Blowin' in the wind?

Possibilities of the International Maritime Organization to promote the uptake of wind propulsion in international shipping

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Executive summary

International shipping transports around 90 percent of global commerce and is of major importance for the global economy. Whilst it is the most efficient and environmentally friendly mode of transport, CO2 emissions from shipping activities still account for an estimated three percent of global emissions. As a consequence, the International Maritime Organization (IMO) has recently introduced mandatory measures to reduce greenhouse gas (GHG) emissions from shipping, making emission cuts not only a normative, but also a legal requirement. One means of significantly reducing fuel consumption and thereby GHG emissions from shipping are wind propulsion technologies (i.e. towing kites, Flettner rotors and sails) - yet current market uptake is very low. Therefore, the aim of this research was to identify the possibilities of the IMO as the main regulatory body in international shipping to promote the uptake of wind propulsion technologies.

To this end, the theoretical approach of technological innovation systems was adopted. This approach combines structural system components with so-called system functions which represent the dynamics underlying structural changes in the system. The fulfillment of these functions is considered important for the development and diffusion of innovations. First, the level of function fulfillment was evaluated, followed by the identification of structural drivers and barriers influencing function fulfillment. Third, the IMO's governing capacities were analyzed, enabling the formulation of policy recommendations tailored to the IMO. Data was collected from newspaper articles, company websites and an expert survey (step 1), 14 semi-structured interviews (step 2), and the review of scientific articles (step 3).

Across all three wind propulsion technologies, function fulfillment was found to be low or medium, at best, which inhibits further technological development and diffusion. Several structural barriers exist, including, amongst others, a lack of policies and incentive schemes promoting wind propulsion, lack of financial resources, insufficient collaboration among different actor groups and conservative and risk-averse attitudes prevalent in the maritime industry. The number and severity of the structural barriers outweigh those of the mostly emerging structural drivers. Next, it could be asserted that in order to promote technological development and diffusion, policy interventions should focus on stimulating the development and diffusion of knowledge and help mobilize resources. Yet, even though the IMO is well-suited to facilitate knowledge development and diffusion, which it could achieve by establishing a working or correspondence group on wind propulsion, it is less suited to mobilize resources. Nonetheless, it is suggested that the IMO intensifies efforts in relation to the introduction of market-based mechanisms (MBMs), as they increase the economic viability of wind propulsion and can provide funds to be used for research and development activities on low-carbon propulsion technologies. Until the introduction of MBMs, the IMO could set up a temporary fund for the same purpose, with financial contributions from international donor organizations, national governments and industry parties.

Key words: international shipping; climate change mitigation; eco-innovation; technological innovation systems; wind propulsion; international environmental governance; governing capacities

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1 Introduction

1.1 Environmental impacts of shipping

International shipping transports around 90% of global commerce and is of major importance for global trade and the global economy (UNEP 2012). It is unparalleled in terms of its physical capacity and ability to carry freight over long distances and at low costs. Without it, the bulk transportation of raw materials and the import and export of affordable food and goods would simply not be possible (Rodrigue and Browne 2008; UNEP 2012). Therefore, the shipping industry is also often referred to as the lifeblood of the global economy. However, international shipping contributes significantly to global environmental problems, such as climate change.

In general, maritime transport is not only considered to be the safest, most secure and efficient mode of transportation, but also the most environmentally friendly one. While this may be true compared to other transportation modes, the sheer magnitude of shipping operations makes the industry a major emitter of greenhouse gases (GHG) (UNEP 2012). The most important GHG emitted by ships in terms of quantity and global warming potential is carbon dioxide (CO2). In 2007, international shipping is estimated to have emitted 870 million tons or about 2.7% of the global emissions of CO2 (Buhaug et al. 2009). This means that if international shipping was a country, it would be the sixth largest producer of GHG emissions worldwide (Harrould-Kolieb 2008). Scenarios for future emissions of ships predict that emissions of GHG from shipping are likely to increase in the future, mainly due to an anticipated increase in demand for transport services (Buhaug et al. 2009).

To avoid the major risks associated with climate change, global warming should be limited to 2°C. The IPCC (2007) estimates this would translate into required global emission cuts of 50% to 85% by 2050 compared to 2000 levels. In order to achieve these drastic emission cuts, all different societal sectors need to be engaged, including industrial actors. Especially industries with a high environmental impact, such as the shipping industry, have to be tackled. It is therefore of paramount importance that the shipping sector rethinks its current behavior and commits to drastic emission cuts.

1.2 The international shipping industry

International shipping, as opposed to domestic shipping, refers to shipping between ports of different countries. It excludes military and fishing vessels (Buhaug et al. 2009). It is mainly focused on freight which can be divided into two categories: Bulk cargo and break-bulk cargo. The former comprises dry or liquid homogenous materials (e.g. minerals, grains, oil) without packaging, while the latter, also known as general cargo, consists of an almost infinite variety of freight that is packaged in bags, boxes and increasingly in containers. Even though maritime shipping is dominated by bulk cargo, the share of break-bulk cargo is increasing rapidly (Rodrigue et al. 2009).

In contrast to maritime freight, passenger movements are only conducted for leisure purposes and constitute a marginal part of the shipping industry (e.g. in 2011, passenger ships only accounted for 0,4% of the world fleet (UNCTAD 2011:37)). The market dynamics determining passenger transport deviate significantly from those in freight transport. The former serves end customers, is supply based and largely unaffected by economic developments, whereas the latter serves businesses, is demand-based and highly correlated with worldwide macroeconomic conditions (Rodrigue and Notteboom 2009; UNCTAD 2011).

Many different actors are involved in the shipping industry. With regard to sustainability, the main stakeholders are: naval architects; ship yards; marine equipment suppliers; ship owners; ship operators; cargo owners; financiers; classification societies; international regulatory bodies and national governments (Mes 2012).

From a regulatory perspective, the most important player in the shipping industry is the International Maritime Organization (IMO) (Wuisan et al. 2012). The convention establishing the IMO was adopted in 1948 at a conference held by the United Nations and entered into force in 1958 (IMO 2011a). The IMO's main responsibilities are to ensure the safety and security of international shipping and to prevent marine pollution from ships (IMO 2011a). The IMO currently oversees more than twenty international conventions governing marine environmental safety. With regard to global warming, the IMO has recently adopted mandatory measures to reduce GHG emissions from international shipping. These measures have entered into force 1 January 2013 (IMO 2011b). Thus, cutting GHG emissions has become not only a normative, but also a legal requirement.

1.3 Possibilities to 'green' the shipping industry

Basically, there are three measures to cut GHG emissions from international shipping: reduce the amount of maritime shipping operations; reduce fossil fuel use; and use emission-reduction technologies (i.e. achieving reduction of emissions through chemical conversion, capture and storage, and other options) (Buhaug et al. 2009). However, the first option is unrealistic given the growing demands for transportation in general and for maritime transportation more specifically. Furthermore, for shipping operators, this option would mean losing business which is against their vital interest and would thus be very hard to realize. The last option is a so-called end-of-pipe solution, which means that it addresses the effects of environmental degradation instead of trying to eliminate their root causes. Such approaches are generally considered unsustainable as they do not solve the problem of excessive material and energy consumption (Ayres 1998).This is why emission-reduction technologies will not be considered further. The only truly sustainable and realizable solution is thus to reduce the use of fossil fuels. This can be achieved by increasing the energy efficiency of ships (both related to ship design and shipping operations) and/or by substituting fossil fuels with renewable energy. Currently, fossil fuels are used to satisfy the energy demands of the propulsion systems and for all other onboard operations non-related to propulsion purposes (i.e. hotel electric power).

The use of fossil fuels in shipping is quite a new development when considering the long history of shipping. Since its modest origins as Egyptian coastal sail ships around 3200 BC, wind has been the main power source for ships (Rodrigue et al. 2009; Wijnolst and Wergeland 2009). It was only in the late 18th/early 19th century that steam ships slowly started replacing sailing ships, rendering maritime transportation faster and more reliable as shipping became independent from wind conditions (Geels 2002). Nevertheless, sail ships continued to stay on the market for some 100 years after the introduction of steam ships, shifting the focus from transporting passengers and high-value goods to goods where speed was not such an important criterion. Ironically, one of the main goods transported by sail ships was coal for steam ships. The completion of the replacement process of sail ships is estimated to have occurred by 1940. By that time, steam ships had already passed their maximum market share by 20 years and were increasingly being replaced by motor ships (Grübler 1990). As an example, the figure below shows the uptake and decline of the different propulsion systems for the United Kingdom.

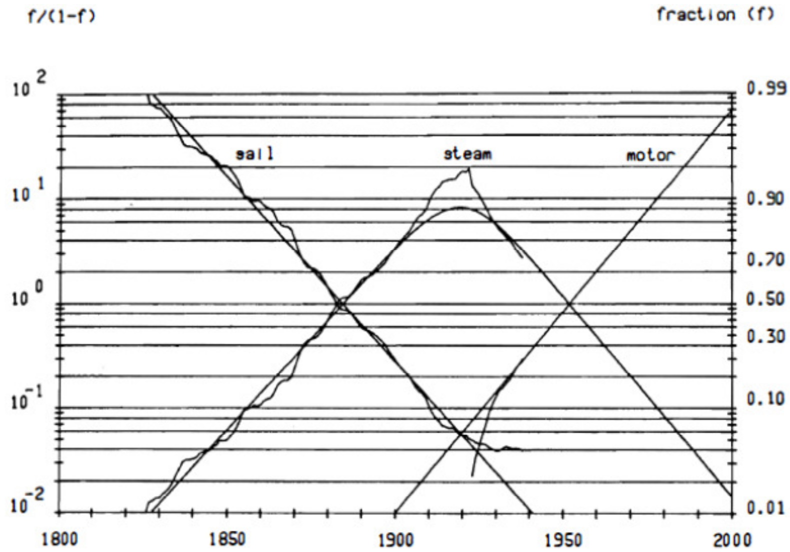

Figure 1: Substitution of sailing, steam and motor ship, UK
Source: Grübler and Nebojsa Nakićenović 1991:330

Nowadays, given the looming threat of climate change, using wind energy for ship propulsion could become attractive again. There are currently three different technologies by which wind energy can be harnessed for propulsion purposes: towing kites, Flettner rotors and sails. Towing kites are installations attached to the bow of the ship which provide a thrust force directly from the wind (DNV 2011). A Flettner rotor is a spinning vertical rotor that converts wind power into propulsive energy (Crist 2009). For sails, one can distinguish between traditional sails, Dynarigs and wing sails. The Dynarig is a modern square rigger with free-standing and rotating mast whereas wing sails are solid structures resembling aircraft wings (Buhaug et al. 2009; SY Maltese Falcon 2010).

1.4 Problem analysis and knowledge gap

Even though these technologies have the potential to reduce fuel consumption and thereby cut GHG emissions from shipping, they are either in their early development stages or have only been adopted by a few customers on a very small scale. This is often the case for new technologies as they usually cannot immediately compete on the market against established technologies. They are what Mokyr (1990:291) calls 'hopeful monstrosities'. They are hopeful in that they often can provide solutions to certain problems, but monstrous because they initially perform crudely and are inefficient (Schot and Geels 2008). Furthermore, current regulations, infrastructure, user practices and maintenance networks are aligned with the existing technology which means that new technologies often face a mismatch with the established socio-institutional framework (Negro 2007).

Due to their initial low performance, innovations often emerge and develop in protected spaces (niches) which shield them from mainstream market selection (Hillman et al. 2011). The presence of niches is important mainly for two reasons: first, they provide locations for learning processes which can relate to technology, user preferences, regulations, the required infrastructure and production systems. Second, they provide space to build the social networks which help to support innovations (Geels 2005). Ultimately, however, innovations need to break out of their sheltered environment and become widely adopted in the mainstream market if they are to replace, improve or supplement current technologies and practices: a transition needs to occur.

A transition can be defined as 'a gradual process of societal change in which society or an important subsystem of society structurally changes'[1] (Rotmans et al. 2000:19). Transition

[1] Quotation originally in Dutch. Translation borrowed from Kemp and Loorbach (2006:105).

processes are not uniform and there is a range of possible transition paths whose direction, scale and speed can be influenced, but not entirely controlled by government policy. Transitions are multi-dimensional and result from developments that take place in various domains which sustain and reinforce each other (Kemp and Loorbach 2006; Negro 2007).

While there are a variety of case studies available in different sectors that analyze these developments and thereby explain the breakthrough of eco-innovations[2], the field of shipping is still relatively untapped. The research available in this field focuses mainly on mere descriptions of the available eco-innovations, assesses their potential in terms of contributing to environmental goals (e.g. GHG abatement potential) and on analyzing their cost-effectiveness (e.g. Buhaug et al. 2009; Eide et al. 2009; Harrould-Kolieb 2008; Lai et al. 2011; O'Rourke 2006). So far, no research explains how a transition towards using wind propulsion in international shipping can be promoted and accelerated.

1.5 Research objective and main research question

The aim of this research is to provide policy recommendations to the IMO on how to promote the uptake of wind propulsion technologies in international shipping, by identifying the factors that stimulate or hinder their development and diffusion.

In order to achieve this objective, the main research question is formulated as follows:

> *What possibilities does the International Maritime Organization have to promote the uptake of wind propulsion in international shipping?*

In order to achieve the research objective, the research project is divided into five phases, as graphically shown in the research framework:

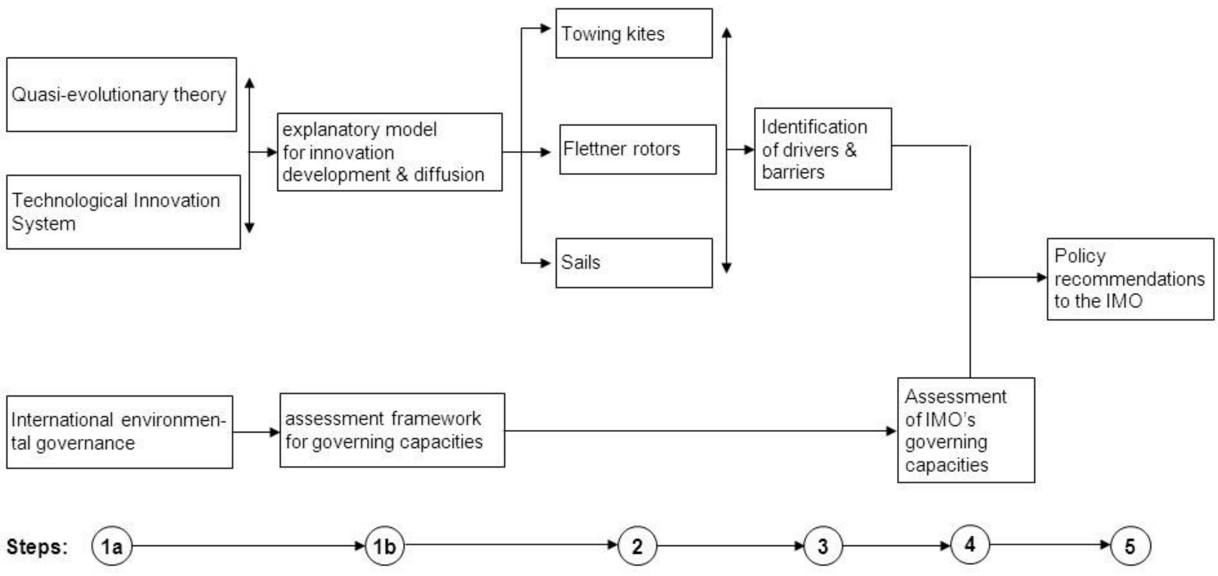

Figure 2: Research framework

Each phase will answer one of the following sub-questions which together will provide an answer to the main research question:

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[2] To give a few examples, Dieperink et al. (2004) study the diffusion of energy-saving innovations in industry and the built environment, Farla et al. (2010) analyze the barriers in the transition toward a sustainable transportation system in the Netherlands and Negro (2007) identifies the underlying factors that induce or block the development, diffusion, and implementation of biomass energy in the Netherlands and Germany.

