost of iron (Ayres, 2002). Lower-cost iron, in turn, reduced the cost of steam engines, creating a positive feedback cycle. It also contributed to the development of railways, which lowered the cost of transporting coal and iron, thereby increasing demand for both. (Sorrell, 2009, p.1458)

In a shipping context, what will happen to total emissions as cost-efficient measures are introduced? Buhaug et al. (2009) dismissed rebound effects:

> In general, policies aiming at improving the efficiency, whether it is operational or design efficiency, may suffer from a rebound effect (Sorrell, 2007). The "rebound effect" is the effect that an improvement in the efficiency often translates into a much smaller reduction in emissions. The reason is that, as the efficiency improves, the marginal costs often decrease (shipping becomes cheaper), which in turn increases demand. The rebound effect is larger if the demand is price-sensitive, i.e. if the price elasticity of demand is high. In shipping, the scarce evidence that is available suggests that the price elasticity is low. Reported price elasticity is in the range from −0.06 to −0.25 (OECD, 2003). The only exception seems to be transport of general cargo in short sea shipping, as noted in paragraphs 6.85 to 6.90. For all other types of maritime transport, the rebound effect is likely to be small.
>
> (Buhaug et al., 2009, p.106)

However, on a longer time-scale, cheap transportation was surely the medium which supported globalization and the shift from *fordian* (local and integrated) to post-fordian (distributed) production (Ruzzenenti and Basosi, 2008). This topic deserves further research, but will not be further discussed in this thesis.

3 The potential for increased energy efficiency

Every good cause is worth some inefficiency.

Paul Samuelson

It is often said that shipping is the most energy efficient means of transportation. We understand from the previous chapter that it is not so meaningful a claim in the context of climate change; what is important is a reduction in total emissions, not solely emissions per transportation work. Moreover, from the perspective of a shipping company, the problem of how to run a fleet in the most economical manner is very relevant in times of high bunker prices, regardless of the comparison to other modes of transportation. In this chapter, we will look at how energy efficiency was addressed during the 70s and 80s—the last time oil was expensive—and, of course, what kind of measures are discussed today.

This chapter does not attempt to claim that no innovation has taken place with respect to energy efficiency in shipping. At this stage it could perhaps simply be appreciated that many of the ideas discussed at that time are discussed again today, especially measures related to managing an existing fleet in an energy efficient manner. For example, articles describing lack of equipment and processes onboard ships for measuring and analyzing performance as a hindrance to increased energy efficiency can be found already in the 60s, a problem which is still not solved (Drinkwater, 1967; Reid, 1985; Leifsson et al., 2008; Petersen, Jacobsen, and Winther, 2011). More historical documents have been gathered through internet database searches and through personal communication. The

US Navy has been particularly good at documenting achievements, all the way back to the 19th century. As such, the review is incomplete and much more can probably be found through searches of physical copies of technical reports.

3.1 After the oil crises

The 70s was a dramatic period for shipping (Chrzanowski, 1980). Freight rates remained low and there was particularly a surplus of tankers and bulkers (Böhme, 1983). The price of fuel had risen considerably since the first crisis in 1973, and had risen from 10-20% of ship operating costs to over 50%, excluding capital and cargo handling costs (Buxton, 1985). It was the deepest recession for the maritime sector since the Great Depression (Böhme, 1984).

The oil crises affected also the military sector. The U.S. Navy were quick to respond with efforts to increase energy efficiency. Discussions on energy efficiency in operations had taken place before (Lowe, 1891), but the surge in fuel prices[1] and the matter of energy security intensified efforts. The short-term response was to reduce operating speeds, but on the longer term research was initiated at for example waste heat recovery systems (Gauthey and DeTolla, 1974; Brady, 1981). In total, 35% reduction in energy use was accomplished from 1973 to 1974 (Sack, 1976). A holistic Shipboard Energy Conservation R&D Program was introduced, which included hull cleaning, anti-fouling hull paints, onboard optimization of machinery systems as well as crew training material to demonstrate the importance of individual contribution (Sack, 1976). The program emphasized that it was not about circumventing the autonomy of the ship's command:

> [The program is not about telling] the Commanding Officer how to operate his ship, but to provide him with a measure of the fuel penalties associated with various practices. He must weigh this penalty against other factors, such as safety, operational need, etcetera. (p. 114)

The optimal rate of hull cleaning, taking into account the effects on the service life of the paint, was further discussed by Preiser and Laster (1981).

The Chief of Naval Operations (upper management of the US Navy) set a long term goal of reducing energy consumption, measured as barrels per steaming hour, by 20% (later changed to 10%) from 1975 to 1985 (Dangel and Brice, 1984). This was difficult to achieve, due to difficulties in translating a general top-down goal to realistic goals on a ship-level:

> Because of differences in material condition, plant configuration, and mission assignments, even among ships of the same class, it is neither fair nor valid to use individual ship consumption rate comparisons as a forcing function to bring pressure to bear on individual command. (p. 48)

The long-term R&D efforts that had been initiated were not possible to put into immediate implementation. More had to be done on a shorter term. A Ship Energy Conservation Assist Team (SECAT) programme was formed in 1982, which aimed at providing individual ships with information on their energy consumption together with practical strategies for increasing energy efficiency (Dangel and Brice, 1984).

[1]The Navy fuel bill doubled from the fiscal year 1974 to 1975, from 495 million to 950 million USD (Sack, 1976).

Reid (1985) described a computerized system that could automatically monitor the energy performance of a ship, both for onboard use and for fleet surveillance. Apart from enabling monitoring of hull and propeller performance, the system gave further understanding of a ship's general operating performance. A 7% increase in energy efficiency was enabled with optimum trim and draft, correct steering controls, navigational and weather routing practices for different loading conditions and correct operating point for the ship-machinery-propeller system. Reid (1985) demonstrated that a system that continuously measures and logs data enables the separation of the effects of these short-term factors from those that affect on the long-term (such as hull fouling).

Morisseau (1978) discussed various applications of sails to reduce energy used. Some years late, he discussed more innovative concepts to harness wind power through the Magnus' Effect, for example with so called Flettner Rotors (Morisseau, 1985). DeTolla and Fleming (1984) developed a large scale computer model (Model of Shipboard Energy Systems, or MOSES) to analyze ship energy consumption, facilitating the design of new more efficient ships. Falling oil prices lead the US Navy to cancel its Energy Conservation Program in 1989, though they restarted it again in 1991, after the Gulf War (Pehlivan, 2000).

The merchant shipping sector was equally keen on energy efficiency, with the immediate reaction similarly being decreasing speed. Charter rates fell and oil prices rose: Artz (1975) described how the tanker charter market "collapsed" and fell 90% in a matter of months, due to a large number of ships being delivered (ordered at high charter rates before the crisis), and due to reduced demand for oil. Zubaly (1975) performed a case study on the effects of reduced speed on a container traffic service in the US. Lavon and Shneerson (1981) discussed the optimal speed for ships, and that energy savings enabled by minimizing idle time in port, that is, reducing speed when possible to arrive just in time before port operations start, could be shared between shippers and shipping company. Ronen (1982) described different models for reducing speed, depending on if the ship was carrying cargo or was on a ballast leg. Researchers studied also the technical implications of slow-steaming. Rein (1980) reviewed various means of increasing efficiency of steam turbine engines at part load. The potential was high, ranging from 0.5 to 10%, because existing engines had not been designed for part load.

> [At the end of the 60's and the beginning of the 70's] emphasis was put on a low fuel consumption at full power, while little or no attention was paid to fuel consumption at lower loads. It was simply considered highly unlikely that the ships would ever be operated continuously at anything but full power. (p. 48)

In order to reduce demand for marine fuel in U.S. ports, the U.S. Department of Energy had the Larbonne Laboratory set up a compendium of measures to disseminate amongst ship owners and operators in 1981 (Bertram and Saricks, 1981). The problem of how an owner or operator should "be encouraged to reduce fuel as a means of cutting costs rather than, for example, laying off crew" was highlighted (p. 27). It was also recognized that

> many operators have operating or financial constraints that severely limit or prevent efforts to save fuel. Difficulty in developing the support of ship crews for operational and equipment modifications to save fuel was identified as a particularly important constraint. (p. 35)

A large range of measures were detailed in the final report "designed to meet the needs of vessel owners and operators anxious to reduce the operating costs of their vessels, many of which were built when the cost of oil was $2.00 (£1.00) per barrel" (Bertram, Saricks, and Gregory II, 1983). Development of crew understanding, motivation, cooperation and participation was deemed to have the highest potential for saving fuel. This could be done for example through introducing a new role in the shipping company responsible for energy efficiency:

> [...] a specific energy conservation manager supported by top corporate officers, [who can give] reassurances to crew concerning safety and legality of new operating procedures, and positive or negative publicity based on performance. (p.162)

Many other measures are further discussed in the article, like speed-reduction, trim optimization, propeller nozzles, contra-rotating propellers, wind-assistance, etc.

In Sweden, the Swedish Ship Research Foundation started a project in 1973 on how choices of machinery systems for ships would be affected by large increases in fuel price (Gisaeus and Stefenson, 1976). The shipyard Uddevallavarvet started a project in 1977 on increasing energy efficiency in ships, as the first energy crisis had made "the need for reducing the costs for ship propulsion almost a matter of "emergency" (Sjögren et al., 1980). The study focused on reducing energy use in machinery systems, cargo handling and other onboard uses. It was followed by another study in 1980, going deeper into aspects such as economizers for auxiliary engines, frequency regulation of pumps and fans, Organic Rankine Cycles, improved air conditioning, and heat insulation (Sjögren et al., 1983). Workshops were held also in Sweden. SSPA sponsored a discussion day on energy efficient ships in the spring of 1982, were topics such as wind propulsion, hull roughness and resistance, and optimizing propeller size were discussed (SSPA, 1982).

3.1.1 An energy management case study

Sweeney (1980) described an energy conservation programme of a ship operator, Matson Navigation Company. This represents, to the best of this author's knowledge, the only case study of an energy efficiency program in a shipping company described in literature. Their process started out by developing a new managerial role, a Manager of Shipboard Conservation, and an energy efficiency strategy, quoted in Box 3.1.

The manager would be placed to in a central position within the shipping company. It was important that he would have "authority commensurate with involvement in the workings of engineering, maintenance and repair, vessel operations, and purchasing; [to also enable] easy communication between the conservation manager, ship crews, and shoreside personnel." (Sweeney, 1980, p. 73). The manager would also have a vary broad range of responsibilities:

> [The Manager of Shipboard Conservation is] engaged in frequent ship visits and maintains close liaison with with vessel personnel primarily in regard to operating procedures. He is also directly involved in certain ship maintenance and repairs, necessitating frequent involvement in the business of port engineers, contractors and vendors; assessing the impact of conservation projects, specifying required work and delineating necessary follow-up action. Finally, he is dealing with the office technical staff on a daily basis, defining the need and scope of engineering design or study assignments, monitoring progress developing economic analysis, coordinating work

Box3.1: General energy efficiency goals of Matson Navigation Company (Sweeney, 1980)

A. The overall objective is to minimize fleet fuel consumption without adversely affecting transportation services.

1. Concentrate attention to the new/large ships of the fleet.
2. Give priority consideration to underway at-sea (as opposed to dockside) operations.
3. Begin by ensuring that optimum efficiency is being achieved with the existing capital plant. Update or tighten shipboard procedures as necessary to further improve vessel economy.
4. Following 3 (above) define and proceed with capital expenditures deemed necessary and justified to further improve vessel economy.

B. Establish close liaison with seagoing personnel and assure their cognizance and support of program goals.

1. Initiate frequent visits to ships. At least two per month should be adequate at the start of the program, considering that one of them will include a four to five day voyage. Become familiar with crews, procedures, and hardware. Confer with ship officers and engineers. Review the conservation imperative. Solicit their suggestions. Report findings and recommendations.
2. As time and priorities permit, publish an energy conservation newsletter, highlighting specific program goals and accomplishments and furnishing vessel operating and maintenance guidelines.

C. Establish a central office file of vessel voyage performance data and fuel conservation information.

1. Develop new forms for vessel data logging to enhance evaluation of energy consumption and efficiency.
2. Review data submitted. Note discrepancies from design and builder's trial data. Define and initiate corrective action as required.
3. Maintain files for future reference and trend analysis.

> timing, and reviewing innovative proposals. These comprise his routine responsibilities at the working level.
>
> He is also available for upper management planning and review projects. Requests for data and analyses of fleet fuel consumption trends and vessel operating tradeoffs are directed to him as are technical questions related to planned vessel conversions, new construction, alternative energy sources or power cycles, and public relations aspects of fuel consumption. His established file of energy conservation data and familiarity with current studies and operating conditions enables such demands to be handled promptly." (p.73)

Sweeney further elaborated on the role of onboard systems for understanding ship performance: "it was obvious that the majority of installed instrumentation and automation was intended to minimize watch-standing labour, and not fuel consumption." (p.81) He noted that this was connected to the traditional role of the engineer onboard:

> [C]onsider the traditional seagoing engineer's watch-standing and maintenance roles. These developed through over a century of experience with progressively more sophisticated machinery but consistently low cost bunkers. The new emphasis on fuel conservation requires a quantum jump in awareness of steam plant cycle efficiency

> and sustained, precise, vigilance over plant operations. The author believes that there is still no shortage of responsible and capable marine engineers. However, the information available to these individuals aboard ship is not always enough, or sufficiently accessible for them to optimize efficiency. This is where the new instrumentation, controls, and information systems generically grouped together and called "performance monitors" can make their most significant contribution, in the daily routine of engine room operations." (Sweeney, 1980, p.81)

Altogether, the program had reduced fuel consumption in sea transit by over 10% in two years time, of which over 7% due to reduced speed and over 3% due to specific measures (p. 90).

3.2 Recent research and development

Today, fuel prices are again high and freight rates low. Moreover, there is another driver: energy efficiency is a key part in the discussion to abate rising GHG emissions. Many recent reviews and reports on the potential for energy efficiency in shipping are therefore spawned by policy discussions in the IMO and the EU and are written in the context of GHG abatement. The actual measures discussed are similar to the 70s and 80s.

In summary, the literature from the previous period can be divided into those that treated speed reduction as a measure, as well as the technical implications; ship modifications or retro-fits, such as waste-heat recovery systems or; operational measures, such as hull cleaning and machinery maintenance procedures; new ship design projects; and finally, enabling technologies and strategies in the form of monitoring systems and management practices.

In the more recent literature, empirical assessments of actual implementation of measures are rare. So are studies of management practices—Article II attached to this thesis being an exception. The treatment of operational and technical measures will be discussed mainly as they are treated in reports to the IMO or the European Commission and related literature. A review of recent technical literature, for example of air cavity systems (Abolfazl et al., 2011), is out of scope for this thesis.

The first IMO study on GHGs from shipping discussed operational as well as technical measures to reduce these emissions (Skjølsvik et al., 2000). In total, 1-40% improvement in CO_2 efficiency was possible due to operational energy efficiency measures. New ships could become 5-30% more energy efficient through technical measures, and existing ships 4-20% (p. 14). The IMO 2nd GHG report detailed more measures and assessed the total potential for increased CO_2 efficiency to range from 25-75%, of which the major share is due to increased energy efficiency (Buhaug et al., 2009). In a report commissioned by the European Commission, the list of measures was expanded to include also solar energy, waste heat recovery, a speed reduction of 20% and Flettner rotors (Faber et al., 2009, p.77). Faber et al. (2011) studied the cost-effectiveness of eight groups of operational measures and 20 groups of technical measures. As this might represent the most complete assessment, they are summarized together with abatement potential and cost in tables 3.1 and 3.2.

Another study focusing specifically on operational measures has recently been conducted. Commissioned by the IMO to assess the EEDI and SEEMP, Bazari and Longva (2011) assessed that a 30% reduction would be possible through the application of measures enabled by the SEEMP only. The dominant measure in this assessment is speed

Table3.1: Operational measures (adapted from Faber et al. (2011))

Operational measures	Gross potential	Cost
Speed reduction	10% or 20%	See Faber et al. (2011, pp. 97-199)
Voyage optimization, reduced port time	0-10%	Not known
Bulbous bow	>10%	Not known
Optimization of ballast and trim	<5%	Not known
Using existing larger ships	<4%	Not known
Increasing cargo load factor	Not known	Not known
Weather routing	0.1-4%	800-1600 USD/year
Autopilot adjustement	0.5-3%	Not known
Increasing energy awareness	Not known	Not known
Polishing on a regular basis	2-5%	3000-5000 USD
Polishing when required	2.5-8%	See Faber et al. (2011, pp. 105-106)
Hull cleaning	1-10%	35-45 USD per foot of the ship

reduction due to increased port efficiency, corresponding to roughly half of the total potential.

A significant contribution to scientific literature has been provided by Eide et al. (2009), Longva, Eide, and Skjong (2010), Eide et al. (2011) and Hoffmann, Eide, and Endresen (2012). Eide et al. (2011) constructed a model to project future CO_2 emissions from shipping, taking into account world fleet development and a range of measures. They conclude that emissions could be reduced by 33% from a baseline scenario when implementing all measures that have a marginal cost below 0 USD. Stabilization at present emissions is technically possible, but any significant total reductions are difficult to reach. Slow steaming has been particularly discussed in recent literature. Corbett, Wang, and Winebrake (2009) found that a fuel tax of 150 USD/ton fuel would lead to reductions in CO_2 emissions of about 20-30%. Lindstad, Asbjørnslett, and Strømman (2011) estimated that emissions could be reduced by 28% through a 19% increase of the world fleet at zero cost, by including also capital cost for the transported goods.

Concluding, it seems as if many of the measures developed and discussed during the 70s and 80s were not institutionalized and made common practice. Many of the more cost-efficient measures are also operational measures. Research in the 70s and 80s highlighted to a large extent the implementation process, for example, the role of crew, the role of organizations, energy managers, performance management and more. Hopefully, more such studies will be carried out again.

Table3.2: Technical measures (adapted from Faber et al. (2011))

Technological measures	Gross potential	Cost
Lightweight construction	0.1-2%	Not known
Optimising hull dimension	<9%	Not known
Aft waterline extension	0.1-2%	Not known
Economies of scale	Not known	Not known
Hull coating	0.5-5%	43000 USD - 265200 USD[a]
Low profile hull openings	Not known	Not known
Optimising water flow of hull openings	1-5%	See appendix
Covering bow thruster hull openings	Not known	Not known
Design speed reduction	Varying[b]	Not known
Optimising propeller hull interface	<4%	Not known
Optimization of skeg shape	<2%	Not known
Interceptor trim plates	<4%	Not known
Air lubrication	10-15%;[c] 5-9%[d]	Varying[g]
Propeller-rudder upgrade	2-6%	Varying[g]
Propeller upgrades (nozzle, winglets etc.)	0.5-3%	Varying[g]
Propeller boss cap with fins	1-3%	146000 USD [e]
Contra rotating propellers	3-6%	Not known
Common rail technology	0.1-0.5%	Varying[g]
Diesel-electric propulsion	<20% [f]	Not known
Main engine tuning	0.1-0.8%	Varying[g]
Waste heat recovery	8-10%	Varying[g]
Towing kite	Varying[g]	Varying[g]
Flettner rotors	Varying[g]	Varying[g]
Hybrid fuel cell auxiliary power generation	<2%	Not known
Solar power	0.2-3.75%	Varying[g]
Low energy lighting	0.1-0.8%	Varying[g]
Energy efficient HVAC	Not known	Not known
Speed control of pumps and fans	0.2-1%	Varying[g]
Fuel-efficient boilers	Not known	Not known

[a] For a Panamax bulker
[b] Higher than operational speed reduction
[c] For a tanker
[d] For a container ship
[e] For a 22,050 kW engine
[f] Depending on operational profile
[g] See Appendix II, Faber et al. (2011)

4 The energy efficiency gap

> Reason is, and ought only to be the slave of the passions, and can never pretend to any other office than to serve and obey them.
>
> *David Hume*

Great ideas for increasing energy efficiency in shipping have apparently been around for a long time. Recent assessments show that substantial reduction could take place that would bring cost-reductions across the sector. This immense potential for cost-efficiently increasing energy efficiency seems at first glance to imply a paradox: why aren't there more energy efficient ships and better practices in the industry to save energy and money? Reality seems to differs greatly from what these models and assessments predict. The phenomenon, observed in many sectors, has been referred to in literature as an energy efficiency gap (Jaffe and Stavins, 1994).

In the following sections, research attempting to explain this gap will be reviewed in three broad groups: from the perspective of engineering and economics, from social science in a broad sense, and from studies of energy management practices in organizations. These groups may feel a bit *ad hoc* and somewhat overlapping. The first group is interesting because it contains most of the "barriers to energy efficiency" discourse; the second because it is partly formulated as a critique; and the third because it is a field where more research has been called for (Thollander and Palm, 2012). The review is not in any sense complete, but is rather a result of the snowballing method of literature search that I've used time and time again throughout the project—a method which is mostly constrained by the need to prevent "information overload" (Wilson, 1996).