1) Which factors account for the development and diffusion of innovations?

2a) What is the state of play in the development and diffusion of towing kites?
2b) What is the state of play in the development and diffusion of Flettner rotors?
2c) What is the state of play in the development and diffusion of sails?

3) Which mechanisms hamper or stimulate the development and diffusion of wind propulsion in international shipping?

4) What capacities does the International Maritime Organization have to influence the factors that hamper or stimulate the development and diffusion of wind propulsion in international shipping?

The questions will be answered in taking the following steps:

1a) a thorough literature review of the quasi-evolutionary theory and of Technological Innovation Systems will be conducted to identify the factors accounting for and hampering the development and diffusion of innovations. Furthermore, the academic literature on international environmental governance will be reviewed to understand which factors are important for an international organization to enable change.

1b) by comparing and integrating the different factors identified in step 1a), an explanatory model of factors that promote and hinder the development and diffusion of innovations will be constructed. The literature review on international environmental governance will result in a framework with which to assess the governing capacities of an international organization. Even though this framework is not needed to answer the first sub-question, it will be relevant for sub-question 4.

2) in the empirical assessment, the explanatory model will be applied to the three wind-assisted ship propulsion technologies: towing kites, Flettner rotors and sails. Each technology will be analyzed separately. This will tell us to what extent the three technologies fulfill the criteria needed for further technology development and diffusion, as outlined in the explanatory model. Thereby, we can evaluate the development of the three wind propulsion TIS's.

3) in step 3), the results of the previous step will be explained by identifying the factors that current stimulate or hinder technology development and diffusion: the drivers and barriers.

4) by drawing back on the assessment framework for governing capacities which was established in step 1b), the governing capacities of the IMO can be assessed.

5) based on the findings of step 3) and 4), the possibilities of the IMO to promote wind propulsion in international shipping can be identified. These will take the form of policy recommendations.

1.6 Research scope

In order to delimit the scope of this study, several choices have been made.

1. The research will focus on maritime freight movements. This is because the market dynamics determining passenger transport differ significantly from those in maritime freight transport. Furthermore, passenger movements only account for a marginal part of the world fleet.
2. In terms of geographic scope, no boundaries are drawn. On the one hand, this is due to the very international character of the shipping industry which is particularly reflected in terms of ownership and flagging (Rodrigue et al. 2009). Many ship owners prefer to register their ship in developing countries to obtain lower registration fees, lower operating costs and fewer restrictions. Due to this practice of using 'flags of convenience' most of the dead weight tonnage being registered in developing

countries (e.g. Panama, Liberia, the Bahamas). These countries are presumably not the ones that will try to foster shipping innovations or where shipping companies conduct their R&D efforts. Instead, this will probably happen in industrialized countries which also represent the top trading nations (e.g. USA, Germany, Japan) (Buhaug et al. 2009; Rodrigue et al. 2009). On the other hand, setting spatial limits would very likely reduce the number of samples to be assessed in this study. Since wind propulsion technologies are already either in their early development phases or have only been adopted in a few cases, this would negatively affect the meaningfulness of this study. Therefore, drawing geographic boundaries in the shipping sectors, especially with regard to wind-assisted ship propulsion technologies, would be tedious, at best, if not impossible.

1.7 Outline

The remainder of this research project is structured as follows:

Chapter 2 reviews the theoretical literature on technological transitions and governing capacities of international organizations. This allows establishing a theoretical framework which allows analyzing and evaluating structures and processes of Technological Innovation Systems as well as a theoretical framework for assessing governing capacities.

Chapter 3 explains the methodologies used for assessing the development of Technological Innovation Systems and describes the data collection process.

In Chapters 4 to 6, the explanatory model developed in Chapter 2 is applied to the three wind propulsion technologies: towing kites, Flettner rotors and sails, respectively. For each technology, a brief description is provided. This is followed by an assessment of the structural and functional components and their interaction. Thereby, we can evaluate how well each TIS is developed.

Chapter 7 contains a meta-analysis of the findings of chapters 4 to 6, resulting in an overall evaluation of TIS for wind propulsion technologies. Expert evaluations which were gathered in a survey serve to triangulate this overarching evaluation. They also allow us to identify the areas where policy interventions are most needed.

Chapter 8 explains the development of the TIS for wind propulsion technologies by identifying the different structural drivers and barriers promoting or hindering further development. This is done by means of analyzing the findings of semi-structured interviews.

Chapter 9 assesses the governing capacities of the IMO. Based on this assessment, areas are identified in which the IMO could potentially exert influence. Its possibilities to promote the uptake of wind propulsion in international shipping are shown.

Chapter 10 contains a conclusion and discussion of the main results of this thesis. In the conclusion, the answers to each sub-question as well as to the main research question are reiterated. The discussion includes a reflection on the theoretical approach and research methods as well as suggestions for further research.

2 Theoretical framework

This chapter provides a review of the main theoretical literature on technological transitions. After a brief discussion of the quasi-evolutionary theory and its short-comings, the Technological Innovation Systems' approach is chosen as the theoretical perspective guiding this research. Based on this perspective, propositions are formulated which will allow us to evaluate the development of Technological Innovation Systems. The development s then explained by identifying underlying structural drivers and barriers. Policy recommendations can be derived by finding ways to promote drivers and mitigate barriers. In order to target policy recommendations to a specific actor, a framework to assess its governing capacities is established. The chosen approach is thus three-fold: 1) assess TIS development by evaluating structural and functional system components; 2) explain TIS development by identifying drivers and barriers; and 3) promote TIS development by providing policy recommendations on how to promote drivers and alleviate barriers based on the recipient's governing capacities.

This will answer the sub-question 1) Which factors account for the development and diffusion of innovations?

2.1 Theoretical insights into technological transitions

Innovation studies provide us with different theories that may explain the break-through of eco-innovations. Basically, there are two strands of literature that aim to provide an integrated perspective on the development and diffusion of eco-innovations. Both of them are based on evolutionary economics which rejects the idea of a static equilibrium as put forward by neoclassical economists and instead, focuses on change processes (Suurs 2009).

The first strand of literature is the quasi-evolutionary theory. It encompasses the theory on strategic niche management (SNM) and the multi-level perspective (MLP) (Suurs 2009). The SNM literature focuses on understanding the early adoption of new technologies that have a high potential to contribute to sustainability. One of the core assumptions of this approach is that sustainable innovation journeys can be facilitated by modulating technological niches. The most important processes in this regard are the building of social networks, on-going learning processes and the articulation of expectations to guide these processes (Schot and Geels 2008).

While the SNM approach concentrates mostly on niche-internal processes, the MLP acknowledges that niches do not exist in isolation but are instead interacting with external processes. Niches are part of a nested hierarchy: they are embedded within socio-technical regimes. Socio-technical regimes refer to the alignment of dominating rules, roles and belief systems carried by different social groups that enable and constrain activities within communities, thus providing for stability (Geels 2002; Markard and Truffer 2008). In turn, regimes are embedded in a socio-technical landscape. The concept of landscapes refers to aspects of the wider exogenous environment that affect socio-technical developments (e.g. macro economy, political culture, demography, natural environment and worldviews) (Geels 2005; Kemp and Loorbach 2006). It is assumed that system innovations come about through the interplay between these different levels.

According to Negro (2007), the problem with the MLP is that despite their acclaimed importance, the interactions between niche and regime are not specified in terms of processes. It is not clear what it takes for a niche to become part of a regime. These interaction processes between an innovation and the surrounding networks and institutions are explained by the technological innovation system (TIS) approach which represents the second strand of innovation literature (Negro 2007; Suurs 2009).

According to Alkemade et al. (2007:2):

> “the rate and direction of technological change is not so much decided through a simple competition between different technologies, but is predominantly decided through competition between various existing innovation systems”.

The idea that technological change can be best understood in terms of innovation systems is increasingly accepted by both science and policy community (Hekkert et al. 2007). In fact, the Innovation Systems perspective has become the dominant theory in the innovation literature to explain the development, diffusion and implementation of innovations (Kuhlmann et al. 2010; Negro 2007). The underlying idea behind this theoretical perspective is that innovation and diffusion of technology is both an individual and collective act (Edquist 2001).

This means that the innovation process takes place within a system comprised of different actors who contribute to the overall goal of the innovation system: the development and diffusion of the innovation in question. The relationships between these actors and the institutional infrastructure in which they are embedded form the innovation system (Alphen et al. 2010; Bergek et al. 2008: Negro 2007).

As the notion of ‘systems’ is so important for understanding the Innovation Systems approach, it will be explored further before delving deeper into the approach itself.

2.2 Systems and system dynamics

The term ‘system’ refers to “a grouping of parts that operate together for a common purpose” (Forrester 1980:1-1). Generally speaking, systems can be divided into two categories: linear and nonlinear. Linear systems are characterized by clearly established causal relationships whose behavior is predictable in time. In contrast, nonlinear systems do not show such well-defined cause-effect relationships. Instead, several elements interact with each other making it difficult to predict the system’s evolution in time (Bardi 2011). It becomes even more complex as the interactions of the different elements reinforce each other in form of feedback mechanisms (ibid.). This is where the notion of ‘system dynamics’ comes in. System dynamics help to understand the different processes within nonlinear, complex systems. System dynamics’ models mainly include three elements: stocks, flows and feedback. Stocks (or levels) are the accumulations within the system, e.g. the number of individuals in a population. Flows (or rates) refer to the variation of a stock in time; they cause the stock to change. Within the same population example, the flow would be the birth or death rate of that population. Flows and stocks are thus closely related: the stock size varies depending on the in- and outflows, whereas the intensity of flows is often determined by the size of the stock, e.g. if a population is small, it is more likely that both birth and death rates are small as well. The population will only start growing if the birth rate surpasses the death rate. If there is a reinforcing relation between stocks and flows, one speaks of feedback mechanisms. These can be both positive, i.e. enhancing growth process, and negative, i.e. restricting the process (Bardi 2011; Forrester 1973). The system may also evolve as a result of outside perturbations. Typically, these perturbations would generate different feedback mechanisms impacting on stocks and flows (Bardi 2011).

2.3 Innovation systems

The common purpose of innovation systems is to contribute to developing, diffusing and utilizing new products and processes (Bergek et al. 2008). Depending on the unit of analysis, one can distinguish between different innovation systems. The focus of the National Innovation System is the role of the nation state and the way country-specific factors influence national innovative capacities (Negro 2007). Sectoral Innovation Systems concentrate on one industrial sector only because it is assumed that different sectors or industries operate in a different context and should thus be studied separately (Carlsson et al. 2002). In this study, however, the focus is on specific technologies which is why the TIS is the appropriate level of analysis. While TISs may have a geographical dimension, they are often international in nature and may cut across national, regional and sectoral boundaries (Bergek et al. 2008; Hekkert et al. 2007).

A TIS can be defined as

> “a network of agents interacting in the economic/industrial area under a particular institutional infrastructure and involved in the generation, diffusion, and utilization of technology” (Carlsson and Stankiewicz 1991:94).

The definition stresses the idea that technological development cannot be understood in isolation, but only when looking at the structural elements surrounding the technology. The key structural elements are actors (or agents), networks and institutions. Speaking in ‘system terms’, they represent the stocks of the system. For incumbent technologies, these structures are well developed and provide stability to the system. For emerging technologies, they still need to be built up. This may ultimately lead to a point where the structures supporting an emerging technology challenge and replace those supporting the incumbent one, thus contributing to a technological transition (Geels and Schot 2007; Suurs 2009).

2.4 Main components of Technological Innovation Systems

1. Actors: A variety of actors is generally involved in the development and diffusion of an emerging technology. According to Alkemade et al. (2007), these actors can be divided into five different categories, depending on how they relate to the technology (see figure below).

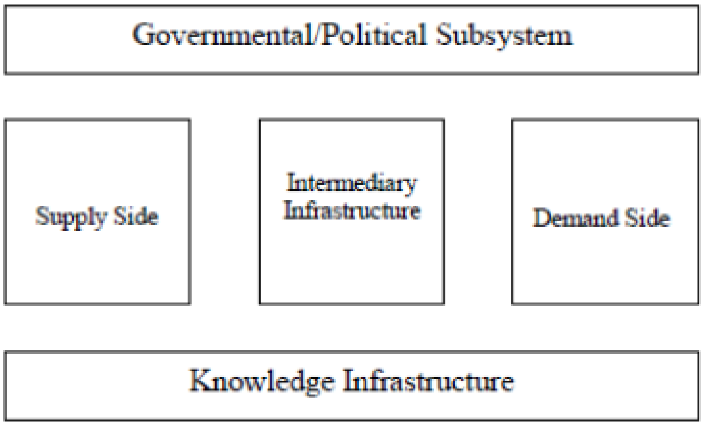

Figure 3: Structure of the innovation system
Source: Alkemade et al 2007:3

The *governmental/political subsystem* consists of government agencies or other political actors that are concerned with the technology in question. The *supply side* covers all the actors involved in the physical production process and the provision of the technology. *Intermediaries* provide a link between the supply and *demand side* – i.e. the consumers of the technology - by enabling a smooth interface and improving knowledge flows. The last subsystem, the *knowledge infrastructure*, supports all other subsystems by generating, assessing and transferring knowledge. It encompasses organizations such as public and private research and development institutes as well as organizations within the educational system (ibid.).

2. Networks: As mentioned earlier, innovation is not an individual and isolated, but rather a collective act. It requires collaboration among the various actor groups in terms of sharing of knowledge and resources, both within and amongst subsystems. The linkages amongst the actors form a network which is important, amongst others, for the diffusion of knowledge as well as for the provision and sharing of resources (Hillman et al. 2011).

3. Institutions: The networked actors are embedded in an institutional context (Markard and Truffer 2008). Institutions guide human behavior and are commonly referred to as ‘the rules of the game’ (North 1994:361). Amongst others, one can distinguish between formal and informal institutions: formal institutions encompass codified rules, regulations, laws and constitutions whereas informal institutions refer to more intangible social rules such as behavioral norms, conventions, habits and routines (North 1994). Institutions provide stability and meaning to social behavior and are often backed up by enforcement and sanctioning mechanisms (Coenen and Díaz López 2010).

The different components of the TIS influence and relate to each other in different ways. On the one hand, the behavior of actors is guided by institutions; on the other hand, their behavior may create new or shape existing institutions. Actors interact with each other, creating networks and in so doing may be guided by the prevailing institutional context (Hillman et al. 2011). Relations between the system components are thus not uni-, but rather multidirectional.

2.5 Functions of Technological Innovation Systems

There is no such thing as an ideal or optimal innovation system. The innovation system is in a continuous flow, never achieves equilibrium and different structures may lead to similar outcomes (Alphen et al. 2010; Bergek et al. 2008; Chaminade and Edquist 2010). Even though the structural analysis of the innovation system can provide us with valuable insights, it is quite static and takes no account of the dynamics that make innovation systems change and evolve over time (Alkemade et al. 2007). Since technological change requires a transformation of the innovation system, an approach which takes these dynamics into account is needed (Hekkert et al. 2007).

In order to address this void, a new approach has been developed in recent years. It focuses on the key activities that take place in innovation systems and result in technological change. These activities contribute to the overall function or goal of the innovation system, i.e. the development and diffusion of innovation, which is why they are called ‘functions of innovation systems’ or ‘system functions’ (Hekkert et al. 2007). Speaking in terms of ‘system dynamics’ again, these functions can be compared to flow variables which, through accumulating, create new system structures.

The set of functions proposed by both Bergek et al. (2008) and Hekkert et al. (2007) is widely cited and accepted my scholars. Except for one function (‘development of positive externalities’), these two sets of functions are congruent. Both authors agree on the following seven functions.