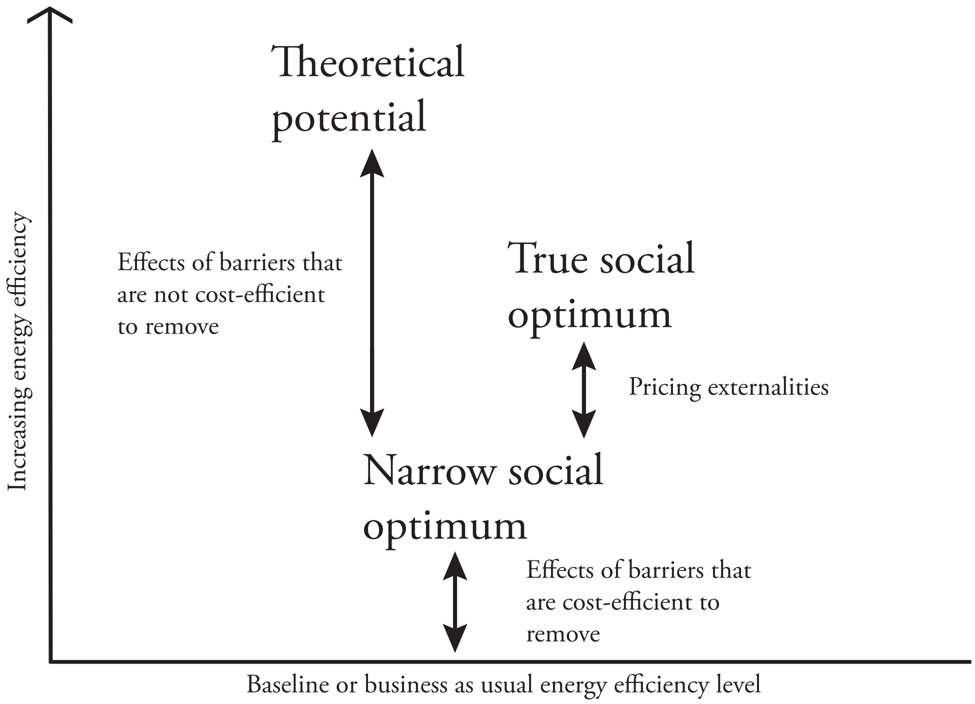


Figure4.1: The energy efficiency gap, adapted from Jaffe and Stavins (1994)

4.1 The economics vs the engineering perspective

A large potential for improvement was noted in many sectors after the oil crises (York et al., 1978). One can perhaps a bit simplified divide the early energy efficiency literature into the optimistic engineers who asserted the existence of this large, cost-efficient potential, and the pessimistic economists who saw the non-adoption of these measures as a sign that there was no *economic* inefficiency: markets had simply made a rational choice to allocate resources for other, more lucrative, purposes (Sanstad and Howarth, 1994). The engineers developed a taxonomy of various *barriers* that explained the slow diffusion of these measures. Economists later intervened to tighten what they perceived as slack use of economic concepts, so that it could be discussed whether these barriers were not just "benign characteristics of well-functioning markets" (Sutherland, 1991). It became possible to make a distinction between barriers and *failures*, failures being a subset of barriers in the sense that these are cost-efficient for society to remove (Jaffe and Stavins, 1994).

This difference, between the theoretical potential and the potential that is achievable through the removal of failures (the "narrow social optimum"), is visualized in Figure 4.1. Some of the barriers will not be cost-effective to remove, but some are, which produces the difference from the baseline energy efficiency level. The marginal abatement costs curves discussed briefly in Chapter 2 is a "theoretical" potential by this definition. Also shown is the effect of pricing externalities, that will bring us further towards the hypothetical potential, to the "true social optimum", as more barriers become cost-efficient to remove.

The term "barriers" is used differently by different researchers and it is inspired by theory from various disciplines. Regardless of the connection to the economical concept of market failures, "barrier" is most often used in a wider sense, including barriers in institutions, organizations and individual behavior (Weber, 1997). Sorrell et al. (2004) defined barriers in the following way:

> [Barriers] are defined as postulated mechanisms that inhibit a decision or behavior that appears to be both energy efficient and economically efficient. [...E]ach of these barriers may have a number of contributory mechanisms and several of these mechanisms may coexist in different situations. (p. 8-9)

"Failure" is used in a wider sense in energy efficiency literature. That is, government intervention also into barriers within organizations is justified if the total cost of intervention and implementation of measures is lower than the savings. From that follows a clear position on what kind of knowledge is needed:

> Ultimately what is required are detailed empirical studies of the nature, origin and operation of the supposed barriers to energy efficiency in a wide range of service markets, together with evaluation studies of the costs and benefits of different types of policy intervention. (p. 4)

In the following two subsections, we will briefly cover the theoretical framework underpinning most of the barriers discourse. It reiterates some of the discussion present in Paper I, but is included here to enable a smoother reading. After that, in the next section, criticism and additions to the barriers discourse are presented.

4.1.1 The role of information

A common theme in energy efficiency literature is the role of information. In order for an individual to make an informed decision about a measure supposedly leading to increased energy efficiency, that individual at least needs estimates about the likely results of the measure and its costs. Markets for measures, or in economic terms, "goods", are expected to be affected by market failure depending on how difficult it is to gain access to information about the product's performance, quality etc. Goods can in this sense broadly be divided into three categories: search goods, experience goods and credence goods (Nelson, 1970; Stern, 1986). With the first type of good, it is possible for the customer to acquire relevant information about a good before purchase. Experience goods need to be used by the customer before quality attributes, performance and other characteristics can be determined. Lastly, credence goods are goods where it is difficult to gather information even after purchase and use.

In this kind of situation, where sellers know more than buyers, information is said to be asymmetrically distributed. Before an agreement, there may be reasons for a vendor of a particular product or service to avoid providing full information on quality or performance. This is known as *adverse selection*, and is also a market failure. Akerlof (1970) famously demonstrated that in markets where it is difficult for buyers to assess the quality of goods—such as markets for second hand cars—sellers are incentivized to market goods of poorer-than-average quality. This leads to a reduction of the average quality of goods, and the market becomes dominated by so called "lemons".

4.1.2 Principal-agent problems

Now consider the case where it is difficult to monitor performance *after* a contractual greement, for example in the case of a service. The procurer of the service (typically referred to as the *principal*) will then have difficulties discovering if the party performing the service (the *agent*) is behaving according to the contract. Assume that these actors have partly differing long-term goals, for example that they aim for profit maximization in their respective companies. It would to a certain extent be rational for the agent to act opportunistically and cheat on the principal.

There is now a market failure due to *moral hazard*. The principal would gain from investing in a monitoring regime to assess the performance of the agent, and the agent would then also pay cost for compliance. Compared to the situation where the principal would have performed the service by him or herself, there is a net residual loss. These types of problems are called *principal-agent problems*, or simply agency problems and are accompanied by a rich stream of theory and empirical research (Jensen and Meckling, 1976; Furubotn and Richter, 2005).

Principal-agent problems have been shown to have substantial impacts on processes to improve energy efficiency. In a review of case studies in five countries carried out by the International Energy Agency, principal-agent problems alone affected energy use for 3,8 EJ, or 85% of the total energy use in Spain in 2005 (T'Serclaes and Jollands, 2007). Furthermore, from a policy perspective, these problems are due to their complex and specific nature said to be difficult to target through single policy interventions. T'Serclaes and Jollands (2007) noted that principal-agent problems are "pervasive, disbursed and complex", and argued that sector-specific and country-specific sets of policies need to be designed.

Principal-agent theory has barely been applied to the shipping sector. Strandenes (2000) studied the relationship between owners and charterers of vessels as a principal-agent relationship, and argued that charterers would not be willing to pay higher charter rates for higher quality vessels since they cannot themselves identify them. Similarly, sellers of second hand ships have more information on ship performance than do buyers. There is thus an adverse selection problem, making it difficult for high-quality ship providers to operate in the market. Moreover, a moral hazard problem arises if the charterer is unable to monitor the performance of the ship. Middle-men, in this case classification societies, are used to sort out the really low quality vessels (Biglaiser, 1993). Vetting is employed for similar reasons. However, they might not separate high-quality vessels from those of normal quality, as displayed in Figure 4.2.

In the words of Akerlof (1970), markets for ships are markets for lemons; it is very difficult for a charterer to understand the performance and quality of a ship, and the seller of a ship will know more about performance and quality than do the buyer. In such markets, ships with better than average quality or performance will not get a premium, and as such they will not be built. It is easy to extend this reasoning to the energy efficiency of vessels.

4.1.3 Split-incentives

Principal-agent problems have much in common with what in energy efficiency literature is typically referred to as a *split-incentive* problem. In such situations, energy efficiency measures are foregone because even if a potential adopter of a particular measure could be aware of the possibilities, another party bears the energy costs and would thus receive the benefits. In the building sector, these have been discussed at length (Blumstein et al. (1980) for example, contains several case studies). For example, the builder of a house has little incentive to minimize life-cycle costs, but rather initial construction costs. The

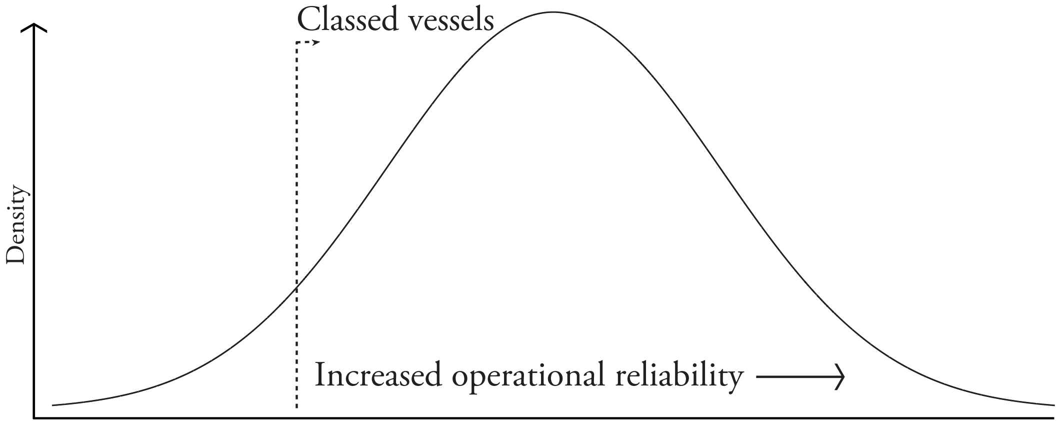


Figure4.2: Distribution of vessels according to operational reliability. Adapted from Strandenes (2000)

builder will thus make energy-inefficient choices of equipment and material, and as a result the overall investment in energy efficiency is not efficient from the perspective of the tenant. Another example is the *landlord-tenant* problem. Renter-occupied buildings (where energy is payed by tenant) are presumed to have less energy efficient technology than buildings that are owner-occupied (i.e. the tenant is the owner).

The concept of split-incentives in shipping has been discussed in reports to the European Commission (Faber et al., 2009, pp.94-98). The dominant split-incentive situation is probably that bunker costs are often payed by the charterer and not the operator. Faber et al. (2009) guessed that bunker fuel costs are passed on to the cargo owner in 70 to 90% of all contracts (p. 95). But even when the bunker costs are internalized, split incentives may also arise in the cases where some functions are outsourced. A technical management company may for example economize on maintenance costs to increase their profits. This may affect bunker costs, but since these are passed on to the commercial operator, the incentive disappears (Buhaug et al., 2009, p.64).