2.5.1 Entrepreneurial activities

Entrepreneurs play a crucial role in innovation systems. In the pursuit of a new business opportunity, they “turn the potential of new knowledge, networks and markets into concrete actions” (Hekkert et al. 2007:421). Without this, the innovation system would simply not exist. Furthermore, entrepreneurial activities reduce the large uncertainties inherent in innovation systems. These uncertainties relate not only to the technology in question. Since there is generally a misfit between the emerging technology and the structure in which it is embedded, uncertainties also relate to possible applications and markets, as well as the unknown responses by various agents (Carlsson and Stankiewicz 1991). Practical experimentation allows collecting knowledge about the functioning of the technology in different situations, as well as evaluating the reactions from various stakeholders, such as customers, suppliers, competitors and governments. Entrepreneurial activities thus set important learning processes in motion by means of which an emerging technology can gradually be shaped to fit its structural environment and vice versa (Bergek et al. 2008; Hekkert et al. 2007; Suurs 2009). In order to stimulate learning and convergence processes, entrepreneurs should engage in many experimentation projects. On the other hand, it is equally important that these projects explore many different options, i.e. different technological options, potential applications of the technology and different market segments.

Proposition 1: The function 'Entrepreneurial activities' is considered well developed if many experimentation projects are conducted and if these are diverse in terms of exploring different technological options, possible applications and different market segments.

2.5.2 Knowledge development

Technological innovations emerge through the recombination of existing knowledge. Therefore, knowledge development is a prerequisite for the development of an emerging technology. Furthermore, the acquisition of knowledge helps overcoming the uncertainties pertaining to emerging technologies. Just as there are various causes of uncertainties, there are different types of knowledge to reduce these uncertainties. One can distinguish between e.g. scientific, technological, market and production knowledge. These different types of knowledge may develop from R&D projects ('learning by searching), but also from practical applications ('learning by doing'). While the former are more likely to generate scientific and technological knowledge, the latter can provide actors with feedback on more practical issues, such as market uptake and customer wishes, the technology's functionality in real life, problems encountered during production etc. Typically, the former are undertaken by universities or other research institutes, whereas the latter fall more within the realm of entrepreneurs (Bergek et al. 2008; Hekkert et al. 2007; Suurs 2009). To conclude, the more knowledge development activities are pursued, the more technological options may be explored and the more uncertainties may be reduced.

Proposition 2: The function 'Knowledge development' is considered well developed if many different knowledge activities of both 'learning by searching' and 'learning by doing' are undertaken.

2.5.3 Knowledge diffusion

Knowledge development alone is not sufficient; it also needs to be diffused among the actors in the innovation system. This is important as it enables different actors to react adequately to new knowledge developments and insights (Hekkert et al 2007). This increases chances that a mutual understanding between different actors, e.g. policy makers and technology developers, will evolve which makes it more likely that institutions are gradually adjusted to technologies and vice versa (Suurs 2009). Furthermore, if many actors command a broad knowledge base, they can work on extending it even further.

Knowledge diffusion takes place where actors involved in the TIS interact with each other, communicate and exchange information. Therefore, knowledge diffusion is also referred to as 'learning by interacting'. Networks play an important role in this respect as they enable the interaction between different actors and thereby facilitate the exchange of information (Carlsson and Stankiewicz 1991). There need to be occasions for actors to exchange information. These can be partnerships where actors agree on sharing their respective knowledge, but also meetings such as workshops and conferences (Suurs 2009). These meetings can also create new links between actors, thus contribute to network density which, in turn, further facilitates knowledge diffusion.

Proposition 3: The function 'Knowledge diffusion' is considered well developed if there are many occasions (e.g. partnerships, workshops and conferences) where actors can meet and exchange knowledge.

2.5.4 Guidance of the search

If a TIS is to develop, a variety of actors have to choose to enter it and actively contribute to its development. For this to happen, incentives must be in place. These incentives increase the visibility and clarity of specific wants among technology users and thereby encourage actors to participate in the innovation system. This is especially important in early technology development stages when the actual potential of the emerging technology is highly unclear. Incentives make actors believe that there is a market potential for the emerging technology. The combination of these incentives is what the function 'guidance of the search' is all about (Alkemade and Suurs 2012; Bergek et al. 2008; Hekkert et al. 2007).

Incentives can take various forms. They may refer to hard institutions, such as the implementation of policy measures or setting of policy targets, but can also take the form of promises and positive expectations regarding future technological development and performance (Alkemade and Suurs 2012).

The exercise of this function is not confined to the government or other political actors, but can also be fulfilled by civil society, industry or other market actors. Expectations and beliefs in a technology's potential may be derived from technical or economic studies. However, they can also come about as a result of an interactive and cumulative process of exchanging ideas and experiences between different actors (Bergek et al. 2008; Hekkert et al. 2007).

> *Proposition 4: The function 'Guidance of the search' is considered well developed if there are clear positive signals in place pushing actors towards entering and contributing to the development of the TIS. These signals may take the forms of clear policy targets or measures in favor of the technology and the voicing of positive expectations regarding the future development of the technology.*

2.5.5 Market formation

As mentioned earlier, innovations often cannot compete with established and institutionally embedded technologies from the outset, but may nonetheless offer solutions to prevailing problems in the foreseeable future. In order to become truly competitive, they may need more time to develop and become institutionally embedded. It is therefore important to create protected spaces (e.g. by introducing subsidies) that shield new technologies from market pressures and to introduce temporary incentive schemes that favor the utilization of the technology in question. This may also help overcome another problem encountered by new technologies; that of the inexistence or the underdevelopment of a market. Innovations may be so novel that potential customers may not have articulated their demand yet. The function thus helps new technologies bridge the 'valley of death' from market introduction until the technology scales up (Bergek et al. 2008; Hekkert et al. 2007).

'Market formation' activities are especially important for the introduction of eco-innovations as they have to compete with products whose negative environmental externalities are not accounted for and may therefore seem more price-competitive to the consumer. As sustainability is claimed to be a societal goal, this mismatch calls for public intervention (Unruh 2000; Suurs 2009).

The function 'Market formation' typically refers to activities that create or increase a demand for the emerging technology. This may be achieved directly by e.g. introducing tax incentives, public procurement policies, standard setting and minimal consumption quotas, or indirectly by taxing the use of competing technologies (Carlsson and Stankiewicz 1991; Hekkert et al. 2007; Suurs 2009).

> *Proposition 5: The function 'Market formation' is considered well developed if public support schemes are in place that effectively incentivize the use of the emerging technology.*

2.5.6 Resource mobilization

One of the main prerequisites for the development of a TIS is the availability of and access to resources. Resources refer to financial (e.g. venture capital), human and physical (e.g. production facilities, infrastructure) capital and serve as the basic input to all activities within the innovation system. An emerging technology can only be supported if there are the necessary financial and physical means and if actors are present with the right skill set (Bergek et al. 2008; Hekkert et al. 2007; Suurs 2009).

> *Proposition 6: The function 'Resource mobilization' is considered well developed if enough financial, human and physical resources are available for the development of the emerging technology and if actors within the TIS have access to these resources.*

2.5.7 Creation of legitimacy

In order for a new technology to develop and diffuse within the market, it has to be perceived as appropriate and desirable by various actors, i.e. the innovation needs to gain legitimacy. Not only will this help to form a demand for the technology, but also to mobilize more resources and gain political strength which, in turn, will promote the further development of the TIS. The creation of legitimacy will also help deal with parties from the incumbent regime who may oppose the development of the technology out of fear that their regime will fall prey to the 'creative destruction' process famously described by Schumpeter (1994) (Bergek et al. 2008; Hekkert et al. 2007).

According to Suchman (1995), there are three different ways of creating legitimacy. The first is to confirm to established institutions. For many low-carbon innovations, however, this is not an option as existing institutions have 'locked-in' fossil fuel-based energy systems ('carbon lock-in') which block the development of new technological options (Unruh 2000). The second and third options are to either manipulate established institutions or create new ones. Both options involve urging authorities to reorganize the current institutional configuration of the TIS (Suurs 2009). Actors in the TIS have to organize and coordinate themselves in advocacy coalitions to lobby in favor of the emerging technology.

The function 'Creation of legitimacy' is similar to 'Guidance of the search' in that both aim at creating positive expectations of the emerging technology, making it desirable and increase its social acceptance. However, they are different in that the 'Guidance of the search' function can be fulfilled by the actors directly, whereas in the 'Creation of legitimacy' function, actors persuade other actors to take particular actions which they cannot conduct themselves (Suurs 2009).

> *Proposition 7: The function 'Creation of legitimacy' is considered well developed if coordinated actor groups exert pressure on actors in power to change institutions which complement the emerging technology.*

2.6 Interactions between system structure and functions

There is a dynamic interplay between the structure and the functions on the one hand, and between the functions on the other hand. The seven key functions are upheld and supported by the structural system components but, in turn, also influence the development of the structure. As in 'stock and flow' models, the accumulation of functional dynamics leads to changes in the system structure, in turn, the emergence and strength of the functions depends on the structural components in place. Accordingly, "structure represent states of the TIS which are subject to change; system functions then represent this change" (Suurs 2009:62) System components and system functions are thus closely intertwined.

On the other hand, the different system functions influence each other in that the fulfillment of one function impacts on the fulfillment of other functions. This creates a non-linear model with multiple interactions between the functions. For example, a certain amount of knowledge creation (F2) is necessary to create expectations (F4) of the new technology, which may then lead to legitimacy (F7) (Negro 2007). These interactions trigger processes of 'cumulative causation':

> "there is no such tendency towards automatic self-stabilization in the social system. (…) In the normal case a change does not call forth countervailing changes but, instead, supporting changes, which move the system in the same direction as the first change but much further. Because of such circular causation a social process tends to become cumulative and often to gather speed at an accelerating pace" (Myrdal 1957:13)

These cumulative processes can have both positive and negative implications on the system performance, either resulting in virtuous cycles that propel the innovation system further or in viscous cycles that hinder the innovation from realizing its potential (Coenen and Díaz López 2010; Hekkert et al. 2007; Markard and Truffer 2008). Due to the fact that positive function interactions can massively accelerate the development of a TIS, they are "considered a necessary condition for structural change and, thus, for systemic innovation" (Hekkert et al. 2007:426).

2.7 Identifying structural barriers and drivers to TIS development

2.7.1 Structural causes for functional barriers

The analysis of systemic structure and function alone does not provide a sufficient basis for identifying barriers to TIS development. While a poorly fulfilled function can form an obstacle to the progress of technological development, the underlying causes for its poor performance can origin in the structure of the TIS (Luo et al. 2012). So the reason why a system function is weak or absent can be related to the structural elements of the TIS (Wieczorek et al. 2012). Therefore, identifying structural barriers for TIS developments requires combining the structural and functional analysis by examining each function through the lens of the systemic structure. Such an analysis allows selecting policy instruments that target and adjust the hindering structural elements so that the barrier can be removed.

Several categorizations of these structural factors are provided in the academic literature on innovation system development. The barriers identified in different articles (also referred to as systemic weaknesses or blocking mechanisms) showed a great overlap and their main difference lied in the structuring of the barriers. Therefore, the categories were restructured in a way to encompass the different barriers mentioned (see figure below). Most articles mentioned the lack or inadequacy of policies and regulations as a barrier ('hard institutional problems'), as well as the lack of legitimacy, credibility and trust, resistance to change and other values and cultural factors ('soft institutional problems'). Furthermore, there was agreement that a lack of information, knowledge and capabilities is counterproductive to technological transitions. 'Interaction problems' in the form of either too dense or too weak network linkages were equally recognized as hindering factors. There was less agreement on the existence of external factors and if so, in what this category would include. Hekkert and Ossebaard (2010) mention the oil price as an example for external effects, Negro et al. (2012) the structure of the market and Sorrell et al. (2000) mention different kinds of market and non-market failures. Therefore, this category includes the economic situation, industry and market structures, resource prices and the (non-)market failures identified by Sorrell et al. (2000). Even though the lack or inadequacy of 'physical infrastructure' was only mentioned in two articles, it is included in the barrier taxonomy given the general agreement that physical infrastructure needs to be adapted to fit an innovation and enable its usage (see e.g. Chaminade and Edquist 2010; Elzen and Wieczorek 2005; Kemp et al. 1998; Negro 2007; Rennings 2000; Schot and Geels 2008; Suurs 2009). The lock-in of existing technologies is not considered in this taxonomy of barriers as it is rather the result of the other barriers than a barrier in its own right (Negro et al. 2012).

Table 1: A taxonomy of structural barriers

Structural barrier	Bergek (2002)	Hekkert and Ossebaard (2010)	Negro et al. (2012)	Klein Woolthuis et al. (2005)	Sorrell et al. (2000)
External factors		External factors	Market structures		Heterogeneity; Split incentives; Hidden costs; Limited access to capital
Hard institutional problems	Inadequate policy	Inadequate policy	Hard institutional problems	Hard institutional failures	
Soft institutional problems	Lack of legitimacy; ambiguous behavior of established firms	Lack of legitimacy; Ambiguous behavior of established firms; Lack of a long-term vision	Soft institutional problems	Soft institutional failures	Principal-agent relationship; Credibility and trust; Inertia; Values; Culture; Power
Knowledge infrastructure	Uncertainty	Uncertainty; Capabilities/ capacities	Knowledge infrastructure; Capabilities/ capacities	Capabilities' failure	Imperfect information; Risk; Form of information; Bounded rationality
Interaction problems	Weak connectivity	Weak connectivity	Interaction problems	Interaction failure	Adverse selection
Physical infrastructure			Physical infrastructure	Infrastructural failures	
		Strong lock-in of existing technologies			

2.7.2 Structural causes for functional drivers

Structural drivers can be identified the same way than the structural barriers, i.e. by linking the functional analysis to the structure of the TIS.

While the literature on barriers to the uptake of eco- and/or energy-efficiency innovations is vast, only few articles identify drivers. This is surprising since reinforcing structural drivers is recognized as important in the promotion of these innovations (Suurs 2009). Hekkert and Ossebaard (2010) argue that driving forces ensuring that functions are well fulfilled are the opposite of the above-mentioned barriers. And indeed, when reviewing the scant literature available, many of the drivers fit well in the scheme developed above.

Cagno and Trianni (2013) and Thollander and Ottosson (2008) focus - more or less - on the same drivers. Both articles state that investments in energy efficiency innovations are motivated by the anticipated cost reductions promised by the technology, by increasing resource or energy prices or the threat thereof as well as the wish to stay competitive. The presence of alternative financing mechanisms is also conducive to technology adoption. These factors are included in the category ‘external factors’. In the category ‘hard institutions’, environmental regulations or the threat thereof, the introduction of MBMs, access to public financing or subsidies and the application of environmental management systems drive technology take-up. Soft institutional drivers include environmental awareness of the management team, societal pressure and demands from clients to become more environmentally friendly as well as the presence of people driven by great ambition and an entrepreneurial mind. Readily available and low-cost information as well as learning about best practices are considered important. Being embedded in an industry network facilitates the access to this information. No mention was made of specific capabilities or capacities or factors related to the physical infrastructure.

Table 2: A taxonomy of structural drivers

Structural drivers	Cagno and Trianni (2013)	Thollander and Ottosson (2008)
External factors	Resource/energy prices; Anticipated cost reductions; Alternative financing mechanisms	Resource/energy prices; Anticipated cost reductions; Competitiveness; Alternative financing mechanisms
Hard institutions	Environmental regulations; Subsidies/ allowances/ public financing	Market-based mechanisms; Environmental regulations; Environmental Management Systems; Subsidies/ allowances/ public financing
Soft institutions	Environmental awareness; Great ambition & entrepreneurial mind; Client pressure	Environmental awareness; Great ambition & entrepreneurial mind; Societal pressure
Knowledge infrastructure	Availability & provision of information; Best practices;	Availability & provision of information;
Networks		Availability of network within the industry
Physical infrastructure		

2.8 Tailoring policy recommendations to recipient’s governing capacities

Based on the identification of structural barriers and drivers that followed from the analysis of both TIS structure and functions, policy recommendations can be formulated. These aim to promote structural drivers and mitigate structural barriers. However, not every actor has the same capacities to influence these factors and bring about change. Therefore, one should consider who the recipient of the policy recommendations is and what its capacities and limitations are. Otherwise, the risk is high that the formulated recommendations are not being implemented because they do not reflect the actual capacities of the recipient. By matching policy recommendations with the actor’s capacities, chances increase that they will be implemented.

In this research, policy recommendations will be formulated for the IMO. Biermann et al. (2009) have established a theoretical framework according to which the level of influence exerted by an international organization can be determined by a set of explanatory variables which in the following will be referred to as governing capacities.

The categories for assessing an organization's governing capacities include: formal competences, organizational structure, embeddedness, resources, organizational expertise, culture and leadership.

The **formal competences** of international organizations vary greatly and might be an explanation for an organization's effectiveness. In this context, Biermann et al. (2009) hypothesize that an organization with far-reaching competences and a high amount of autonomy is likely to be more effective compared to one with little competences and little discretionary room for action.

The way an organization is **structured** can also have an impact on its effectiveness. Tasks and responsibilities should be communicated clearly in order to avoid internal confusion and conflict between the staff, while at the same time maintaining a certain openness for changes and encouraging a learning atmosphere (Biermann et al. 2009).

The third criterion in the analytical framework is **embeddedness**. Here, the larger organizational context within which a particular organization is embedded is examined. It is assumed that "if multi-issue organizations are well connected to other institutions and actors in all different policy fields and do not prioritize one over another, the more likely it is that they use linkages and learning processes, thereby increasing their influence" (Biermann et al. 2009:54).

Another explanatory factor for an organization's effectiveness are its own and its members' **resources.** Resources often determine an actor's influence and thus easily translate into power. Since influence and power are essential for an organization's ability to make an impact, its resources need to be examined (Kaasa 2007).

Biermann et al. (2009) also identify **organizational expertise** as an important criterion for assessing effectiveness. If an organization is based on knowledge and produces knowledge itself, it is likely to be perceived as more legitimate which in turn can increase its effectiveness (Najam et al. 2006).

Another influential point regarding an organization's effectiveness is its **culture**, which is understood as "the set of commonly shared basic assumptions in the organizational learning processes and include the professional cultures and backgrounds of the staff members" (Biermann et al. 2009:56). An organization can only be effective if its members understand their allotted role, behave accordingly and thus accept and adapt to the commonly shared assumptions on which the organization is based (Rydin 2006).

Finally, the analytical framework acknowledges the fact that there are different types of **leadership** an organization can adopt: hierarchical, consultative, cooperative and participatory. While a top-down approach can be more straightforward and save time in dealing with internal matters, it is believed that a more participatory leadership style will foster innovation, creative solutions and can increase the acceptance and commitment of participants (Biermann et al. 2009). Furthermore, deliberation has the potential to contribute to the progressive diffusion of norms and to the creation of a shared vision which will enhance participants' motivation and commitment (Pretty and Ward 2001). Also, it will strengthen the organization's social capital and thus help to overcome collective action problems and to lower transaction costs (ibid.). The role of leadership would thus be more facilitative in the sense that it should encourage deliberation and discussion and open up opportunities for participants to make a meaningful contribution.

The analysis of these factors thus helps understand in which areas an organization could exert its influence. Here, Biermann et al. (2009) distinguish between three different areas: cognitive, normative and executive. Influencing actors on a cognitive level means changing their knowledge and belief systems. An international bureaucracy can also act as a negotiation-facilitator and thereby contribute to creating, supporting and (re-) shaping normbuilding processes. Executive influence refers to the ability of an organization to create and/or increase capacities to act, e.g. by providing technical assistance to countries with a view to making them comply with their obligations stemming from international agreements. These areas closely relate to six of the seven system functions and thus, the governing capacities framework can be used to understand to what extent an international organization can stimulate better function fulfillment. Knowledge development and diffusion are closely linked to the cognitive area of influence, Guidance of the search and Creation of legitimacy to normative influence, whereas Resource mobilization and Market formation relate to an organization's executive area of influence.

2.9 Conclusion

This chapter focused on identifying the factors that account for the development and diffusion of innovations. These factors were derived from reviewing theoretical insights provided by the literature on Technological Innovation Systems. Overall, seven propositions have been formulated to evaluate the fulfillment of system functions. By means of these propositions, the current development of the TIS functions can be established. This was followed by an analysis of the underlying structural drivers and barriers that explain the current performance. To facilitate the identification of such barriers, a brief literature review has been conducted, resulting in a taxonomy of both drivers and barriers. These were related to external factors, such as resource or energy prices, market and industry structure, hard and soft institutions, the lack or existence of a knowledge infrastructure, the embeddedness in networks as well as the existence of physical infrastructure required to use the innovation. Based on the identification of structural drivers and barriers, policy recommendations can be formulated. To make sure that the policy recommendations match the actor's capacities, a theoretical framework from the literature on international environmental governance was introduced which allows to assess the governing capacities of international organizations and thereby help explain what kind of influence they can possibly exert.

3 Methods and data collection

In the following, the research and data collection methods used for answering the main research question and the different sub-questions are outlined.

3.1 Assessing TIS development

The previous section has shown that structural components influence the development of system functions and vice versa. Thus, in order to understand the development of a TIS, insight into both system structure and function fulfillment is required.

3.1.1 Structural analysis

In a first step, the structural components of each TIS - the actors, networks and institutions surrounding the emerging technology - are analyzed. To this end, a stakeholder analysis is carried out. The discussion of the institutional framework of each TIS focuses on the so-called formal institutions which encompass codified rules, regulations, laws and constitutions (North 1994).

The information required to describe the system components was derived from scientific articles, reports, newspaper articles found via the search engine LexisNexis as well as the homepages of the different wind propulsion technology providers.

3.1.2 Functional analysis

One of the most widely used theoretical perspectives in social sciences is the so-called variance approach. This perspective explains outcomes as the product of independent variables acting on dependent variables. The underlying causal process is presumed to operate continuously over time (Poole et al. 2000). This approach is especially suited for explaining continuous change driven by unidirectional causation (Hekkert et al. 2007). However, when assessing function fulfillment, we have to bear in mind that the different system functions influence each other and that the fulfillment of one function impacts on the fulfillment of other functions. This creates a non-linear model with multiple interactions between the functions (Negro 2007). Due to this non-linearity and the cumulative causation triggered by the interaction of functions, the variance approach is ill-suited for analyzing system functions.

An approach that makes up for the short-comings of the variance approach is thus needed. Such an approach is offered by the Event History Analysis, or process approach. It has been developed by van de Ven and colleagues (see e.g. van de Ven 1990; Poole et al. 2000) and has been applied to study innovation systems in a number of studies (see e.g. Alkemade and Suurs 2012; Hekkert and Negro 2009; Negro 2007; Suurs 2009; Verbong et al. 2008).The Event History Analysis conceptualizes development and change processes as sequences of events; outcomes are explained in terms of the order in which events unfold (Poole et al. 2000). With regard to TIS development, the difference between variance and process approach can be explained as follows:

> "Where the variance approach leads to insights as for instance: the presence of function X explains partly the development of the new technology, the process approach presents a story line of *how* function X influences technology development and at the same time all the other functions." (Hekkert et al. 2007:427)

The process approach thus helps to better understand the underlying mechanisms determining technological change over time. TIS development is explained by constructing a narrative based on the identification and interpretation of events. In this context, an event is defined as

> "an instance of rapid change with respect to actors, institutions and/or technology, which is the work of one or more actors and which carries some public importance with respect to the TIS under investigation" (Suurs 2009:67).

According to the logic of the Event History Analysis, TIS functions are operationalized and measured by relating them to events and the interaction of system functions can be understood by tracking the sequence of these events (Suurs 2009). This allows us to assess the extent to which the propositions set out in the previous chapter have been fulfilled.

The table below shows the scheme used to allocate events to system functions. The signs + and – signify whether the event has positive or negative effects on TIS development.

Table 3: Classification scheme for measuring system functions

	System Functions	Event types	Effect on TIS
F1	**Entrepreneurial Activities**	Project started	+
		Project stopped	-
F2	**Knowledge Development**	Desktop/ Assessment/ Feasibility study on the technology	+
F3	**Knowledge Diffusion**	Workshops, Conferences	+
		Co-operation between actors	+
F4	**Guidance of the Search**	Positive expectations of the technology	+
		Government regulations complementing the technology	+
		Negative expectations of the technology	-
		Government regulations hampering the technology	-
		Expressed deficit of regulations complementing the technology	-
F5	**Market Formation**	Specific favorable tax regimes, environmental standards or public procurement policies	+
		Expressed lack of favorable tax regimes, favorable environmental standards or public procurement policies	-
F6	**Resource Mobilization**	Availability of financial, human and physical capital	+
		Expressed lack of financial, human and physical capital	-
F7	**Creation of Legitimacy**	Lobby activities for the technology	+
		Support of technology by government, industry	+
		Lobby activities against the technology	-
		Expressed lack of support by government, industry	-

Source: Negro (2007)

After having identified and allocated events to system functions, the actual analysis begins. Both trend patterns and interaction patterns need to be identified. Trend patterns indicate how an individual system function has developed over time. They can be identified by plotting the aggregated number of events per year per function, distinguishing between positive and negative function fulfillment. Sudden increases or declines in the fulfillment of the function may point to a turning point in the development of the function. Interaction patterns help us understand the interaction between system functions and may provide causal explanations for the rise or decline of individual functions. Therefore, the trend patterns of the individual system functions are compared to and contrasted with each other.

The functional analysis and the construction of the event database were informed by newspaper articles accessed via the Lexus Nexus search engine as well as articles from Lloyds List, the leading professional journal for the maritime industry and from sustainableshipping.com, an online news and information resource dedicated to marine transportation and the environment. The following search parameters were used: (marine) shipping, propulsion, wind energy AND NOT (offshore or off-shore), kites, Flettner, sails, dynarigs and wing sails. In order to make sure no important information on the different technology providers was missing, an article search for each company was conducted. Overall, this search resulted in a total number of about 190 useful articles[3].

In order to triangulate the results of the event analysis, an anonymous expert survey was carried out in which professionals working in the field of wind propulsion were asked to quantify both the level of fulfillment and the importance of each function. The aim was to identify areas where action, e.g. in the form of policy interventions, was needed the most in order to accelerate TIS development. In total, nine experts took part in the survey. For an overview of survey questions, please see Appendix A.

3.2 Explaining TIS development: identification of structural drivers and barriers

This analysis provides an explanation for the development of the TIS assessed in the previous chapters. Therefore, the performance of each function is linked to the structural components of the TIS. This yields insights into the structural drivers and barriers of the TIS. The analysis is guided by the categorization of drivers and barriers as set forth in chapter 2.7.

The identification of underlying structural drivers and barriers is based on 14 semi-structured expert interviews. Research interviews are particularly useful to investigate complex behaviors and motivations as well as to collect a variety of meanings, opinions and experiences and are therefore particularly useful to identify the underlying causes for the development of the structural and functional elements of each TIS (Hay 2010). Furthermore, the interviews were used to corroborate the results obtained in the structural and functional analysis. Such a triangulation of different sources can diminish bias and enhance the external validity and robustness of the results obtained (Potter 1996).

The interviews were designed to cover different topics and consisted of open questions to provide space for free-form responses (Hay 2010). In order to cover a broad spectrum of viewpoints, interviewees included technology providers, (potential) customers, policy actors, environmental NGOs and port initiatives, academia and classification societies. The large amounts of data obtained were processed and analyzed by using descriptive codes which helped to identify recurring themes, but also contradictory statements. A list of interviewees is provided in Appendix B, however, in the analysis itself the identity of the interviewees was disclosed to make sure they could speak openly. A list of questions guiding the interviews is provided in Appendix C.

3.3 Assessing the IMO's governing capacities

In order to understand the extent to which the IMO could potentially influence structural drivers and barriers to promote the uptake of wind propulsion, its governing capacities were assessed. This analysis was primarily based on academic articles, but also on information provided on the IMO's website and some interview statements.

[3] However, the overall number of reviewed articles was much higher given that not all articles contained useful information.

4 Towing kites

This chapter aims at answering the following sub-question:

What is the state of play in the development and diffusion of towing kites?

Following the theory and methodology outlined in chapter two and three respectively, this will entail a structural analysis of the TIS related to towing kites, followed by an evaluation of the different system functions and their interactions. This will result in an assessment of how well developed the TIS for towing kites is.

4.1 Description of the technology

Kites are attached to the bow of the ship to provide a thrust force from the wind which can substitute power of the ship engines (DNV 2011; Faber et al. 2011). The shape of these installations is comparable to paragliders. The Skysails system which is the only commercially available system right now consists of three main components: a towing kite with rope, a launch and recovery system, and a control system for automatic operation (Brabeck and Schnackenberg 2008). The system can operate at altitudes between 100 and 420 meters where stronger and more stable winds prevail and is designed for wind forces of 3 to 8 Beaufort (DNV 2011). It can be used both downwind but also at courses of up to 50° to the wind. Compared to conventional sails, kites can generate five times more power per square meter sail area. An additional advantage is that they require no superstructure which would obstruct cargo handling (Brabeck and Schnackenberg 2008).

The system can be retrofitted on any ship with a minimum length of 30 meters, but it works best on ships with an average speed no higher than 16 knots which is why primarily tankers and bulk carriers are being considered as potential users. (Faber et al. 2011)

Kites of up to 320m² are currently in use, but kites up to an area of 5.000m² are planned (DNV 2011; Faber et al. 2011). Purchasing costs are estimated to range between USD 480.000 and USD 3,43 million for kites between 320m² and 5.000m². Yearly operational costs are assumed to be in the range of 5-15% of the purchasing price (Buhaug et al. 2009). The potential reduction of fuel consumption is difficult to determine because it depends on a variety of factors, such as the kite's size, the route and weather conditions. Therefore, average reduction estimates vary greatly, ranging from 2,1 % to 25,8% (Faber et al. 2011).

4.2 Structural analysis of the kite TIS

4.2.1 Main actors and networks

Skysails is currently the only supplier of towing kites used for propelling merchant ships. Previously, it faced competition from KiteShip but the company went bankrupt several years ago[4]. Recently, another kite provider entered the market – KitVes – however, the company is still in its early development stages. Due to the fact that it is not clear yet whether KitVes' technology will be used for propulsion purposes or only for on-board electricity generation (KitVes 2010), the further discussion will primarily focus on Skysails.

So far, customers of Skysails have included the shipping lines Briese, Wessels and Beluga. However, Beluga declared insolvency in March 2011 (Hergert 2012). Since recently, Cargill has joined the list of customers. Cargill is a multinational corporation and one of the leading traders of agricultural and energy commodities worldwide. It always has about 350 ships on charter (Matthews 2011). Given the power of Cargill within the industry, a successful collaboration with this company could mean a breakthrough for Skysails.

[4] No written evidence exists of this claim. Yet this information is based on an interview statement, the fact that the last activity on the website dates back to 2006 and that the company's legal status in the California Company Registry reads suspended.

Actors included in the category ‘intermediary infrastructure’ are characterized by the fact that they contribute to a smooth interface and knowledge flows between the supply and demand side. One of Skysails’ partners is the Germanischer Lloyd, one of the major classification societies, and as such “offers traditional classification services as well as expert advice, consultancy, advanced engineering, certification, training and software solutions” (Germanischer Lloyd 2012). Furthermore, the Sustainable Shipping Initiative of the NGO Forum for the Future is actively promoting the uptake of towing kites and working together with Cargill and Skysails to realize their agreement of installing kites on the ships chartered by Cargill (Matthews 2011).