4.1.4 Transaction costs and organizational failure

An important assumption in neo-classical economics is that market operations are costless. Rational choice by actors in the market is enabled by immediate access to all information at zero cost. In such a setting, why cost-efficient energy efficiency measures are not implemented is surely a paradox. A natural development in economic thought was the introduction of positive such costs, referred to as *transaction costs*. Without these, it would make no sense for firms to exist at all: everyone could just procure everything from a market (Coase, 1937). Transaction costs are, simply put, the "costs of running the economic system" (Arrow, 1969), or in the words of Williamson (1981), the market equivalent of friction:

> A transaction occurs when a good or service is transferred across a technologically separable interface. One stage of activity terminates and another begins. With a well-working interface, as with a well-working machine, these transfers occur smoothly. In mechanical systems we look for frictions: do the gears mesh, are the parts lubricated, is there needless slippage or other loss of energy? The economic counterpart

> of friction is transaction cost: do the parties to the exchange operate harmoniously, or are there frequent misunderstandings and conflicts that lead to delays, breakdowns, and other malfunctions. Transaction cost analysis [...examines] the comparative costs of planning, adapting and monitoring task completion under alternative governance structures. (Williamson, 1981, pp. 552-553)

Included in the concept of transaction costs is thus not only costs for searching for information in markets, but also costs internally to the firm. Neo-classical economics usually treats firms as "black boxes", and disregard these kinds of factors, but later economic literature problematized this treatment. Stiglitz (1991), for example, made it clear that "if economists wish to understand how resources are allocated, we must understand what goes on inside organizations." (p. 15). One can then discuss market as well as managerial transaction costs (Furubotn and Richter, 2005, pp. 51-57). In this way, complete rationality as enabled by free access to information is replaced by a rationality *bounded* by its abilities to search and process information (Simon, 1997).

The earlier energy efficiency literature seemed to avoid transaction costs as a possible target of government intervention (Jaffe and Stavins, 1994). Sorrell et al. (2004) argued for its inclusion, and thus analogously extending the concept of market failures to also include *organizational failures* when existing firm structures do not lead to efficient use of society's resources (see e.g. also Gabel and Sinclair-Desgagné (1997)). This opens up for policies that attempt to change firm structures and behaviour, if this can be argued to be cost-efficient for society. In paper III, it is argued that the SEEMP could be understood in this way. On the same note, mandatory implementation of energy management systems have been a successful part of governmental energy efficiency programmes for industry (Stenqvist and Nilsson, 2011).

The introduction of transaction costs into the energy efficiency discourse makes it easier to fathom the large cost-effective potential: there are other costs associated with the measures that are excluded in the assessments, like building and maintaining sub-organizations that search for, implement and follow-up on measures.

The application of transaction cost economics (or *new institutional economics*, a common denominator for economic theory past the neo-classical (Furubotn and Richter, 2005)) to shipping is rare. Button (2005, p.52), when attempting to "look at the degree to which we really understand the economics of the shipping sector" conclude that while "the new institutional economics itself still has severe limitations, its broader perspective may offer a more satisfying, holistic way of looking at the economics of shipping. To date, however, the literature taking this track is relatively thin."

For readers unfamiliar with the shipping industry, Figure 4.3 below shows a typical division of actors in a shipping service. Many different actors might be involved: a ship owner, a port (with its many sub-organizations), a crewing company, a technical management company, a commercial ship operator, a cargo owner. In some cases, these roles are integrated within the same company, in others they are separate. Sometimes additional agents are involved for example between cargo owner and ship operator. Shipyards play a role, as do banks when providing finance to shipping companies or as actual ship owners. Depending on how well these gears mesh, transaction costs are expected to arise.

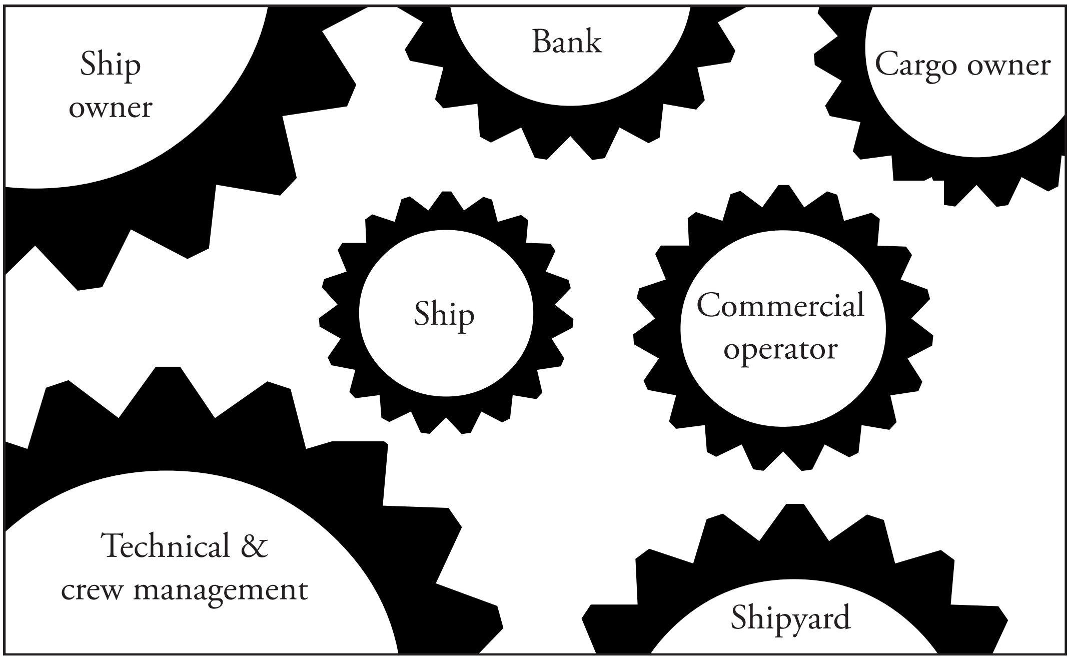


Figure4.3: Examples of actors involved in shipping

4.1.5 Resulting barriers to energy efficiency

The classification of barriers as done by Sorrell et al. (2004) has become something of a standard in recent literature, and will for that reason be re-iterated here. Based on a similar theoretical overview provided in previous subsections, they proposed six barriers (p.55):

- *Risk:* energy efficiency investments may represent higher technical or financial risk than other types of investments.
- *Imperfect information:* companies may neglect cost-efficient measures because of a lack of information about them.
- *Hidden costs:* transaction costs such as costs for searching and analyzing information, as well as managerial transaction costs due to staff training, monitoring regimes etc.
- *Access to capital:* insufficient capital internally, difficulties raising external funds, internal capital budgeting procedures or short-term incentives for staff.
- *Split incentives:* for example, individual departments are not accountable for their energy use.
- *Bounded rationality:* individuals are constrained by time, attention and the ability to process information.

For ideas on how to study barriers empirically through case studies, please see e.g. Sorrell et al. (2004, pp. 54-82).

4.2 The social science perspective

The discussion in the previous section was dominated by theories and frameworks mostly derived from economic theory, leading to a broad taxonomy of barriers. A broadened understanding can be gained from connecting with various social scientists.

Some have studied what we really know of organizations and efficient use of resources. Their conclusion is that organizations should perhaps not be expected to behave according to rational routines and rules (Meyer and Rowan, 1977). Organizations seem to be more shaped by surrounding institutions than for example profit maximization. Actually, organizations may become more similar over time, rather than more efficient (DiMaggio and Powell, 1983). For example, the tendency to recruit from a small number of educational institutions and having closely guarded and set career paths effectively filters personnel so that "the individuals who make it to the top are virtually indistinguishable". Further, "they will tend to view problems in a similar fashion, see the same policies, procedures and structures as normatively sanctioned and legitimated, and approach decisions in much the same way." (p. 153).

Shove (1998) criticized the use of barrier models altogether because of the focus on separating the social from the technical—that there are measures that go unadopted because of some social barrier. She favours instead frameworks which are "contextual, localized and temporally specific" (p. 1109). Her conclusions with regard to typical assessments of potential, is that if the non-adoption of these cost-effective measures can be made intelligible through "perfectly explicable sociotechnical reasons", these measures should not be treated as relevant for CO_2 abatement. The challenge for science thus lies providing deeper understanding of the socioeconomic, cultural and environmental context in which markets energy-using goods exist (Lutzenhiser and Shove, 1999), and also what is necessary for the future if we want to see these measures realized:

> [W]hat new techno-economic networks do technological visions presume and what forms of social re-alignment are required along the way? More prosaically, what would everyday life be like in a world which used 50 or even 20% less energy? What organisations are involved, what sorts of companies are implied, and how are the details of energy consumption to be arranged? In other words, there is real work to be done in articulating the features and characteristics of social worlds presupposed by proposed energy-saving scenarios (de Laat, 1996). (Shove, 1998, p. 1110)

Along this line of reasoning, scientists have sought to increase understanding the social and institutional context of energy efficiency measures. Palm (2009) used lifestyle categorization from research on households adapted to explain attitudes to energy efficiency in industrial small-medium sized enterprises (SMEs). Palm and Thollander (2010), when re-examining previous research, emphasized that the barriers that had been found were embedded in "traditions, value structures and rumors that the actors seldom have tried to verify or refute." (p. 3258). They suggest also that perspectives to barrier theory could be brought by in-depth studies of company energy efficiency discourses, "i.e. how employees talk about energy efficiency and how the discourse relates to environmental issues and cost allocations in regard to energy efficiency measures." (p. 3258). Ryghaug and Sørensen (2009) studied the Norwegian building industry from the supply-side point of view and concluded that lack of public policy, a conservative industry and low government interest were main causes of why energy efficiency "fails". They also highlighted the formidable challenge in producing a comprehensive analysis due to the many actors, institutions, practices, and industrial and market structures involved. Biggart and Lutzenhiser (2007) discussed our perception of rationality in decision-making when it comes to energy efficiency in the building sector:

> [F]ailure to decide and failure to act can sometimes be traced to the division of labor, power and responsibility in the organization. For example, the separation of "environmental" mandates from "operations" may mean that the impetus from the former cannot affect the latter. The low status of "buildings" and "facilities" departments (and their managers) vis-à-vis better positioned and endowed "marketing", "production," and "finance" actors and groups are disadvantaged in struggles for resources. In addition, accounting rules (e.g., annual budgeting or the separation of "capital" and "operating" budgets) and conventions (e.g., regarding organizational priority setting or abundant heating/cooling "to please customers") shape (and block) efficiency choices. So the "decision maker" is usually neither an individual nor necessarily able to execute "best practices" even when well understood. Choices are made by organizations–that is, as social outcomes, and by means of social arrangements. (p. 1079)

Compared to the approach outlined in this section, the barriers approach can thus been criticized for being reductionist (Palm and Thollander, 2010), i.e. reducing reality into elementary abstract concepts (in this case barriers) and then attempting to gain understanding by analyzing these abstract parts.[1] We will return to this critique somewhat in the next chapter on whether such ultimate theories are useful.

4.3 Studies of energy management in organizations

It has been argued that we do not really understand what is going inside organizations when it comes to energy efficiency. Sorrell et al. (2000) described the area as being "the least developed", and a decade later, Thollander and Ottosson (2008) still point to a gap in research literature when it comes to understanding actual energy management practices and strategies in companies. Bunse et al. (2011) argued that existing energy efficiency research is not practical and comprehensive enough to address the needs of industrial production companies, and called for future collaborative research projects. Trianni and Cagno (2012) noted that while there is a "huge" amount of theoretical contributions on barriers in literature, empirical investigations are more scarce.

Selmer (1991, 1994) studied management practices through longitudinal case studies of five companies in the building sector during five years. Starting from a study of 69 building management organizations, he picked out five to represent different types of organizations and energy management practices. Two broad groups in Selmer's taxonomy are defensive and offensive organizations, characterized by having little control over their revenues, or as much control over both costs and revenues, respectively. His conclusion is that different kinds of policies are needed since they affect companies differently. For example:

[1] In some of the more recent literature, for example, researchers attempt to make a distinction between "perceived" and "real" barriers, as well as to separate barriers as far as possible: "[T]o clearly identify the barriers, it is important to precisely separate all the barriers, thus avoiding any possible overlap or implicit interaction. Therefore, on the one side, the elements of the taxonomy should be reduced to the minimum terms, in order to analyze the possible interactions among independent barriers."(Cagno et al., 2013, p. 295). Contrast that with Shove's arguments, or the viewpoint of earlier energy efficiency research, for example DeCanio (1993, p. 907): "[A]n understanding of the forces that lead to any particular pattern of behaviour (regarding, say, energy management) could only be obtained by a careful, microlevel examination of the actual decision making processes of the firms themselves. It would be necessary to see, *in specific instances*, exactly what sort of informational, computational and organizational constraints were faced *by particular firms* in order to understand why they did or did not make particular investments." (my emphasis)

> [Defensive organizations] can be influenced by governmental programs subsidizing or sponsoring the establishment of organizational positions in charge of energy-conservation management. Once established, such organizational positions can more easily be identified and become the target of governmental training programs and informational support to sustain energy-conservation activities in those organizations. (Selmer, 1994, p.1029)

Managers interested in improving practices will also face different kinds of challenges. In defensive organizations, they may need to create specific sub-organizations that work with energy efficiency. Top management support is especially necessary. This is not as important in offensive organizations:

> [Managers in offensive organizations] could either offer their respective organizations additional business opportunities or improve the economic situation of the regular business activities through energy-conservation management. In the former case, energy-conservation management would be developed into specific business proposals, based on the technical competence and market opportunities of their respective company. In the latter case, energy-conservation management is performed as a means of cost control to keep unit costs at a low level. (p.1029)

Cebon (1992) studied behavioural aspects of energy management at two universities. He emphasized that the people making decisions concerning energy efficiency measures need to have sufficient information gathering and analysis capacity, as well as sufficient power within their organizations to implement solutions. One of the universities had a decentralized organizational structure, while the other was more centralized. In the former university, simple and cheap solutions had been implemented (like energy efficient lighting) while the latter had been able to implement more expensive solutions that spanned organizational boundaries (like centralized heating control systems).

Kannan and Boie (2003) looked specifically at energy management practices in small-medium sized enterprises (SME), where limited efforts are seen partly due to lack of expertise, access to finance and low energy costs in relation to total costs. In a case study of the introduction of energy management in a German bakery (an energy-intense industry), they aim at providing a guideline for implementing energy management in such companies. A lot if initial work was put into finding past data of benchmarking. The authors highlight the role of a third party in starting up the process (in this case study, the company did it themselves), to avoid bias and bring in external knowledge.

Researchers have used more directly the barriers framework for understanding management practices. Rohdin and Thollander (2006) investigated barriers and drivers for better energy management practices in Swedish non-energy intense manufacturing industry. Barriers included costs and risks due to possible disruptions in production, lack of time and lack of sub-metering, i.e. the ability to measure and analyze energy use at a more specific organizational level, not just overall use. Drivers included ambitious staff and the existence of a long-term energy strategy. The same drivers were found in a continued study by Rohdin, Thollander, and Solding (2007) on the Swedish (energy-intensive) foundry industry. Barriers were also similar, but included also lack of access to capital for investing in measures. Thollander and Ottosson (2010) described and analyzed energy management practices in the pulp and paper industry and the foundry industry in Sweden. They mentioned the management trend of focusing on core business, which might leave out energy management even if energy costs are a large part of total costs (p.1126).

They conclude that if the energy intense industry does not prioritize energy management, neither will less energy intense industries, indicating a great potential that has not been realized.

Finally, at least two groups of researchers have approached energy management from the more general perspective of production and performance management, and information technology. Based on an effort to discern gaps between research and industry needs in this areas, Bunse et al. (2011) outlined three future research areas: measurements, including KPIs and benchmarks; control and improvement, particularly enhanced decision support tools and in-process measurement systems; and other enablers, such as energy management standards. Sivill et al. (2012) explored how energy performance measurements were prioritized in three energy-intensive companies in Finland. They identified a need to further develop systems for such measurements: "[t]here is a lack of explanatory information and translating data into knowledge". Further, the know-how of operators was not used and energy efficiency was seen mostly as a management issue. They recommended that further research is directed towards understanding the actual managerial process of energy performance measurements. This could be done in the form of case studies, where better measurement systems are designed and implemented.

4.4 Personal reflections

Some personal reflections will conclude this chapter. I mentioned in the previous climate change chapter that the use of marginal abatement cost assessments for policy-making had been problematized (Kesicki and Strachan, 2011; Kesicki and Ekins, 2012). I interpret this as a re-formulation of the debate that has been going on between economists, engineers and social scientists since the beginning. The conclusion seems to be that we cannot create policies that assume that companies will behave "rationally". The explanations are diverse: there are market failures and barriers, organizations are not rational, institutions shape organizations more than the quest for profit, and the manner in which companies organize their effort to improve energy efficiency matters. The last perspective—that organizing matters—has been the starting point of this research project. By trying to understand what companies and individuals actually have to do, how they in nitty-gritty detail need to change to increase energy efficiency of their operations, we could perhaps also understand why there seems to be such a large cost-effective potential. As will be discussed in the next chapter, it was necessary to work *together* with the actual organizations in order to do this. There was no room for the detached scientists. This choice will now be looked at from a epistemological perspective. What kind of science is the science of understanding how companies change in order to be better at energy efficiency? Many have argued that this kind of science is not only possible but in some cases necessary.

5 How can science contribute?

A task becomes a duty from the moment you suspect it to be an essential part of that integrity which alone entitles a man to assume responsibility.

Dag Hammarskjöld

THE previous chapters have outlined and sketched a tricky problem. Increased shipping facilitates growing economies as they increase international trade. Increased energy efficiency will play a crucial part in meeting this demand, as a way to curb the growth of emissions. However, based on what innovations regarding energy efficiency we see before us now, the sector growth is projected to be faster than what these measures can achieve. As was discussed at length in the previous chapter, it is also most troubling that the shipping market does not even implement measures that are existing and cost-efficient. Increasing energy efficiency would also cut costs for shipping companies in the present times of high fuel costs, great supply of vessels and not enough demand. How can this problem be understood and solved?

Sometimes society demands solutions to problems from the scientific community that are different from those asked by science itself. These problems cannot be "neatly divided into clearly separable elements, one scientific, the other political" (Weinberg, 1972, p. 209). Neither do they seem to arrange themselves nicely within a single scientific discipline (Collingridge and Reeve, 1986). Concurrently, society demands an urgent solution. I believe—as do hopefully also you, the reader, having read the previous chapters—that the issue sketched in this thesis falls within this class of problems. Should scientist try to address such problems?

5.1 Science, sustainability and society

Popper (2002) urged us to not loose sight of problems when working within a scientific discipline, problems "which may cut across the border of any subject matter" (p. 88). Disciplines, he argued, were largely there for historical reasons. Confinement within disciplinary research is attractive, however, as it enables scientists to be really efficient at solving certain kinds of problems:

> Just because he is working only for an audience of colleagues, and audience that shares his own values and beliefs, the scientist can take a single set of standards for granted. He need not worry about what some other group or school will think and can therefore dispose of one problem and get on to the next more quickly than those who work for a more heterodox group. Even more important, the insulation of the scientific community from society permits the individual scientist to concentrate his attention upon problems that he has a good reason to believe he can solve. Unlike the engineer, and many doctors, and most theologians, the scientist need not choose problems because they urgently need solution and without regard for the tools available to solve them. (Kuhn, 1996, p. 164)

Kuhn's view of the scientist is less in fashion today, as society is continuing to demand solutions to its own tricky problems.[1] It has been argued for decades that a new mode of research has been emerging, or needs to emerge. This new mode is to a larger extent based on articulated needs in society, rather than on problems generated by traditional academic disciplinary research. It has been referred to as, for example, Mode-2 (Gibbons et al., 1994) or post-normal research (Funtowicz and Ravetz, 1993), the latter a reference to Kuhn's distinction between normal science and scientific revolutions. In this new context, scientists need to somehow mingle with the rest of society. For example, Etzkowitz and Leydesdorff (2000) saw a need for academia to, apart from research and education, focus on a "third mission" of economic development together with industry and government as part of a "triple-helix" innovation structure. Ziman (1996), however, saw a risk in losing objectivity:

> The virtue of academic science was that it took a strong line in support of the norm of 'disinterestedness' and often managed in practice almost to live up to its ideals. The transition to post-academic science is eroding the practices that underpin this norm. [...] Objectivity is what makes science so valuable in society. It is the public guarantee of reliable disinterested knowledge. Science plays a unique role in settling factual disputes. This is not because it is particularly rational or because it necessarily embodies the truth: it is because it has a well-deserved reputation for impartiality on material issues. (p. 382)

In particular, society poses tricky problems to scientists when it comes to policy issues related to the effects of human activity on the natural environment. These problems are tricky in at least two ways. First, human and natural systems are "coupled" in the

[1] Different problems may still require different approaches. As Friedrich Hayek argued "The physicist who is only a physicist can still be a first-class physicist and a most valuable member of society. But nobody can be a great economist who is only an economist—and I am even tempted to add that the economist who is only an economist is likely to be a nuisance if not a positive danger." (Hayek, 1956, p. 463). He received the Nobel Memorial Prize in Economic Sciences some twenty years later. Perhaps his argument applies not only to economists but also to engineers.

sense that the one always affects the other (Liu et al., 2007). Policies that attempt to solve these problems need to be based on understanding provided by different scientific disciplines. Second, the solutions need to be useful in practice, bearing in mind that there are no panaceas, no blue-prints that apply equally everywhere (Ostrom, 2007). For these reasons, it is necessary to deviate from the traditional definitions of objectivity and disinterestedness. Scientists working on these kinds problems rather need to seek quality assurance from a wider group of stakeholders, and not only from peer-review within their own disciplines. Proponents of *sustainability science* typically argue that in order to reach such usefulness, knowledge even "needs to be 'coproduced' through close collaboration between scholars and practitioners." (Clark and Dickson, 2003, p. 8059), i.e. such research needs to be *transdisciplinary*.