Skysails has been working together with the University of Applied Sciences Oldenburg/ Ostfriesland/ Wilhelmshaven and some of the institutes affiliated with it (Institut Seefahrt Leer; Institut für Angewandte Wirtschaftsforschung) to research and test the use of towing kites.

No political actors seem to be actively involved in the development of the TIS of towing kites. However, the diffusion of the kites might be influenced by recent IMO regulations which set reduction targets for air pollutants and GHG emissions (see 4.2.2).

Overall, it can be said that only few actors are involved in the TIS of towing kites and the majority of them is focused around Skysails. Especially on the demand side, the number of actors is low. This is also the case for actors in the category ‘intermediary infrastructure’. Only two actors are working on smoothing the interface and knowledge flows between Skysails and potential customers, which could be one explanation for the lack of the latter. Furthermore, except for the IMO who is only indirectly involved in Skysails’ development, no political actors are active in promoting this new technology. This suggests that the overall structural development in terms of actors is relatively poor which inhibits the further development and diffusion of towing kites.

4.2.1 Institutions

The overall institutional framework[5] in which the international shipping industry operates is set by the IMO and consists of more than 50 conventions and protocols (Sainlos 2011). To become law, these have to be transposed into national legislation by the IMO’s member states (Hackmann 2012). Enforcement responsibility lies with the member states, where one distinguishes between flag and port states. While the flag state is legally responsible for all ships registered under its flag, no matter where they are, port states enforce maritime laws on ships in their territorial waters (Stopford 2009). The idea behind this distinction is to ensure that all ships, regardless of their flag, abide by the IMO conventions. It is generally known as the “no more favorable treatment” principle and one of the fundamental principles underlying international maritime governance (Buhaug et al. 2009; Hackmann 2012). Another important actor group are the classification societies. They develop rules and standards for ship construction and maintenance, and issue a classification certificate to reflect compliance (Stopford 2009). Their role has increased considerably over the years: because of their significant technical expertise, they assist regulators in making and implementing maritime laws and carry out technical inspections on behalf of governments (Stopford 2009).

With regard to environmental protection, the most important IMO regulation is the Convention on the Prevention of Marine Pollution from Ships (MARPOL Convention) (Harrison 2011). The Convention was adopted in 1973 and five years later, additional measures were added in the form of a Protocol (Stopford 2009). Originally, the treaty included five annexes regulating the pollution of oil, noxious liquid substances, packages substances, sewage and garbage, respectively. (Harrison 2011) In 1997, a new annex was adopted: MARPOL Annex VI sets limits on the main air pollutants contained in ships exhaust gas - sulfur oxides (SOx)

[5] The hard institutions which are important in the context of towing kites are the same than those relevant for Flettner rotors and sails. Therefore, they will only be discussed once.

and nitrous oxides (NOx) – and prohibits deliberate emissions of ozone depleting substances. Following its entry into force in 2005, MARPOL Annex VI was revised with a view to significantly strengthening the emission limits previously set. Furthermore, emission control areas (ECAs) were introduced - designated sea areas with even stricter emission limits for SOx, NOx and/or particulate matter (PM) (IMO 2013d). To date, four ECAs have been adopted – Baltic Sea-, North Sea -, North American - and United States Caribbean Sea ECA – which have or will come into force in 2006, 2006, 2012 and 2014, respectively. (IMO 2013f). More ECAs are expected in the future– particularly in the Mediterranean and the Far East (Aagesen 2011).

In July 2011, further amendments to MARPOL Annex VI were adopted, introducing mandatory technical and operational measures to reduce GHG emissions from ships (IMO 2013b). The Energy Efficiency Design Index (EEDI) is a technical measure aiming to promote the use of more energy efficient equipment and engines. It is a goal-based standard, leaving the choice of technologies to the industry in the hope of stimulating innovation (Leeuwen 2010). The energy efficiency level will be tightened incrementally every five years (IMO 2013g). It is expected that initially, EEDI compliance will mainly be achieved via hull, propeller and main engine optimization. (Bazari and Longva 2011) However, the formula used to calculate the EEDI also contains the possibility to use innovate mechanical energy efficient technology, such as kites, sails and Flettner rotors (BIMCO 2012).

In contrast to the EEDI, the Ship Energy Efficiency Management Plan (SEEMP) is an operational measure that stimulates more energy efficient operational practices. (IMO 2013g). There are a variety of options to improve efficiency, including improved voyage planning, weather routing, speed reductions and hull maintenance (MEPC 2012). With regard to wind propulsion, the guidelines state that it “may be worthy of consideration” (MEPC 2012:11).

While the EEDI only applies to new-build ships, the SEEMP is to be used on all ships. Both regulations apply to ships over 400 gross tonnage and have entered into force on 1 January, 2013 (IMO 2013b; IMO 2013e).

Yet in view of the growth projections of world trade, the MEPC recognized that these technical and operational measures would not suffice to satisfactorily reduce the amount of GHG emissions from shipping. Therefore, it was agreed to introduce a market-based mechanism (MBM) in the future which would provide a financial incentive to the maritime industry to cut fuel consumption and offset growing ship emissions. MBMs could also generate funds to be used for e.g. adaptation and technology transfer purposes. However, discussions regarding the specific design of this policy instrument are still on-going and it is unclear when a decision is likely to be taken (IMO 2013c).

Even though some of these regulations have the potential to promote the uptake of wind propulsion technologies, there is currently no policy instruments that directly targets these technologies. It remains to be seen what effect the outlined regulations will have on the uptake of these technologies.

4.3 Narrative

In 2001, Stephan Wrage set up the start-up company Skysails and applied for his first patent. Initial experiments with dinghies and store-bought kites were conducted in the Baltic Sea, but turned out to be little successful (Kundnani 2006). Due to its high debts, the company was unable to finance a new prototype or pay patent costs (ibid.). In 2002, Wrage persuaded another engineer to join the company as a co-founder and put in some private equity, allowing them to pursue the technology development. In the following year, testing of the technology was continued in cooperation with the German shipping company Rickmers (‘German Skysails develops…’ 2003). In 2003, the renowned ship financing company Jan Luiken Oltmann Group became Skysails’ lead investor. More financial support was provided by the BWA Agency for Business and Labor Affairs of the Free and Hanseatic City of Hamburg (Skysails 2012). For several weeks in summer 2004, Skysails conducted some more test across the Baltic Sea in order to assess the potential of kites to pull a ship across the ocean. Despite unfavorable conditions of weak and variable winds, the tests showed that the kite can generate 1-1,15 kilowatt per m² of aerofoil (Hamer 2005). Despite the positive results, some skepticism about the technology's potential was voices by the Institute for Shipping Technology in Flensburg (Schwede 2004). 2005 saw more testing, generating more knowledge and positive expectations (Sommer 2006). Furthermore, Skysails entered partnerships with the shipping companies Briese and Beluga, the classification society Germanischer Lloyd and the high-tech company AeroLabs which specializes in kite systems. To continue technology development, Skysails purchased the tanker “Beaufort” in 2006. In cooperation with academic institutes, the kite system was tested onboard the ship for a period of 18 months, during which the viability of the technology was further proven (Sommer 2006). The tests were supported financially by the German Federal Ministry of Education and Research ('Segel setzen lohnt sich', 2007). In the meantime, Skysails and Beluga Shipping signed a purchase agreement, making Beluga the first ship operator to use the towing kite for commercial purposes (‘Skysails und Beluga Shipping GmbH unterzeichneten Kaufvertrag’, 2006). On December 15, 2007, the Beluga Skysails was christened and set sail to Venezuela from Bremen on January 22, 2008. It reached the Norwegian port of Mo-I-Rana on March 13, 2008, traveling a total of 11,952 nautical miles (Emling 2007). Amongst others, the ship was chartered by DHL and the US Navy (Brigham 2008; 'DHL uses wind power…', 2008). The first flights with the Beluga Skysails demonstrated how the towing kite was able to substitute for 20 per cent of the engine's power which would result in daily cost savings of USD 1.000 ('Beluga SkySails completes maiden voyage', 2008). After having conducted some more tests on a ship owned by the shipping company Wessels in late 2007, Wessel decided to order the Skysails system for three new ships in July 2008 ('German inventor claims success…', 2008). In December 2008, Zeppelin Power Systems and Skysails concluded a partnership agreement, bringing in substantial financial resources and expertise for Skysails. In 2010, Skysails lost some of its orders due to the economic and financial crisis (Hergert 2010). The same year, the IMO adopted new rules that prescribe a progressive reduction in sulfur dioxide emissions by its members ('Climate crusade for both sea and sky', 2010). One year later, the IMO agreed on mandatory CO2 emission cuts: as of 2013, newly build ships have to comply with certain energy efficiency requirements (Otzen 2011). These two regulations may create a demand for alternative ship propulsion technologies like the towing kite. In the meantime, DSM Venturing made an investment into Skysails and thereby became one of the lead investors (Chew 2011b). Furthermore, Cargill signed an agreement with Skysails to start using a kite on one of its chartered ships as of December 2011 (Jameson 2011b). At the same time than the acquisition of this new client, Skysails lost another one: in March 2011, Beluga declared insolvency (Hergert 2012). Another client, Wessels, had to cancel two orders due to a lack of liquidity (ibid.). These developments resulted in Skysails having to dismiss about half of its employees in February 2012 ('Der Zugdrachen zieht nicht' 2012).

4.4 Event analysis

The figures below show the accumulation of events from 2000 onwards. Overall, 164 events have been identified. It can be noticed that the development accelerates in 2006 and peaks in 2008. From then on, the number of events decreases until 2011 when another peak is reported, only to decrease again in 2012.

Table 4: Total count of events per function per year - kites

Year	F1	F2	F3	F4	F5	F6	F7	TOTAL
2000	0	1	1	1	0	1	0	**4**
2001	2	1	0	1	0	0	0	**4**
2002	1	2	1	0	0	2	0	**6**
2003	0	0	1	1	0	2	0	**4**
2004	1	1	2	2	0	0	0	**6**
2005	1	1	2	2	0	1	0	**7**
2006	3	2	5	6	0	6	0	**22**
2007	1	2	2	8	0	0	1	**14**
2008	8	4	3	15	0	5	0	**35**
2009	0	2	0	7	0	3	0	**12**
2010	1	0	3	5	0	2	0	**11**
2011	3	3	5	8	0	4	1	**24**
2012	2	2	3	4	0	4	0	**15**
TOTAL	**23**	**21**	**28**	**60**	**0**	**30**	**2**	**164**

F1: Entrepreneurial activities; F2: Knowledge development; F3: Knowledge diffusion; F4: Guidance of the Search; F5: Market formation; F6: Resource mobilization; F7: Creation of legitimacy

How can this bumpy development be explained? In the newspaper articles it was suggested that the oil price development has impacted the development of the company and that 2005 marked a turning point for Skysails as oil prices had increased drastically. “The economics of the shipping business changed and any idea, however bizarre it sounded, seemed worth exploring. Doors that had been previously closed to Wrage opened“ (Kundnani 2006). In fact, when contrasting the fluctuations of events with the price developments of heavy fuel oils, one can see some similarities. The figure below shows that the oil prices have been rising steadily since 2005, with a steep increase in 2007 and 2008 which is also the case for the number of events reported. In 2009, then, oil prices dropped which is also mirrored in the number of events. In 2010, however, oil prices start rising again which is not the case for the number of events. This shows that, while the oil price may provide an explanation for the number of events reported, there must be other explanatory factors as well. These factors will be explored in the following sections.

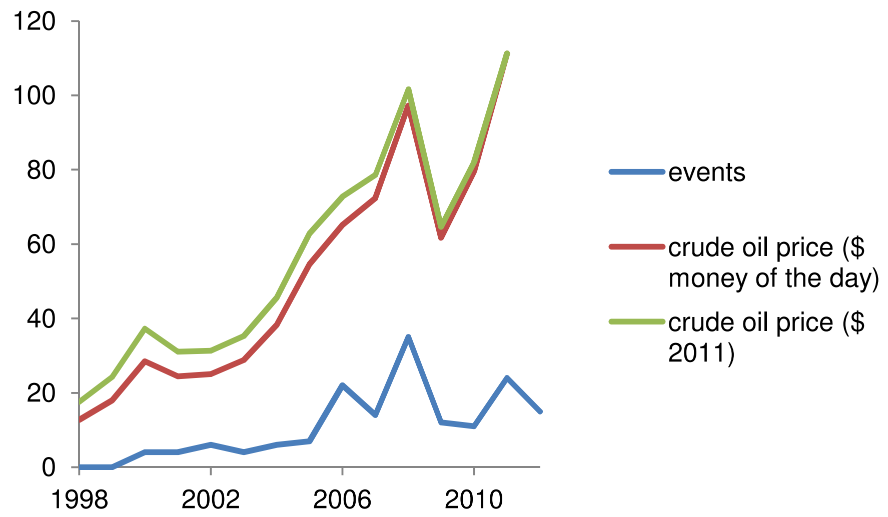

Figure 4: Comparison of oil price development and temporal event pattern - kites
Source: BP (2012)

4.4.1 Fulfillment of individual system functions

The review of newspaper articles on towing kites to be used in merchant shipping resulted in the identification of 164 events over the period 2000 to 2012. Each event was allocated to a particular system function. The overall allocation of events to the individual system functions is shown in the figure below. The figure also shows the number of events contributing positively to the TIS in question, as well as those contributing negatively.

Table 5: Function fulfillment - kites

	F1	F2	F3	F4	F5	F6	F7
Positive	18	21	28	44	0	18	2
Negative	5	0	0	16	0	12	0
TOTAL	**23**	**21**	**28**	**60**	**0**	**30**	**2**

F1: Entrepreneurial activities; F2: Knowledge development; F3: Knowledge diffusion; F4: Guidance of the Search; F5: Market formation; F6: Resource mobilization; F7: Creation of legitimacy

As a first observation regarding the spread of the events over the several categories, significantly more positive (131) than negative events (33) were identified. Furthermore, some functions were assigned more events than others. More than a third of events are linked to Guidance of the Search (60), followed by Resource Mobilization (30); Knowledge diffusion (28), Entrepreneurial Activities (23) and Knowledge Development (21). Only two events were identified for Creation of Legitimacy and none for Market Formation.

In the following paragraphs, each of the functions will be discussed based on the mapping of the events and evaluated by means of the propositions put forward in chapter 2.3.

Entrepreneurial activities

The development of entrepreneurial activities is depicted in the figure below. It starts slowly in 2001 and sees two peaks in 2006 and 2008 after the development slows down again. During this time, Skysails conducts first practical tests with its towing kite, refines it and scales it up, acquires its first customers and fits the kite on three commercial vessels (Berkenkopf 2008c; Biederman 2008; Emling 2007; Erdogan 2006; Hamer 2005; Kundnani 2006; Sommer 2006; 'Vom Winde bewegt' 2008). These experimentation and demonstration activities are positive for TIS development. However, after the second peak in 2008, five negative events are reported; most of them relate to the cancellation or postponement of orders (Hergert 2010; Hergert 2012; Krieger 2008). Given the limited number of clients and the size of the orders, their withdrawal has had a significant negative impact on Skysails, as reflected in the downsizing of the company beginning of 2012 ('Der Zugdrachen zieht nicht', 2012; Hergert 2012).