Of course, already the Ancient Greeks knew about this. Within social science, *phronetic* research, or *phronesis* has recently emerged as a discourse with similar aims as those described above (Flyvbjerg, 2001). *Phronesis* is one of Aristotles three intellectual virtues—kinds of knowledge—besides *episteme* and *techne*: *Episteme* represents what is usually considered as 'scientific' knowledge: knowledge that is universally applicable and analytically derived. *Techne* is a similar mode of knowledge, though directed at technical application and know-how, like how to construct buildings. For the definition of *phronesis*, Flyvbjerg (2001) quotes Aristotles original definitions:

> Prudence [phronesis] cannot be science [episteme] or art [techne]; not science, because what can be done is a variable (it may be done in different ways, or not at all), and not art because action and production are generically different. For production aims at an end other than itself; but this is impossible in the case of action, because the end is merely doing *well*. What remains, then, is that it is a true state, reasoned, and capable of action with regard to things that are good or bad for man... We consider that this quality belongs to those who understand the management of households or states. (pp. 56-57)

Flyvbjerg (2001) argued extensively that *phronesis* is of more relevance to social science.[2] Social scientists should rather than try to emulate the natural science (produce

[2] In fact, the traditional (positivist) stance in social science has been under attack for decades, sometimes in harsh language. Greenwood (2002) recently questioned "how many times the intellectual incoherence and bankruptcy of conventional social science must be asserted by philosophers and social theorists (Fuller 2000; Rabinov 1984; Bourdieu 1997; Giddens 1973) before those conventional social science practitioners, who claim to be more than fee-for-service researchers in positivist body shops, simply accept their failure and abandon their field. [...] To be blunt, it is clear that the conventional social sciences are not driven by the intensity or importance of social problems. They are driven by external funding and oriented around professional communities of social researchers commenting on each other's work, answering commentaries, and commenting again." (pp. 118-119). In more practical terms, Moreby (2004) noted in an editorial to *Maritime Policy & Management* that research on shipping a couple of decades ago had not been as "academically vigorous" as today, but had been closer connected to "real shipping": "it is fair to say that the nature of the papers changed when it became more difficult to carry out field research. Contributions shied away from the turbulent reality of global shipping and focused on 'safer' topics such as container shipping, ports and terminal operations, competition policy, pricing, regulation, and fiscal policies, etc. In this author's view, these topics have been so extensively researched and reported that they are now as dry as dust. In fact, they are like the dry, white bones of a wildebeest lying out in the sun after the lions, jackals, vultures and ants have all picked over them!" (p. 90). He also argued that academics should try to not take themselves too seriously and try to enjoy life more. He recommended that real shipping could be better understood for example by having "a few beers then go and kick down a few doors in London, Piraeus, Mumbai and Hong Kong." (ibid, p. 91)

general, predictive theory), attempt to answer other kinds of questions, like: Where are we going?, Is this desirable? and What should be done? These are different kinds of problems than those addressed by the natural sciences, which have had "little to offer to the reflexive analysis of goals, values, and interests that is a precondition for an enlightened development in any society." (Flyvbjerg, 2001, p. 53). The conclusion is that "where natural science is weak, social science is strong" (p. 53).

Later, Flyvbjerg (2012) highlighted that the results of phronetic research are results only to the extent that they have an impact on practice:

> In public affairs, reason is made capable of action by effectively having reason enter the public sphere and public deliberation. It is reason times exposure in the public sphere that matters, not reason alone. (p.95)

Flyvbjerg, who has had a long background of successfully exposing poor planning in megaprojects (Flyvbjerg, Skamris Holm, and Buhl, 2002, 2003, 2004, 2005), emphasized the importance of focusing research on "tension points". At these points, practice is so fraught with potential conflicts, that even problematization of the matter by a single researcher can initiate large changes. The call for such research comes also with a warning; researchers should not expect it to be easy. On the other hand, Flyvbjerg is clear that this is probably an inherent part of this kind of research: "if nobody is against a specific piece of phronetic research, most likely the research is unimportant as regards its implications for practice." (Flyvbjerg, 2012, p. 117).

In summary, there has been a strong movement the last decades for research to be carried out in a participatory manner, together with other stakeholders which are affected by some problem, not only related to sustainability but also to social science as a whole. Now that we have discussed the *why*, we will in the remaining parts of the chapter go through *how* previous researchers have been doing this in more detail. The specifics of *this* research project will come in the next chapter.

5.2 Action research

Transdisciplinarity and participatory research methodologies are key concepts in problems related to sustainability. In this section, the concept of *action research* will be introduced and discussed. In order for us as researchers to be able to identify problem areas and work out solutions, we need to cooperate well with our surroundings. Hirsch Hadorn et al. (2006) argued for the need to address three basic questions:

1. In which way do processes constitute a problem field and where are the needs for change?
2. What are more sustainable practices?
3. How can existing practices be transformed?

In the previous chapter, it was argued that management practices may need to be transformed in order for a company to be more successful at increasing energy efficiency. Researchers have called for more studies on actual management practices. This provides an answer to the above question number one. Basically, there were two ways in which we could have explored questions two and three. Either through locating and studying organizations that were already, by their own accord, successful at increasing energy efficiency of their operations. From these studies, we could also attempt to retrospectively understand their route from *non*-successfulness. Or, we could (and so we did) study organizations that were still in motion, still understanding their own need for change. In this way, we could be part of the process from the beginning. It would perhaps also be easier to address question number three.

Kurt Lewin, who is usually attributed to be the originator of action research methodology, famously wrote: "Research that produces nothing but books will not suffice." (Lewin, 1946, p.35). This is not only because end results are nice and hopefully appreciated by society. Researchers have argued that it increases the likelihood that the researcher is exposed to reality; that it produces more interesting results. Action research is about finding a point of mutual interest between researcher and the stakeholders involved. Without such a mutual interest, the researcher may not get the understanding or data he or she had hoped for. Gummesson (2000) gave the following example as a warning:

> Over a lunch, the following conversation took place between myself and a senior marketing executive from a major multinational corporation based in Europe (E = executive; A = author).
>
> E: Some type of professor is over here again from the USA wanting to interview us about strategy. He had a long questionnaire with him containing about fifty different factors. He wants to find out which factors are important when we decide to enter a new market.
> A: What are these factors?
> E: Just the usual sort of thing—market potential, competition, political stability, et cetera.
> A: What did you reply?
> E: Well, you know, you go through the list and tick of a few factors, show him some marketing plans, and then send him off to meet a few other people. I have no idea what he gets out of it all.
> A: You don't seem too enthusiastic about his research.
> E: No, it doesn't really work like that in practice, does it? Let me tell you what happened when we decided to enter a country in Latin America. Four of us got together over a dinner in New York: a divisional director, the vice president of R&D, a department head, and myself. We sat and chatted around the problem but just couldn't agree. In the end we had to take a vote: two in favor, one against, and one undecided. Well, that was it; in we went. Two men flew down on the following Thursday to check the lay of the land.
> A: Did you tell the professor about all this?
> E: Of course not! He might have thought that we're not serious.
>
> (p.26)

Moreover, not only may the lack of a mutual interest in a traditional management research project represent a problem, but also the *form* of the data. Archival records, questionnaires, interviews and observations might provide only superficial kind of access (pp. 25-55). The reason is that an intervention setting enables the researcher to get closer to stakeholders' "theories-in-use" rather than their "espoused theories" (Argyris, 1976); what they actually do, rather than what they say they do. In that sense, action research provides a direct access to management reality. Insights can be drawn from "naturally occurring data in the form of expressed experiences, views, action-centered dilemmas, actions of participants and events in the life of practitioners rather than through interviews or questionnaires"

(Huxham and Vangen, 2003, p. 385). Further, a focus on change processes by itself produces more interesting data: "intervention settings can provide rich data about what people do and say—and what theories are used and usable—when faced with a genuine need to take action." (p. 385). Finally, the researcher is simply believed to learn more when actively participating in change processes rather than observing (Gummesson, 2000, p.80).

The drawback of having "rich" data is of course that it is by definition heterogeneous, complex and even messy. Just like "real" problems (Näslund, 2002). Formally analyzing such data is no easy task. Eden and Huxham (1996) were clear on the fact that there needs to be an explicit process, though what it is exactly is less important:

> [T]hough we may debate the validity of any particular one; what is crucial is that the process exists explicitly. [... T]he outcome of data exploration cannot be defended by the role of intuitive understanding alone—any understanding must be informed by a *method of exploration*. In essence this means that compared to the 'everyman' as researcher, professional researchers need to be professional. (pp. 81-82)

In a later paper, it does not seem as if this methodology needs to be explicit *as it happens* (Huxham and Vangen, 2003). Rather, they identify the stages that their analysis had gone through "in hindsight". Moreover, at the start of the project, they "had no expectations for the kind of output we would produce." (p. 245). Coughlan and Coghlan (2002) argued for the importance of a research cycle: of data gathering, data feedback back into the organization, collaborative data analysis, action planning, implementation and evaluation. A meta-step of monitoring by the researcher takes place through-out the cycle. Flyvbjerg's argument support Huxham and Vangen's:

> The most important issue is not the individual methodology involved, even if the methodological questions may have some significance. It is more important to get the results right, that is, arriving at a social science which effectively deals with public deliberation and praxis, rather than being stranded with a social science that vainly attempts to emulate natural science. [...] In fact, it seems that researchers doing *phronesis*-like work have a sound instinct for getting on with their research and not getting involved in methodology. (Flyvbjerg, 2001, p. 129)

While Lewin's original framework was directed at using the data gathered for testing hypotheses, many action and case study researchers now highlight opportunities for rather generating hypotheses, or "theory"; the method is inductive rather than deductive. Some researchers favor a more inductive, "grounded theory", approach. The aim is then to suppress the pre-understanding of the researcher as far as is practically possible, in order to promote creativity (Huxham and Vangen, 2000). This is also stressed in Eisenhardts classical text on case studies for the reason that it may "bias and limit the findings" (Eisenhardt, 1989, p. 536). Others highlight the role of "confronting theory with the empirical world", by going back-and-forth between theory and different research activities (Dubois and Gadde, 2002, p. 555). This is referred to as *abductive* reasoning, and is placed somewhere in-between inductive and deductive.

My tentative stance is that when the focus is as much solving a problem as understanding a phenomenon, one is inclined to look for tools in what ever form available. Theories might be used for improving an outcome as much as providing enlightening on what is going on in a process. At the same time, it is important to have freedom of thought when trying to understand the thick and complex "data". While theories are elucidating, sometimes one must throw away the ladder.

5.3 Some philosophical considerations

This is not to say that "anything goes" in action or phronetic research. But there is a large variation in opinions with regard as to what (if anything) enables action research to be a *science* (whatever that means):

> However, even a cursory view of the philosophy of science would also show how any epistemological and ontological stance is always contentious: there is no incontestable scheme of ontological and epistemological standards which may be deployed to govern action research. [...] Hence, trying to articulate a set of all embracing standards of quality criteria to apply to all action research seems a rather pointless mission. [...] This highlights the importance of evaluating any action research project from within the particular logic of justification articulated by its particular philosophical stance. By implication it also requires action researchers to reflexively articulate their particular ontological and epistemological commitments as a resource for such evaluations. (Cassell and Johnson, 2006, p. 80)

My tentative ontological and epistemological standpoint—my opinion on what things exist and what we can know about them—is thus as follows. Personally, I find it easiest to interpret this exploratory quest, as well as action research framework itself, as *phronesis*, possibly *techne* but not *episteme*. The problem concerns of course ships and technological measures, but to a larger degree organizations and management of people. And people are not objects but subjects "that talk back, interpret back, kick back" (Latour, 1991, p. 5). Being an engineering physicist, I believe I can tell the difference (though Latour might not agree). Peter Drucker, management guru, questioned whether there could ever be such a thing as a management *science*:

> Management [...] deals with action and application; and its test is its results. This makes it a technology. But management also deals with people, their values, their growth and development—and this makes it a humanity. So does its concern with, and impact on, social structure and community. Indeed as has been learnt by everyone who, like this author, has been working with managers of all kinds of institutions for long years, management is deeply involved in spiritual concerns—the nature of man, good and evil. Management is thus what tradition used to call a liberal art: 'liberal' because it deals with the fundamentals of knowledge, self-knowledge, wisdom and leadership; 'art' because its practice and applications.
> (Drucker, 2003, p. 223)

There is great similarity between Drucker's and Aristotle's definitions of management and phronesis; the latter a quality which even explicitly "belongs to those who understand the management of households or states." How could then a science like a natural science, producing abstract, predictive theory be at all possible (see Flyvbjerg (2001), pp. 25-37)? *Phronesis* it is, then; its test is its results; *the proof of the pudding is in the eating.* For the purpose of this project, I take it to be a more useful and convenient framework in which to work. Luckily, increased energy efficiency can be measured.

Finally, some words of caution. Flyvbjerg mostly ignores the action research literature, except for making a short demarcation in a footnote. He argues that the difference is that action researchers typically adapt the perspectives and goals of those that they study, and then attempt to use their research results as means to meet those goals. It took me some time to agree with the importance of this differentiation. After all, the two frameworks have a lot in common. I chose to interpret this as a general warning. The researcher, in his or her struggle to be useful and relevant, must not “go native” and become “one of the tribe”. It is important to maintain a (self-)critical stance, and not without question accept the problems as formulated by others. Karl Weick made a strong argument directed towards proponents of collaborative (Mode-2) management research that seems to join this line of thinking:

> Much of the heat in discussions about bridging the relevance gap comes from the infamous real world. Practitioners who chide academics for their naivety regarding the ‘real world’ are sometimes people who want their real world to be treated as if it where *the* real world. That is not the academic’s job. The academic’s job is to understand how an idiosyncratic individual world comes to be seen as a universal world and how vested interests work to convey this definition of universality. Then the job is to convey these fundamentals in ways that encourage people to speak up when the vested interest produces blind spots and to enact alternative vested interests.
> (Weick, 2002, p. 74)

In summary, then, science could and thus should address these problems (though this is an ethical argument), as long as care is taken to remain a “third party”. In the next chapter, we will go through what we did in practice.

6 Implementing energy management systems in shipping

"I am looking for someone to share in an adventure that I am arranging, and it's very difficult to find anyone."
"I should think so—in these parts! We are plain quiet folk and have no use for adventures. Nasty disturbing uncomfortable things! Make you late for dinner!"

John R.R. Tolkien

IN ORDER to produce useful knowledge, that can have an impact on practice, previous researchers have argued that such knowledge needs to be co-produced. In this PhD project, the emphasis has been on conducting the project such that the performance of the shipping companies with respect to energy efficiency would be enhanced in an effective manner, i.e. that they would be able to save more bunker soon. The second priority was personal learning on what effective energy management can be. The third priority was generalization of results to the public and the scientific community.

After having done a one-year study on the possibilities of implementing energy management systems in shipping companies, the possibility existed for actually trying to implement such systems, to create two good examples. Two companies with expressed interest in improving energy efficiency were approached. The cases were thus not random, but rather chosen through "theoretical sampling", i.e. that the companies where chosen "because they are particularly suitable for illuminating and extending relationships and logic among constructs." (Eisenhardt and Graebner, 2007, p.29): they would be *interesting* cases.

The goal of the project was to implement an energy management system in each company according to the ISO 50001 standard.[1] It was thus a study of organizational change,

[1] Please see Paper II and III, that both discuss the ISO 50001 standard.

with the researcher participating in the process for all the reasons mentioned in the previous chapter. An observatory methodology was never really on the table. As a senior manager in one of the companies explained it: "Facilitation is when we have a meeting and [the researcher] serves us coffee. We need more than facilitation."

The companies were chosen so that their markets were different, to avoid a situation where the involved could not be open to each other because they where commercial competitors. The two companies were also different in their organizational structure and strategy for ship-owning and management. Both companies had some energy management activity going on at the start, but neither of the companies had a structured way of working similar to that prescribed by e.g. ISO 50001. From a research design perspective, this was then a multiple and embedded case study (Yin, 2009, pp.46-64). Multiple, because we had two companies. This would strengthen the internal and external validity of our findings (pp.40-45). Embedded, because the intention was to describe parts of the processes as the project went along. I didn't know from the beginning what kind of framing would be most interesting, what events to describe and analyze in more detail. I did suspect, however, that I would probably have way too much material to describe and analyze the implementation process of each company in a single article each.

In order to ensure that the knowledge developed was up-to-date and relevant (we wanted to avoid re-inventing the wheel), the maritime consultancy branch of Det Norske Veritas (DNV) were included as mentors to the project. In this way, we would strengthen the external validity of our results, i.e. that the results were generalizable beyond these two companies. DNV had been working with energy efficiency from a management point of view for many years. This was important as there were other parties addressing energy efficiency from a more technical perspective, while we believed that it was necessary to focus on the managerial aspects. This was the realization after the initial one-year project, which also formed the basis for Paper I.

The project started officially with a one-day kick-off meeting at DNV headquarters in Hovik, outside Oslo. Since then, full-day meetings have been held with representatives from all companies twice a year, on Chalmers campus. The purpose of these meetings was to give a chance for the companies to exchange knowledge and discuss challenges that they had experienced. In the meanwhile, I have been working together with staff in each of the shipping companies. Both companies created teams to work with energy efficiency, and I was made part of both. The environmental manager of each company was the project manager for the implementation project. In practice, this meant that I worked with gathering and analyzing data, making presentations, writing reports, participating in project meetings as well as larger company meetings and so on. When Transatlantic acquired Österströms, the project continued with them as partners and the scope of the project was broadened to the whole of Transatlantic.

6.1 A summary of the appended papers

Three papers have been completed as a result of this research project. All of them have been presented at peer-reviewed conferences before being submitted to journals. This was in a sense also done to increase validity. As my background is not in social science nor economics, I figured I would receive the most criticism if I went to those conferences. Only the second paper is the direct outcome of the joint-industry project, and based on almost two years of work at one of the shipping companies. The first paper was written based on interviews conducted in the project before the joint-industry project started. The third paper is purely an analytical paper.

- Paper I - *Barriers to energy efficiency in shipping* was first presented at the 2011 International Association of Maritime Economists (IAME) Conference in Santiago de Chile. It was then rewritten and submitted to the journal *Maritime Policy and Management*.

- Paper II - *Improving energy efficiency in short sea shipping: a case study* was first presented at the 2012 International Research Conference on Short Sea Shipping in Estoril. A rewritten version was submitted to the journal *Energy Policy*.

- Paper III - *Will the ship energy efficiency management plan reduce CO_2 emissions? A comparison with ISO 50001 and the ISM code* was first presented at the 2012 IAME Conference in Taipei. It was chosen for publication in a special edition of *Maritime Policy and Management*.

The papers will be summarized in the following sections.

6.1.1 Barriers to energy efficiency in shipping

Is there an energy efficiency gap also in shipping? If so, are the research frameworks and experiences from other industries relevant when trying to understand the problem in a shipping context? Questions such as these guided the production of this exploratory paper. The results of semi-structured interviews with different stakeholders in the Swedish shipping sector, mostly from shipping companies, are discussed in the context of previous energy efficiency research.

The paper highlights that barriers may arise from uncertainties and asymmetries in information regarding the effectiveness of measures as well as regarding the performance of shipping operations in general; fragmentation of responsibilities and action with regards to energy use, within as well as between firms and especially in the absence of performance monitoring; and organizational structure that inhibit innovation and learning.

It is suggested that further research could be directed towards better understanding the role of energy performance monitoring in various forms of contractual agreements: new buildings, third party management, charter parties etc., as well as internally in a shipping company. Following the latter, we also suggest that research can be carried out to understand how to enhance shipping companies knowledge and competence on energy efficiency.

6.1.2 Improving energy efficiency in short sea shipping: a case study

This paper details the work I had carried out in one of the shipping companies, ending with an external energy audit (followed in time directly by the acquisition of Transatlantic). I made the choice to present the case study in the form of a condensed chronological narrative. We then discuss a number of aspects of how organizing seems to matter in the paper, including project management capabilities, measuring abilities, allocation of responsibilities, communication, and access to knowledge and competence—based on this narrative.

While the paper was in the end written based on a reading, re-reading and sorting of material gathered throughout the project; material in the form of meeting notes, interviews, project reports etc., many of these aspects had of course arisen in coffee-table talks at the company, discussions with my supervisor, when reading literature on the 3-hour train ride between my office and theirs and so on. They are not solely the outcome of an analytical process *ex post*; after the case study was "finished".

The paper was presented in a longer form than what was finally sent in to a journal, at the 2012 International Research Conference on Short Sea Shipping in Estoril, Portugal. One of the things that had to be cut out to fit into the journal requirements for article length, was a comment by my mentor at DNV, Mikael Johansson, who had performed an energy audit in the company. I had asked him to give his opinion on the conclusions of the paper, to strengthen the external validity. This was his response:

> The lack of resources in the industry is generic. Structured project management addressing continuous development becomes a tremendous challenge for many operators, especially in a volatile macroeconomic environment with continuously changing business prerequisites, i.e. weather fluctuations, technical breakdowns etc. However, as this pattern is so widespread in the industry it has become a status quo and a scape goat for not addressing the challenges.
>
> It is also typical that organisations blame lack of data as an "excuse" for not addressing energy management. However, on many areas the data is available but not structured and transformed into information that can be used in the decision making process. Furthermore, the information is not communicated, neither upwards in managerial level, back to the vessel crew or if applicable, the third-party management companies. As long as the client do not enforce the contractual agreements that are in place over the service provider using available data, the efficiency gap will not be addressed.
>
> The instrumental importance of managerial commitment is also illustrated in this case. When management does not prioritise energy efficiency, the process comes to a halt, in this case when key roles in the company are vacant.
>
> Using external knowledge as a catalyst will propel development, but it is evident that the organisation needs act on the momentum that is created. And that momentum must come from top level and results demanded. Just as outer requirements addressing the core of the business will put priority on energy efficiency (propagating from the charter to the management company or form the operator clients), it will become prioritised on the day to day agenda if management is focusing on the area. It is important to realise that energy management is not a project but something that needs to be built into the organisational culture and day to day operation.

The paper was also reviewed by a representative from the shipping company, to further strengthen the internal validity of the paper.

6.1.3 Will the SEEMP reduce CO_2 emissions? A comparison with ISO 50001 and the ISM code

The intention of this article was simply to explore if anything interesting could be written about the SEEMP guideline, based on previous research on similar instruments—ISO 50001 and the ISM code—and the knowledge already generated in this project. The requirements in each standard were compared and analyzed, and gaps in the SEEMP guideline in the context of the other two instruments were identified. Through a review of research on the instruments, the extent as to how these gaps were relevant to the success of the SEEMP as a regulatory instrument or as a "best-practice" for shipping companies was discussed.

In conclusion, the SEEMP is missing requirements which are typically standard in these kinds of best-practices, such as a company policy, management representative, handling of non-conformities, commitment to providing resources, internal audits and management reviews. Further, the ISO 50001 is more demanding in terms of requiring an energy review process, goals and indicators as well as processes for energy efficiency in design and procurement.