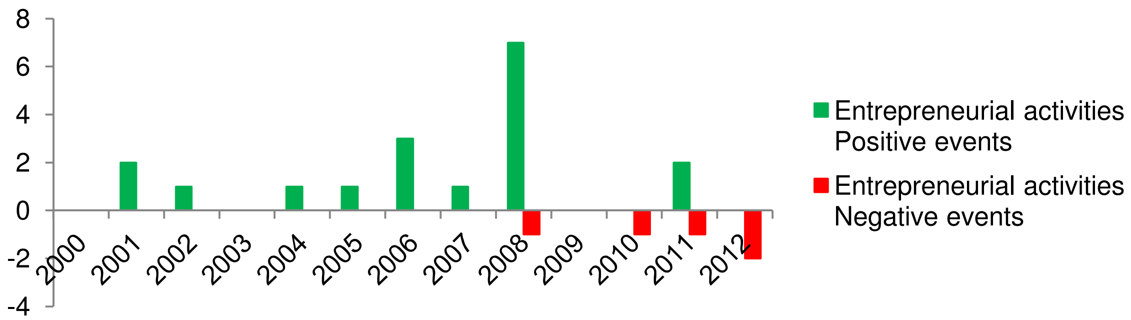

Figure 5: Activity pattern of Entrepreneurial activities - Kites

Even though overall, the positive events related to entrepreneurial activity outnumber the negative ones, it is worrying that all negative events have occurred in the past few years.

There is a downward trend in entrepreneurial activities which negatively impacts on the whole TIS for kites. The explanation for this trend is caused by an external factor: the economic crisis. The shipping industry has been severely affected by the recession in that demand for shipping services as well as freight rates dropped, leaving many ship owners struggling for economic survival. Their lack of liquidity, coupled with the unwillingness of banks to invest in shipping, meant that many of Skysails' orders had to be cancelled or postponed.

Another negative factor concerning this function is that the majority of activities are performed by only company: Skysails. KiteShip which never truly entered the merchant shipping market is believed to be bankrupt, yet no written proof was found to substantiate this claim. KitVes entered the market in 2008, yet they are not at the prototype stage yet and do not even know yet if their technology will be used for propulsion at all (KitVes 2010). The concentration of activities on Skysails makes the TIS vulnerable because everything stands and falls with this company; every hit to Skysails is a blow to the TIS for kites.

Due to these negative factors, the positive influence of the experimentation and demonstration projects is reduced which means that, overall, function fulfillment is low to medium.

Knowledge development

Knowledge development activities have started in 2000 when Stephan Wrage (founder of Skysails) first tested a prototype of the technology on a small catamaran (Wille 2005). The spread of these activities over time is relatively continuous, with a peak showing in 2008.

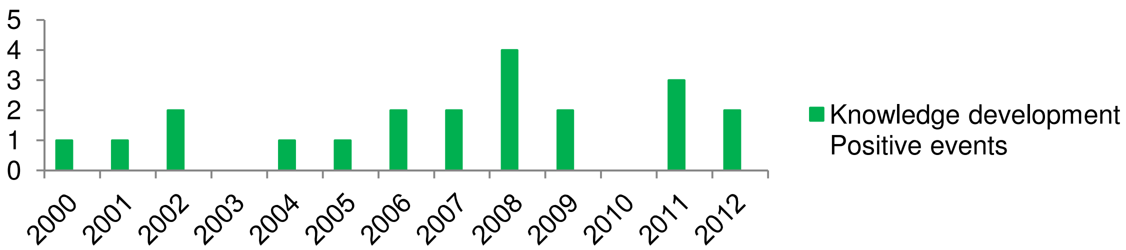

Figure 6: Activity pattern of Knowledge development - Kites

Knowledge development is driven by entrepreneurs (primarily Skysails) who experiment with the technology and based on the outcomes, develop it further. In most cases, this required finding a ship owner willing to support these trials ('German Skysails develops…' 2003; Jameson 2008; 'Vom Winde bewegt' 2008). While some of their research has been conducted together with universities and research institutes, it was mostly left to entrepreneurs to investigate the potential and feasibility of the technology (Sommer 2006). This might change in the future given that two research consortia have been formed in 2012. The classification society Lloyd's Register has joined forces with wind turbine manufacturer Totempower Energy Systems and ship management company Zodiac Maritime Agencies to assess the potential of wind-generation devices onboard commercial ships ('Zodiac, Totempower and Lloyd's Register embark…' 2012). The other project is the EU Interregg SAIL which is supported by provinces, port authorities, universities, research institutes, consultancies, a sailing technology provider and NGOs. Until 2015, this group aims to research the technical and economic viability of several wind propulsion technologies on different routes and weather conditions and review policy in relation to building and operating hybrid sailing ships (Hillmer 2012; NSR SAIL 2013).

Due to the lack of scientific research and the dependence of knowledge development on primarily one entrepreneur, function fulfillment is low. The recent upsurge of research attention could lead to better function fulfillment in the future.

Knowledge diffusion

The development of the system function Knowledge diffusion is depicted below. Overall, a build-up of events can be observed over time, except for the decreases between 2007 and 2010 and after 2011.

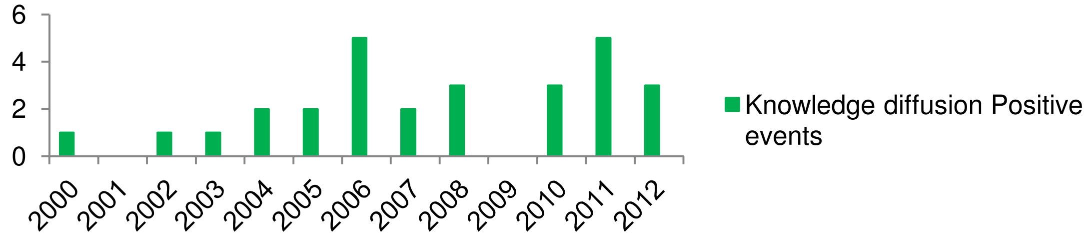

Figure 7: Activity pattern of Knowledge diffusion - Kites

Many events link to the formation of partnerships between industry actors and knowledge institutes (Chew 2010; Chew 2011b; Einemo 2011; Jameson 2011b; Krieger 2008; Matthews 2011; Pettigrew 2004; Schwede 2004; Wille 2005), but some of them also to presentations held at conferences or the presence at industry fairs (Hillmer 2010; Kastendieck 2012; 'Technology and the containership challenge' 2007). While the former allows for a more intense knowledge exchange between actors by means of which new knowledge can also be generated, the latter is important to transfer knowledge to actors outside the TIS, create awareness of and generate interest in the technology. This is especially important given the limited amount of codified, scientific knowledge on kites. Without this general sense of awareness and knowledge, there would be no base on which to build a partnership.

Even though there are different occasions for knowledge exchange, both in the form of presentations and partnerships, these occasions are not sufficient given the big size of the shipping industry. Therefore, function fulfillment is estimated to be low to medium.

Guidance of the search

The temporal development of the function Guidance of the search is relatively continuous with a pronounced peak of positive events showing in 2008. Besides positive events, several negative events have been reported over time.

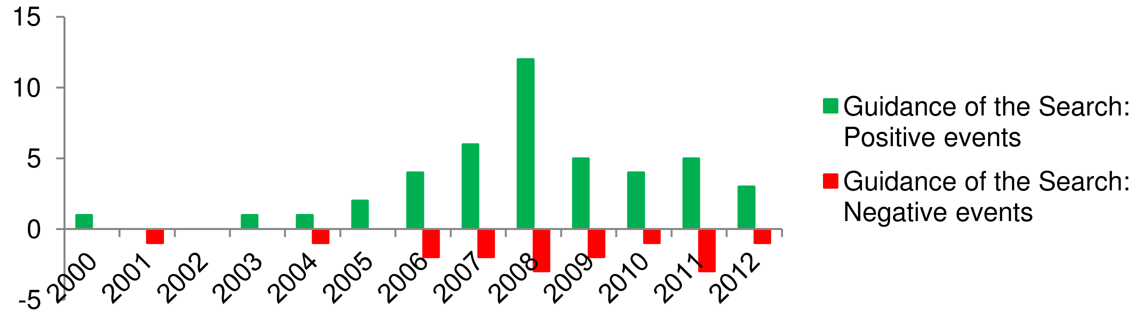

Figure 8: Activity pattern of Guidance of the search - Kites

The majority of events relates to the voicing of either positive or negative expectations, the latter primarily in the form of doubts or skepticism. When taking a closer look at the identified events, it is striking that many of the positive expectations are based on research results or the outcome of practical tests ('Drachensegel-Tests auf Tonnenleger erfolgreich' 2006; Hamer 2005; Jameson 2007; Jameson 2008; 'Vom Winde bewegt'), whereas the majority of negative opinions or doubts rely on assumptions, a gut feeling or tacit knowledge of the industry (Alexander 2010; Berkenkopf 2008b; Kan 2012). Another interesting observation is that positive expectations are mostly voiced by technology providers, whereas doubts and skepticisms come from actors with a relatively high standing in the maritime industry, e.g.

from representatives of the German Shipowners' Association, the British Chamber of Shipping or the International Chamber of Commerce (ibid.). It is thus likely that even though a lot of positive expectations are based on factual knowledge, doubts and skepticism gain the upper hand within the shipping industry since they have been voiced by people of influence.

Only three events relate to policies which all aim at reducing air pollution from shipping: the cut of SOx and NOx in Emission Control Areas and the introduction of both the EEDI and the SEEMP (Geoghegan 2012; Knauer 2012; Otzen 2011) (see section 4.2.1). While these instruments could promote the use of kites as they reduce air pollution, they are not aimed specifically at incentivizing them, but rather set targets to be achieved by the industry, no matter how. Therefore, the use of kites is only promoted in a very indirect way. Given the level of skepticism facing the kites, it is likely that ship owners will first chose other measures before resorting to kites, so the impact of these instruments on the uptake of kites is estimated to be rather low.

To conclude, the positive influence of the high number of positive events is likely to be reduced by the voicing of doubts and skepticism of influential actors and it is estimated that the impact of existing policies on the uptake of kites is limited. Therefore, function fulfillment is considered to be medium.

Market formation

No events have been reported for the function Market formation. There are no financial incentive schemes which could create a niche market for kites and shield technology development from market pressures. This function is thus absent.

Resource mobilization

The temporal development of the function Resource mobilization is highly discontinuous. Until 2008, function fulfillment is primarily positive and peaks in 2006, but as of 2008, most reported events related to negative function fulfillment, indicating a downward trend in function fulfillment.

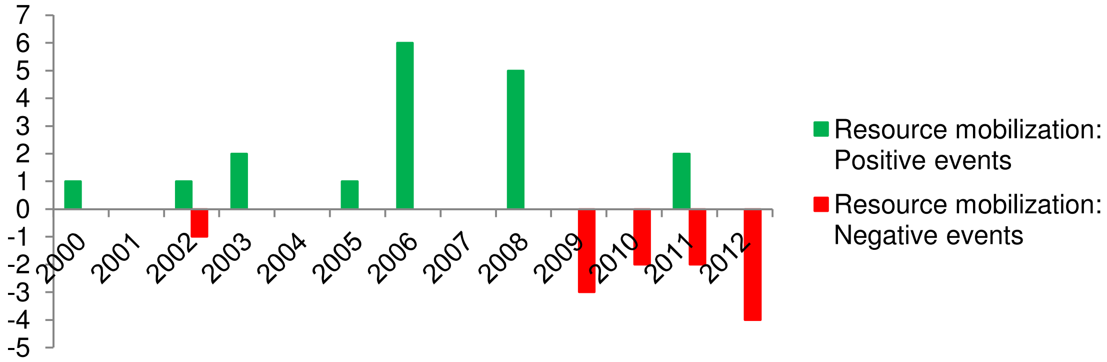

Figure 9: Activity pattern of Resource mobilization - Kites

The negative events occur mostly as of 2009 and peak in 2012. The reason for this has to be found in the economic crisis which left ship owners without the financial means to invest in their ships and banks unwilling to finance these investments (Klooß 2012; Werner 2012). As a result, several orders had to be cancelled which in turn led to Skysails having to downsize: the company had to let go of about half of their employees (Berkenkopf 2012; Hergert 2010; Hergert 2012). This means that the recent economic crisis and all that it entailed has not only diminished Skysails' financial resources, but also human capital, hindering its further development. Hence, function fulfillment is low.

Creation of legitimacy

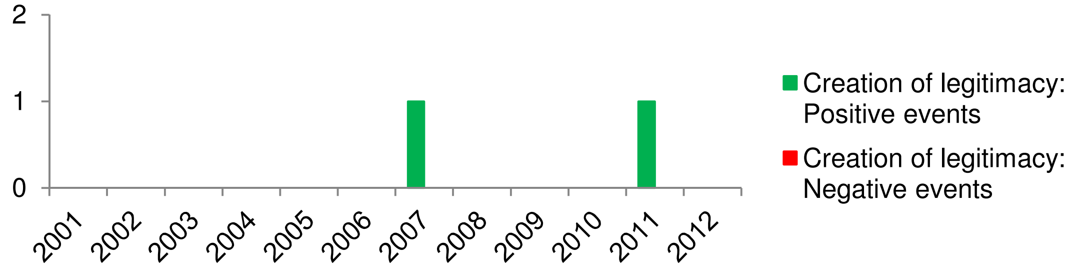

Figure 10: Activity pattern of Creation of legitimacy - Kites

Only two events related to creating legitimacy for different sail technologies, including kites. In the first instance, a member of the European Parliament urged the IMO for the introduction and promotion of renewable energies for shipping, such as wind. (Bruckner-Menchelli 2008a) In the second case, an advisory group to the British government has recommended to fit ships with sails or other wind propulsion technologies again. (Millward 2011) However, there are no coordinated actor groups exerting pressure on actors in power to change institutions which complement the emerging technology. Yet this would be needed to counter the skepticism prevalent in the industry. In conjunction with the low number of events reported, this means that the function is only poorly fulfilled.

4.4.2 Interaction of system functions

The previous sections have shown that system functions influence each other in both a positive and negative way.

On the positive side, entrepreneurial activities drive knowledge development and diffusion which both generate positive expectations. This is particularly the case up until 2008. That year, however, the economic recession hits the shipping industry resulting in a lack of resources which inhibit the continuation of entrepreneurial activities. No market formation activities exist that could counterbalance this lack of resources. The voicing of doubts and skepticism by influential actors is likely to have a negative impact on entrepreneurial activities, especially since they are not offset by any lobbying activities. These developments could easily lead to the formation of a vicious circle in the future.

4.5 Conclusion

The table below shows the evaluation of the different propositions according to which the development of the TIS is being evaluated. Two functions are medium fulfilled, one low to medium, three poorly and one is completely absent. Therefore, it can be concluded that overall, the TIS for kites is poorly developed which indicates that it is obstructed by structural barriers. These structural barriers will be identified in Chapter 8.

Table 6: Overview of system function fulfillment – kites

Proposition No.	Content of proposition	Evaluation
1	The function 'Entrepreneurial activities' is considered well developed if many experimentation projects are conducted and if these are diverse in terms of exploring different technological options, possible applications and different market segments.	L/M
2	The function 'Knowledge development' is considered well developed if many different knowledge activities of both 'learning by searching' and 'learning by doing' are undertaken.	L
3	The function 'Knowledge diffusion' is considered well developed if there are many occasions (e.g. partnerships, workshops and conferences) where actors can meet and exchange knowledge.	L/M
4	The function 'Guidance of the search' is considered well developed if there are clear positive signals in place pushing actors towards entering and contributing to the development of the TIS. These signals may take the forms of clear policy targets or measures in favor of the technology and the voicing of positive expectations regarding the future development of the technology.	M
5	The function 'Market formation' is considered well developed if public support schemes are in place that effectively incentivize the use of the emerging technology.	-
6	The function 'Resource mobilization' is considered well developed if enough financial, human and physical resources are available for the development of the emerging technology and if actors within the TIS have access to these resources.	L
7	The function 'Creation of legitimacy' is considered well developed if coordinated actor groups exert pressure on actors in power to change institutions which complement the emerging technology.	L

L = low; M = medium; H = high; - = absent

5 Flettner rotors

This chapter aims at answering the following sub-question:

What is the state of play in the development and diffusion of Flettner rotors?