6.2 Common themes

The aim of this research project was to understand the existence of a large cost-effective potential from the perspective of shipping companies. A variety of perspectives have been provided in this thesis and in the papers. My interpretation of the problem of increasing energy efficiency in shipping is that it constitutes of four parts, of which this research project can contribute to one and possibly two:

1. The future contribution of the shipping sector in relation to global GHG emission reduction scenarios need to be better understood. Is there room for a sector to increase its share of global emission from 3 to 10,15 or 20%?

2. The potential for improvement is well understood in technical and economical terms. A lot of efforts have been put into this area, in reports to the IMO (Buhaug et al., 2009), the European Commission (Faber et al., 2009) and in scientfic journals (e.g. Eide et al. (2011)). Less understood is the contribution of other types of measures, like other fuels.

3. How and why the shipping sector does not implement cost-effective measures can be better understood. This PhD project is a contribution to this development.

4. How can policies be created that meet the requirements established in (1), while catering to conceivable measures (2) as well as barriers etc. in the sector (3)? It can be noted that little discussion has taken place in a scientific arena on *present* instruments.

It is not yet possible to fully assess this research project in terms of its results, i.e. in the sense that both shipping companies in the project have finished changing with respect to energy management. The main conclusion so far must be that while the potential is substantial, reaping the benefits is far from trivial, at least for a small-medium sized shipping company. The reader of the papers and the chapters of this thesis may notice some common themes, listed below in no particular order.

- Creating an organization and assigning resources to work with energy efficiency is crucial. Previous research describe an energy manager person as a jack-of-all-trades, placed in-between traditional departments (Sweeney, 1980). In Paper II, project managements skills, and an organization that can supply resources to projects, are highlighted. It took decades for accounting practices to become the specialized and institutionalized role it serves today's modern organizations (Burchell et al., 1980).

Will it require a similar time period for energy managers to become common in shipping companies? Different types of energy management practices are expected in different types of shipping companies, for example related the degree of vertical integration of different functions, such as commercial management, technical management, ship-owning etc.

- Monitoring performance is a key feature of earlier literature in shipping (Drinkwater, 1967; Reid, 1985) as well as in energy efficiency literature on other industries (Thollander and Ottosson, 2010; Bunse et al., 2011; Sivill et al., 2012). The optimal design and implementation of such a system will vary with available monetary and human resources and what incentives are in place for investing in actual equipment on-board ships. The companies in this project have taken different paths. More specific studies on this topic will be needed in the future.

- Economic theory projects that markets suffering from information imperfections and asymmetries related to performance will not be kind to innovation beyond average performance. Theory also predicts that third-parties, can be an important contributor in producing trustworthy information. This would imply a need for transparency of performance, not only in organizations but also in markets. Various indices are now being introduced (Wuisan, Leeuwen, and Knoppen, 2012). Paper I called for more studies of contract monitoring.

- Research and reports in the 70s highlighted crew motivation as key in enabling more energy efficient practices. More research could be directed towards understanding how this can be done as companies today often outsource manning to third party companies. The practice is connected to outsourcing the technical management (maintenance etc.) of ships (e.g. Mitroussi (2003)), which as indicated in Paper II might have consequences for what technical competence is left in-house.

These themes will be further explored in coming publications.

7 Discussion

The good men of every age are those who go to the roots of the old thoughts and bear fruit with them, the agriculturists of the spirit. But every soil becomes finally exhausted, and the ploughshare of evil must always come once more.

Friedrich Nietzsche

Unfortunately, this thesis is the first of its kind in many ways. Unfortunately, in the sense that there was little immediate context in which to frame this project. Bar a study published only in a conference in 1980 (Sweeney, 1980), there are no recent studies of energy management practices in shipping companies. In energy efficiency literature in general, more in-depth studies of practice have been called for but not than many have been carried out. Action research projects exists in the shipping sector but are scarce. It has never been applied to energy management in this way. In a classical introduction to management research, Easterby-Smith et al. (1991, p.9) suggested that the easiest way of reaching results as a PhD student is to replicate an existing study but change "one or two" variables. We took the path less travelled.

7.1 Problem delimitation

Working on interdisciplinary problems, especially as a lone researcher, induces a certain risk that the researcher will face an information overload (Wilson, 1996, p.195): "Staying within disciplinary boundaries means giving up trying to understand concrete phenomena; not giving up means facing intractable overload." In this project, transaction costs related to searching for and assimilating information—i.e. understanding—were significant. I wanted this thesis to frame energy management in shipping from various angles. Energy efficiency is now of tremendous interest from policymakers as a strategy to mitigate CO_2 emissions from the shipping sector, so I wanted to understand this context. I also wanted an historical perspective on the subject, and found lots more than I had suspected.

Wilson (1996, p. 202) moreover argued that "[e]ven if we praised solo interdisciplinary work for having its heart in the right place, we might hope for greater success from a system of inquiry in which individual workers narrowed their scope while contributing to a collaborative result beyond the capacity of any of them singly." My strategy for the future will be to perform projects and write more articles with researchers with already established disciplinary knowledge.

7.2 Methodological choices

Was it a good idea to study this problem in the form of action research? Why not just do normal case studies, interviews or surveys? Older and wiser researchers have indeed pointed out that action research can be difficult:

> Action research is also challenging for two further reasons: (i) the uncertainty and lack of control creates anxiety for anyone other than confident and experienced researchers; and (ii) doing *action* in action research demands experience and understanding of methods for consulting and intervention. This second challenge suggests the need to face up to conceptual issues about the nature of problems in organizations and the concomitant demands for change, the nature of a client-centered activity, the issues involved in building and sustaining a consultant-client relationship, and so the nature of power and politics in the context of intervention. As an aside, the above suggests that action research is likely to be a problematic research methodology for doctoral students. (Eden and Huxham, 1996, p. 85)

Eden and Huxham (1996) recommend as a solution that doctoral students are put in a mentor or apprenticeship program. While I had no academic mentoring with regard to intervention *research*, I am deeply indebted to my mentor on energy management at Det Norske Veritas for understanding intervention. I've had the opportunity to study reports of energy management projects in another companies, but the most important learning experience was the two times I could join him on two energy management auditing projects in the shipping companies in my own project. He was also a great aid in discussing the articles. Clearly, there are benefits in being more than one researcher in this kind of project. Not only to have more disciplinary knowledge at hand, but because many of the strategies used by other researchers require *discussion*.

Still, my conclusion is that the insights we have gained from such a long and involved study seem to be very hard to acquire by other means. Also, as Gummesson (2000) predicted, *I* learnt a great deal about energy use and efficiency onboard ships and ashore by working with them first-hand.

7.3 Recent literature on shipping

A thorough discussion of the implications of this research on the recent policy-discussions concerning shipping, energy efficiency and GHGs is out of the scope of this thesis. Some small comments can be made at this stage. I have argued throughout the thesis for many ways in which companies cannot be assumed to be rational decision-makers. What kind of conclusions can we then draw from these assessments? I would like to raise two issues:

- Some have argued that the assessments tell us what measures need to be incentivized and those that do not. It might even be the opposite: if it seems to be very cost-efficient, it *really* needs policy-makers attention.[1]
- Some have argued that the implementation of the measures will lead to a cost-saving equal to the theoretical potential, so that for example a particular prize of carbon will lead to a particular level of savings. If it can be acknowledged that there are transaction costs associated with the measures, this becomes problematic. The theoretical potential in that case represents only an upper limit, see also Figure 4.1.

A very important answer that these models have given us is that they show how shipping markets do not respond well to energy price signals with innovation in terms of energy efficiency (Eide et al., 2011, p.32). How do we then create policies that promote the necessary change (c.f. Sandén and Azar (2005))? Further research could also be directed at understanding how existing models can take into account barriers.

7.4 Final comments

More case studies are on their way as part of the joint industry project, particularly related to energy audit procedures as well as on performance management systems. The knowledge developed in this project will also be canalized into a new course in an upcoming M.Sc. Programme in Maritime Management, given at Chalmers from autumn 2013. The first step is to write the course material, which will be done jointly with Det Norske Veritas. A supportive argument for stepping out of the line of research for focusing on education can be provided by Kaplan (1998). He took part in creating the Balanced Score Card, using an "innovation action research" circle, consisting of i) observing and documenting innovative practices, ii) teaching and speaking of these innovative practices, iii) writing journal papers and books, and iv) implementing the concept in new organizations. Teaching has a special role:

> The preparation and teaching processes motivated us to understand the underlying phenomena in a deeper, more systematic and more conceptual way. (p.100)

As mentioned in the introduction, an underlying purpose when writing this thesis is the hope that an academic reader can appreciate that the problem outlined in the thesis could be an extremely rich research field. There is a great need for empirical studies as well as theoretical development, possibly utilizing a wide range of research frameworks. Effective policy-making could have great use of such work, as could the management of shipping companies, and other stakeholders. As was outlined, the pace of innovation regarding the reduction of anthropogenic CO2 emissions also from the shipping sector, needs to be greatly enhanced. And due to the slow turnover of the world fleet, *very soon*, at that.

[1] "Speed reduction due to increased port efficiency"—I'm looking at you.

8 Concluding remarks

The philosophers have only *interpreted* the world, in various ways. The point, however, is to *change* it.

Karl Marx

Energy efficiency in shipping needs to be greatly improved. It can be a viable cost-cutting strategy for shipping companies and is also a necessary policy-route towards mitigating the climate impacts of the shipping sector. At first glance, it seems like a win-win situation. Many have pointed out that a substantial part of the potential could be implemented cost-effectively. Moreover, it isn't rocket science: many of these measures were discussed already during the oil crises of the 70s. This is surely a paradox. Why aren't companies moving faster to implement these measures?

Researchers and policy-makers all over the world have been asking this question for decades, as this paradox has been found in many other sectors. The approach of this research project was to create a joint industry-academia project aiming at implementing energy management systems in two shipping companies. We wanted to make sure that the knowledge generated was grounded in actual practice.

Since this is only a licentiate thesis, I'd like to take the liberty to refrain from making sharp conclusions. This thesis contributes to existing knowledge in three ways:

1. It places shipping in the extensive body of discourse on barriers to energy efficiency.
2. It tries out a new methodology—action research—for understanding energy management practices.

3. It further nuances the notion that a large "cost-effective" potential exists by reference to previous as well as new research performed within this project. Rather, the potential should be understood as a theoretical optimum which can be approached through intervention in markets, institutions and company practice, but not reached.

Based on the previous chapters and the appended papers, a number of conclusions can be made.

- Collaborative, transdisciplinary, research projects can provide a unique win-win situation for companies and researchers if a mutual interest is found.
- Energy management is not an immediate fit to existing organizational structures, but may require new organizational forms and new infrastructure for performance monitoring. Though what is the most optimum technical and organizational solution may vary.
- Competence and communication is necessary, in-house or from a third-party, as is management commitment to providing resources to propel efforts forward.
- Lack of trusted performance data in contractual relationships may inhibit increased efficiency in the longer term due to adverse selection and moral hazard problems.

Hopefully, it will also incite the necessary further research we need to bridge the energy-efficiency gap in shipping.

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Appended papers