Following the theory and methodology outlined in chapter two and three respectively, this will entail a structural analysis of the TIS related to Flettner rotors, followed by an evaluation of the different system functions and their interactions. This will result in an assessment of how well developed the TIS for Flettner rotors is.

5.1 Description of the technology

A Flettner rotor is a spinning vertical rotor that converts wind power into propulsive energy (Crist 2009). It is based on the scientific principle known as the Magnus effect: a cylinder rotating in the wind exerts a force in the perpendicular direction to the wind. On the side of the cylinder that moves against the wind, air piles up and causes pressure. Decreased air friction on the opposite site of the cylinder creates suction, exerting a pull. These two forces together move the ship (Seybold 1925; Martin 1926). This means that in side wind conditions, the ship will benefit from the added thrust, but it cannot sail down- or upwind. The rotor itself has to be set in motion by another energy source ('Keine Rückkehr, sondern…' 2009; Wärtisilä 2013). Because the system requires free deck space, it is only suitable for tankers, bulk carriers and Ro-ro vessels (Crist 2009; Faber et al. 2011). It is estimated that by employing Flettner rotors as an auxiliary engine, fuel consumption can be reduced by up to 30 per cent, with average annual fuel savings of 13,6% (Crist 2009; Greenwave 2013b; Wärtsilä 2013). The costs for manufacturing and installing rotors on a bulk carrier of 60.000-200.000 dwt are to range between USD 960.000 and USD 1.200.000, and for a crude oil tanker within the same size ranges between USD 720.000 and USD 900.000 (Faber et al. 2011).

5.2 Structural analysis

5.2.1 Main actors and networks

There are currently four organizations working on the Flettner rotor: Enercon, Magnuss, Windagain and Greenwave. Enercon is a German wind turbine manufacturer which has used its knowhow in wind technology to build the E-Ship 1, a ship equipped with Flettner rotors. This ship is used to transport the company's wind turbines around the world. Magnuss is an American maritime shipping technology firm aiming to provide ships with its Flettner rotors. The Singapore-based company Windagain produced and sells a collapsible Flettner rotor system. The fourth organization, Greenwave, is a UK-based environmental NGO aiming to reduce shipping emissions by providing affordable technological solutions to the industry, one of which is the Flettner rotor.

Little information was available on the partners of these four technology providers and none at all for Magnuss and Windagain. Enercon's research on the development of rotor sails was supported financially by the German Federal Environment Foundation. Further support was provided by the private research institute Hamburg Ship Model Basin, by Arkon Shipping and the Wessels Shipping Company. The E-Ship 1 as classified by the classification society Germanischer Lloyd. (Enercon 2010; Enercon 2011)

Partners of the environmental NGO Greenwave include other NGOs – the Carbon War Room, the Sustainable Shipping Initiative and the World Ocean Council -, public research institutes – Auckland University, Southampton Solent University, Warsah Maritime Academy and the Royal Institution of Naval Architect - as well as the shipping organization Intercargo and the classification society Lloyds Register (Greenwave 2013a).

The little information available shows that a demand side for Flettner rotors has not yet developed. There is no indication of ties existing between technology providers. Furthermore, no political actors are actively involved in this TIS.

5.2.2 Institutions

The institutions that are important for the TIS for Flettner rotors are the same than those for kites. Therefore, please see chapter 4.2.2 for more information on the institutional infrastructure.

5.3 Narrative

The Flettner rotor was developed by the German engineer Anton Flettner. After having conducted extensive tests and modeling exercises, he built the first rotor ship, the schooner Buckau (Welleck 1926). In 1925, the ship was first put out to sea in Kiel, Germany. Initial tests showed that depending on weather conditions, the ship could achieve average speeds of 4,5 to 8 knots (Seybold 1925). The invention triggered great expectations, but also encountered some skepticism:

> "Several authorities, including officials of a great steamship line, pronounced the invention the most startling maritime development since Fulton's steamboat. Others were more skeptical, asking how the Buckau would perform in a heavy sea, and are yet to be convinced of the value of the invention." (Seybold 1925)

The Hamburg American Steamship company was so convinced of the invention that it decided to use rotors on ten of its ships and several other shipping companies are reported to have shown great interest. (Seybold 1925) Two American naval officers were so enthused with Flettner's invention that they built a rotor ship themselves. Just like the Buckau, initial test voyages showed promising results. At the time, this was seen as "an indication of future rotor uses" ('America's First Rotor Boat' 1925). However, from then on, no more activities related to Flettner rotors were reported.

This changed in the late 1970's/early 1980's when Lloyd Bergeson formed the Wind Ship Development Corporation in the US to promote the idea of Flettner rotors. Together with the engineer Hanson who had previously studied the potential of Flettner rotors, he retrofitted a ship with a Flettner rotor in 1981. Again, test voyages confirmed the potential of the technology and interest within the shipping industry and the Navy was growing (Gilmore 1984). Two years later, another boat, the 'Moulin Rouge', a catamaran equipped with a Flettner rotor, was launched from Marseille for a test run (Popeski 1983). Financed with French government funds, it was under the supervision of French naval officer and explorer Jacques Cousteau, who also founded the (still existing) Cousteau Society ('Wind-Driven Boat Launched By Cousteau' 1983). Despite heavy storms, the Moulin Rouge made it across the Atlantic, turning its maiden voyage into a success (Comegys 1983). In 1984, Cousteau teamed up with the French aluminum producer Pechiney to "market on a worldwide basis a wind propulsion system for oceangoing ships" and develop Flettner rotors commercially (Betts, 1984). During this period, the last reported activity related to Flettner rotors was in 1985 when Cousteau's new rotor ship was just about to embark on a two-year trip around the world. The scientific and technical director of the Cousteau Society commented this trip by saying: "We have really great expectations, great hope for the development of the system in the marine world" ('Cousteau's Experimental Ship Set For World Voyage' 1985). Yet at the time, these expectations were not fulfilled.

More than 20 years later, the idea of Flettner rotors was picked up again. In 2006, the University of Flensburg built a catamaran equipped with such a rotor to better understand the technology and demonstrate it to scholars. (Luttmer 2008b) The same year, German wind turbine manufacturer Enercon commissioned a German ship yard with building the first rotor freight ship. (Einemo 2006) In August 2008, the ship, named E-Ship 1, was launched. (Luttmer 2008b) While the launch of the E-Ship 1 gave rise to great expectations in the technology, doubts and skepticism concerning the viability of the Flettner rotor remain. This probably also has to do with the fact that Enercon always maintained “an air of secrecy around the vessel” (Berkenkopf 2010). The company had planned to publish details on the performance of the vessel after some test runs, yet apart from stating that the technology works, has not made any details public. It is also unknown if Enercon will build a second rotor ship, as was envisaged in 2006. (Berkenkopf 2010)

In 2008, Greenwave started to develop different fuel saving technologies, but is currently focusing on the Flettner rotor as it has shown the best potential for cost savings. Despite a lack of finance attributable to the downturn in the shipping industry, Greenwave began conducting practical tests in 2009 to further its knowledge on the technology and refine its concept. (Wallis 2009)

The same year, the Dutch ship management company Q-Shipping commissioned a feasibility study for a vessel with large Flettner rotors. The director of the company stated that “the design is ready, and it is now up to investors to get involved. We are currently waiting mainly for government subsidies to help attract interested parties” (Hill 2009). It is unknown whether Q-Shipping has been able to realize its plans for a rotor ship.

In 2010, the two other organizations developing Flettner rotors – Magnuss and Windagain - were founded in the US and Singapore respectively to re-introduce Flettner rotors to the market (Eason 2012; LinkedIn 2013)

5.4 Event analysis

The narrative has shown that the development of the TIS for Flettner rotors can be divided into three phases: the mid 1920’s when Flettner developed the rotor engine, the late 1970’s/early 1980’s where it was rediscovered both in the US and in Europe and finally the mid 2000’s until now where different organizations are not only experimenting with the technology, but are also trying to market it commercially. These three phases are mirrored in the table below: the first events were reported in 1925, then nothing happened until 1979 and again no events from 1986 until 2006.

Table 7: Total count of events per function per year – Flettner rotors

Year	F1	F2	F3	F4	F5	F6	F7	TOTAL
1923	0	1	0	1	0	0	0	**2**
1924	1	1	0	0	0	0	0	**2**
1925	3	2	0	7	0	0	0	**12**
1926	0	1	0	1	0	0	0	**2**
1927-1978	0	0	0	0	0	0	0	**0**
1979	1	0	0	0	0	0	0	**1**
1980	0	0	0	0	0	0	0	**0**
1981	2	4	2	2	0	0	0	**10**
1982	0	0	0	0	0	0	0	**0**
1983	1	1	0	2	0	1	0	**5**
1984	0	1	1	1	0	1	0	**4**
1985	0	1	0	1	0	0	0	**2**
1986-2005	0	0	0	0	0	0	0	**0**
2006	1	2	0	1	0	0	0	**4**
2007	0	0	0	1	0	0	1	**2**
2008	2	1	1	7	0	1	0	**12**
2009	1	4	1	4	0	2	0	**12**
2010	2	1	1	5	0	0	0	**9**
2011	0	0	1	2	0	0	0	**3**
2012	0	3	2	3	0	1	0	**9**
TOTAL	**14**	**23**	**9**	**38**	**0**	**6**	**1**	**91**

F1: Entrepreneurial activities; F2: Knowledge development; F3: Knowledge diffusion; F4: Guidance of the Search; F5: Market formation; F6: Resource mobilization; F7: Creation of legitimacy

In the analyzed articles, this development is explained by the fluctuating oil prices:

> "But the Flettner rotor on the Buckau lost its economic appeal when oil prices dropped in the first half of the 20th century." (Luttmer 2008b)

> "Only in 1987 did Blohm & Voss plan a chemical tanker with Flettner rotors, but again falling oil prices put a stop to the energy-saving and environmentally-friendly project." (Luttmer 2008b)

When plotting the number of events against development of the oil price, it shows that the curves are remarkably similar and that peaks in the number of events coincide with peaks in oil prices and decrease as the oil price decreases (see figure below):

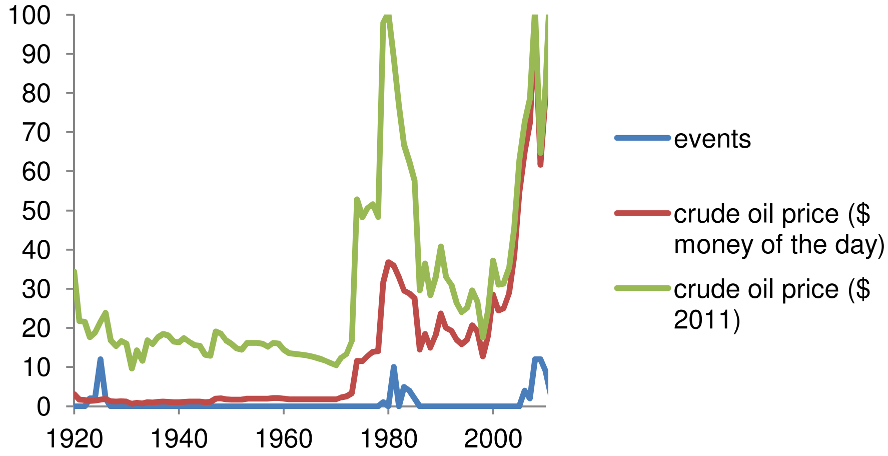

Figure 11: Comparison of oil price development and temporal event pattern – Flettner rotors
Source: BP (2012)

It is therefore suggested that a high oil price is a driver for the development of the TIS for Flettner rotors.

5.4.1 Fulfillment of individual system functions

The review of newspaper articles on Flettner rotors to be used in merchant shipping resulted in the identification of 91 events that have impacted the TIS in the period 1925 to 2012. According to the specific content of the event, each of the events was mapped on a particular system function. The overall allocation of events to the individual system functions is shown in the figure below. The figure also shows the number of events contributing positively to the TIS in question, as well as those contributing negatively.

Table 8: Function fulfillment – Flettner rotor

	F1	F2	F3	F4	F5	F6	F7
Positive	14	23	9	31	0	3	1
Negative	0	0	0	7	0	3	0
TOTAL	**14**	**23**	**9**	**38**	**0**	**6**	**1**

F1: Entrepreneurial activities; F2: Knowledge development; F3: Knowledge diffusion; F4: Guidance of the Search; F5: Market formation; F6: Resource mobilization; F7: Creation of legitimacy

As a first observation regarding the spread of the events over the several categories, significantly more positive (81) than negative events (10) were identified. The comparison of the number of events allocated to each function shows that the highest number is linked to the function Guidance of the search (38), followed by Knowledge development (23) and Entrepreneurial activity (14). Only few events relate to Knowledge diffusion (9), Resource mobilization (6), Creation of Legitimacy (1) and none to Market formation.

In the following paragraph, each of the functions will be discussed based on the mapping of the events and evaluated by means of the propositions put forward in chapter 2.3.

Entrepreneurial activities

The development of the system function 'Entrepreneurial activities' is depicted in the figure below. The figure shows activities in 1925 and 1925, from 1979 to 1983 and again during 2006 and 2010. In between these three development phases, there are two long periods of inactivity of more than 50 and 20 years, respectively. These gap periods can be explained by the dropping oil prices at the end of both phases which destroyed the economic case for the use of Flettner rotors (Luttmer 2008b; Luttmer 2008c). Entrepreneurial activities were thus not continued. Since more precise information on insolvencies or the termination of projects was not available, these events have not been included in the event analysis. Therefore, the event allocation to this particular function is biased and suggests a more positive development than it would have shown if data had been available.

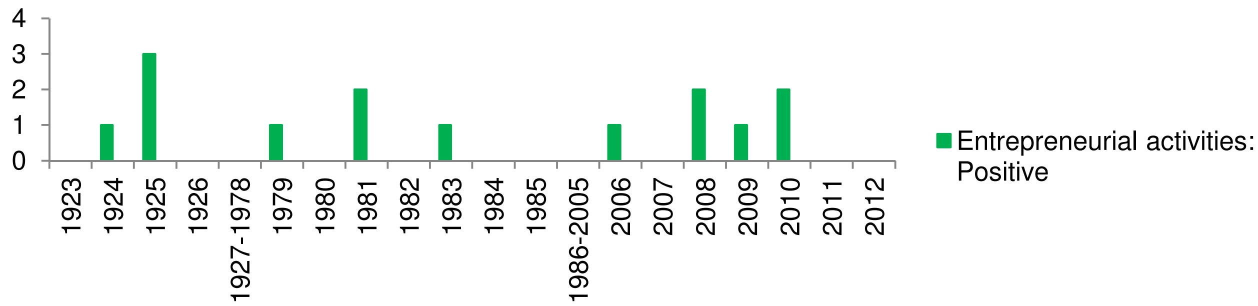

Figure 12: Activity pattern of Entrepreneurial activities – Flettner rotors

Over the years, several organizations have been involved in entrepreneurial activities with regard to Flettner rotors and different activities have been conducted in different settings to experiment and explore the viability of the Flettner rotor ('America's First Rotor Boat' 1925; Eason 2012; Einemo 2006; Gilmore 1984; Hach 2007; Popeski 1983; Seybold 1926; Smith 2008). This is considered positive. However, the uneven temporal pattern indicates that these activities have been discontinuous and stopped at some point. There is no continuation in the different entrepreneurial activities which is a prerequisite for becoming an established actor in the field. Therefore, the fulfillment of this function is only considered to be low to medium.

Knowledge development

Knowledge development on Flettner rotors started in 1923 when Anton Flettner invented the Flettner rotor (Hach 2007). Over the next three years, more experiments and trials were conducted but these activities came to a halt after 1926, only to be taken up again in 1981 (('America's First Rotor Boat' 1925; Gilmore 1984; Hach 2007; Seybold 1925). After four years only, activities were stopped again and were only resumed in 2006 (Luttmer 2008b; Luttmer 2008c; Popeski 1983).

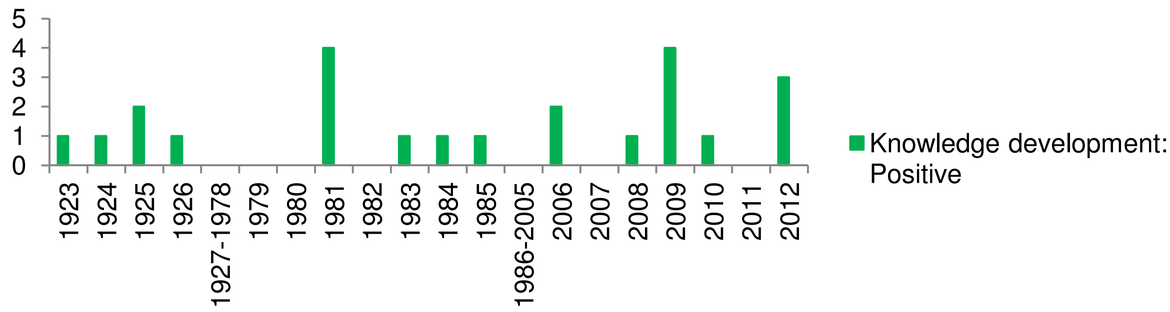

Figure 13: Activity pattern of Knowledge development – Flettner rotors

Especially in the first two phases, knowledge development was driven by entrepreneurs. This explains why knowledge development activities were terminated at the same time than entrepreneurial activities, it was simply not considered worth it to continue investigate a technology that did not make economic sense. These large periods of inactivity between 1927 and 1980 and again between 1986 and 2005 coupled with the lack of codified, scientific knowledge meant that a build-up of knowledge did not take place. Every time, actors have to begin anew rather than basing their experiments and trials on existing knowledge and contributing to furthering this knowledge base. This creates inefficiencies and research redundancies. Even though in recent years, knowledge development has still been driven by entrepreneurs, some public research institutes have started conducting research in the field of Flettner rotors, e.g. University of Flensburg who developed a catamaran equipped with a Flettner rotor in 2006 (Luttmer 2008c) or the different research institutes who cooperate under the framework of the Interreg SAIL program (Hillmer 2012)

While the renewed interest in the Flettner technologies as witnessed in the past few years is a positive sign, the lack of a knowledge base resulting from the discontinuous development of this function means that function fulfillment is low.

Knowledge diffusion

The temporal pattern of the function knowledge diffusion is highly discontinuous and shows a lack of activities until 1981, and again between 1985 and 2007.

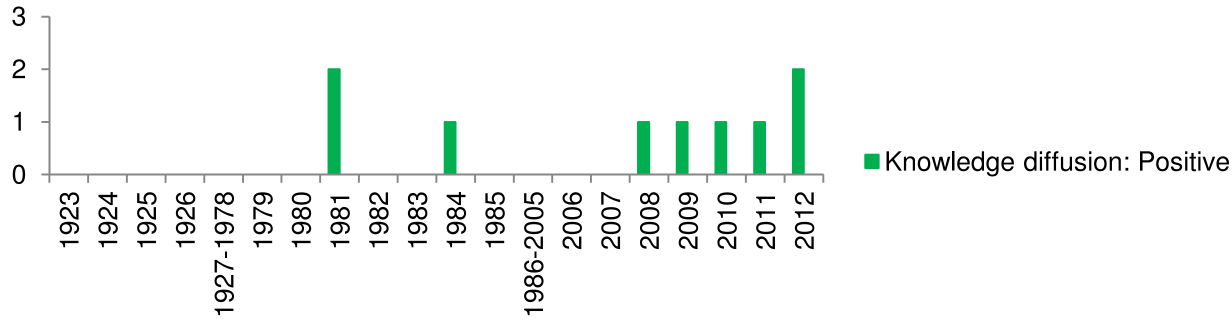

Figure 14: Activity pattern of Knowledge diffusion – Flettner rotors

This confirms the statement of the previous section, i.e. that a knowledge build-up did not take place because actors could not benefit from other experiences and knowledge and instead had to make these experiences by themselves. A possible reason for this lack of knowledge diffusion in the past is that actors involved in knowledge development were geographically too far apart to collaborate. During the 1920's knowledge development took place both in Germany and the US ('America's First Rotor Boat' 1925; Hach 2007), and in the 1980's, activities were confined to France and the US (Gilmore 1984; Popeski 1983). Another possible explanation lies in the motivation of the knowledge generators – being entrepreneurs, they might have hoped to gain a competitive advantage from keeping their knowledge to themselves. Even though activities related to knowledge exchange have increased in the past few years, the function is still poorly developed which also relates to the fact that the company currently most advanced in terms of knowledge development – Enercon – is secretive about his experience with the technology and does not want to share knowledge (Berkenkopf 2010). The recent involvement of more public research institutes who have a mandate to disseminate knowledge could lead to better knowledge exchange in the future.

Guidance of the search

The temporal pattern shows a similar distribution of events than the previous functions with events taking place in the mid 1920's, 1980's and as of 2006. In-between these periods, no events were reported.

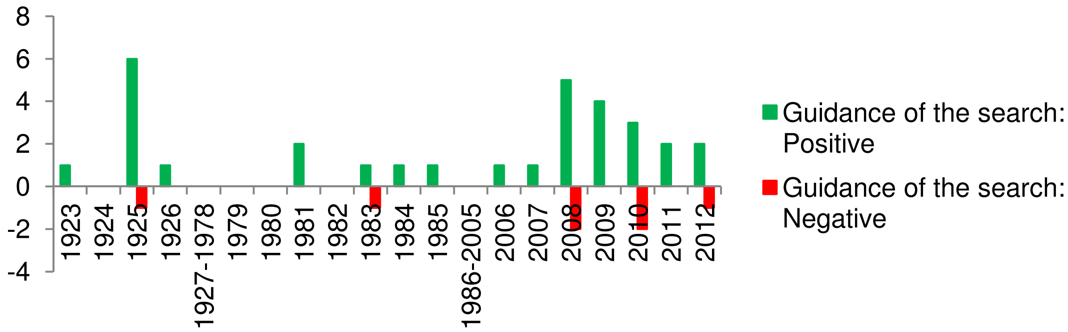

Figure 15: Activity pattern of Guidance of the search – Flettner rotors

Most reported events relate to the voicing of positive expectations which peaked in 1925. At the time, "several authorities, including officials of a great steamship line, pronounced the invention the most startling maritime development since Fulton's steamboat" (Seybold 1925) and the spectators of the Buckau's maiden voyage "were convinced that they had witnessed what was going to be the future of shipbuilding" (ibid.). The enthusiasm at the time was great, spurred on entrepreneurial activities and knowledge development and hardly any negative expectations that could have reduced this enthusiasm have been reported. Yet this enthusiasm did not survive the consequent drop of oil prices and all activities came to a halt. Upon resuming them in the 1980's, interest in the technology was renewed and positive expectations built up again. Even the US Navy took an interest in the potential conversion of its vessels to rotor-assisted propulsion (Gilmore 1984). Again, interest faded away as the technology lost its economic appeal due to low fuel prices.

While expectations regarding Flettner rotors were almost exclusively positive during the first two development phases, more doubts and skepticism have been voiced in the past few years (Alexander 2010; Kan 2012; Wee 2008). According to a survey amongst ship owners, only three per cent believe in the potential of Flettner rotors (Berkenkopf 2008a). Due to the lack of knowledge diffusion and the secrecy of Enercon, this skepticism is difficult to combat. Yet even nowadays, most expectations are positive and the recent IMO regulations could further increase interest in the technology (Eason 2009a; Geoghegan 2012; Grimm 2009; Hach 2007; Knauer 2012; Luttmer 2008c; Otzen 2011; Tiedemann 2010). Coupled with the optimism voiced in the two first development stages of the technology, this means that function fulfillment is considered medium to high.

Market formation

No events have been reported for the function Market formation. There are no financial incentive schemes which could create a niche market for kites and shield technology development from market pressures. The function is thus absent.

Resource mobilization

Only few events have been reported with regard to Resource mobilization and activities only started in the 1980's when the Cousteau society received French government funding and support from the French aluminum company Pechiney (Betts 1984; 'Wind-driven boat launched by Cousteau' 1983). In 2008, more public money was made available for the development of the E-Ship 1, this time by the German government (Luttmer 2008c). As of then, only negative events have been reported which relate to actors struggling for financial resources due to the economic downturn (Hills 2009; Wallis 2009; Werner 2012).

The fact that half of the events relate to negative function fulfillment and were all reported in the past few years means that function fulfillment is low.

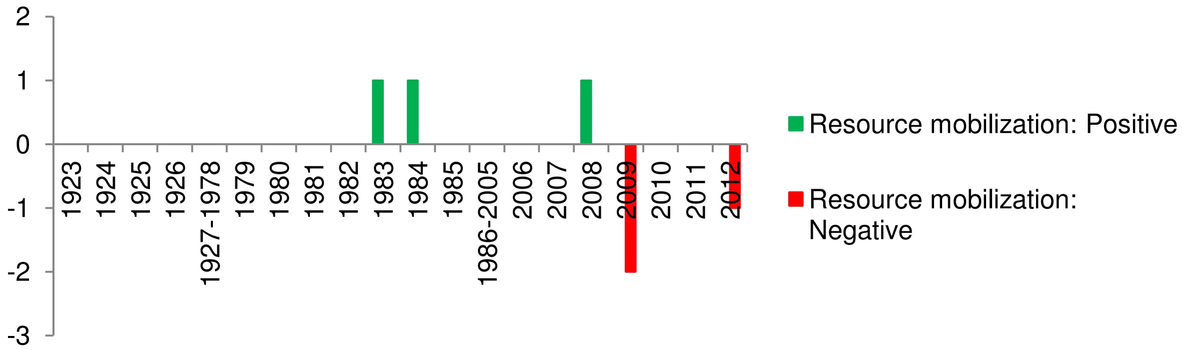

Figure 16: Activity pattern of Resource mobilization – Flettner rotors

Creation of legitimacy

Only one single event related to creating legitimacy for Flettner rotors is reported: in 2007, a member of the European Parliament urged the IMO to introduce and promote renewable energies, such as wind, for shipping. (Bruckner-Menchelli 2008a) There are no coordinated actor groups exerting pressure on actors in power to change institutions which complement the emerging technology as is postulated in proposition 7. Taken together, this means that the function is only poorly fulfilled.

5.4.2 Interaction of system functions

The previous sections have shown that system functions influence each other in both a positive and negative way.

On the positive side, entrepreneurial activities drive knowledge development which generates positive expectations. These in turn have spurred on more entrepreneurial activities and thereby knowledge development. What could have led to a virtuous cycle was interrupted by external events: the falling oil prices after the first two development phases made the technology economically unattractive and caused all activities to stop. The other external event is the economic recession starting in 2008 which left both technology providers and interested customers struggling for money. Given that no other financial incentives are in place to mitigate the negative effect of the economic downturn, less entrepreneurial activities have been reported. Nonetheless, knowledge development has been continued which is mainly due to the presence of public research institutes.

5.5 Conclusion

The table below shows the evaluation of the different propositions according to which the development of the TIS is being judged. With most functions being poorly fulfilled, it can be concluded that overall, the development of the TIS is rather poor which suggests that there are few drivers in place that could accelerate the development of the TIS, but instead many barriers that obstruct it. In order for the TIS to flourish, these barriers need to be alleviated and the drivers accelerated.

Table 9: Overview of system function fulfillment – Flettner rotors

Proposition No.	Content of proposition	Evaluation
1	The function 'Entrepreneurial activities' is considered well developed if many experimentation projects are conducted and if these are diverse in terms of exploring different technological options, possible applications and different market segments.	L/M
2	The function 'Knowledge development' is considered well developed if many different knowledge activities of both 'learning by searching' and 'learning by doing' are undertaken.	L
3	The function 'Knowledge diffusion' is considered well developed if there are many occasions (e.g. partnerships, workshops and conferences) where actors can meet and exchange knowledge.	L
4	The function 'Guidance of the search' is considered well developed if there are clear positive signals in place pushing actors towards entering and contributing to the development of the TIS. These signals may take the forms of clear policy targets or measures in favor of the technology and the voicing of positive expectations regarding the future development of the technology.	M/H
5	The function 'Market formation' is considered well developed if public support schemes are in place that effectively incentivize the use of the emerging technology.	-
6	The function 'Resource mobilization' is considered well developed if enough financial, human and physical resources are available for the development of the emerging technology and if actors within the TIS have access to these resources.	L
7	The function 'Creation of legitimacy' is considered well developed if coordinated actor groups exert pressure on actors in power to change institutions which complement the emerging technology.	L

L = low; M = medium; H = high; - = absent

6 Sails

This chapter aims at answering the following sub-question:

What is the state of play in the development and diffusion of sails?

Following the theory and methodology outlined in chapter two and three respectively, this will entail a structural analysis of the TIS related to sails, followed by an evaluation of the different system functions and their interactions. This will result in an assessment of how well developed the TIS for sails is.

6.1 Description of the technology

One can distinguish between three different types of sails: traditional sails, the Dynarig and wing sails (Englebert 2013).

The Dynarig is a square rig with freestanding and rotating masts. The cambered yards are connected rigidly to the mast and the sails between them are set in such a way as to leave no gaps to the sail plan when deployed. This way, each spar's sail plan works as a single sail. By rotating the mast, the sail is trimmed to the wind direction. When not deployed, sails are furled into the mast ('Keine Rückkehr, sondern…' 2009; SY Maltese Falcon 2010). The sails can be operated electronically and be turned swiftly out of the wind in the event of a sudden squall. Because the rig comprises multiple relatively small sails, they can be easily replaced (B9 Shipping 2011b). The system was developed in the 1960s by the German engineer Wilhelm Prölss. While it has not been deployed on a commercial vessel yet, but since 2006, it is being used on a super yacht, the Maltese Falcon. In the first year of operation, the Maltese Falcon crossed the Atlantic twice, used sail at 61% of the time while at sea and achieved top speeds of up to 24,9 knots (B9 Shipping 2011b).

Wing sails are solid structures which resemble aircraft wings. Compared to conventional sails, they provide more thrust with less drag. They can also be equipped with solar panels, thereby harnessing more renewable energy (Buhaug et al. 2009). Fuel savings vary largely with weather conditions and the route. In ideal wind conditions, it was found that fuel reductions can reach a maximum of 40% while on average, 25-30% fuel reductions can be expected (Hobson et al. 2007).

6.2 Structural analysis

6.2.1 Main actors and networks

Several technology providers are currently working on the development and diffusion of sails, Dynarigs and wing sails. With regard to sails, these are the environmental NGO Greenheart which is based in Japan, and the French sailing freight transport company TransOceanic Wind Transport (TOWT). Greenheart collaborates with two other sailing technology providers – FairTransport and B9 Shipping - as well as two intermediary actors: sustainableshipping.com, one of the leading information providers on sustainable shipping and the project Sailing for Sustainability which investigates how sailing technology can improve sustainability and resilience for small villages in Fiji (Greenheart Project 2011). On information could be found on partners of the TOWT.

Three companies are working on the Dynarig system: B9 Shipping, a subsidiary of the British B9 Energy Group, the company FairTransport and Energy Ship which is based in Germany. No data was found on the partners of the latter two. B9 Shipping, on the other hand, collaborates with several other organizations. Concerning vessel design and manufacturing, it is supported by Humphrey Yacht Design, the Wolfson Institute, Rolls Royce and Tata Steel, the classification society Lloyds Register as well as the Maritime and Coastguard Agency provide expertise on the technical and regulatory challenges and on how to overcome them and the Met office helps in providing detailed route analyses according to weather conditions (B9 Shipping 2011a).

In different parts of the world, companies are working on bringing wing sails to the market. Propelwind is based in Begium and France, Seagate in Italy and SolarSailor in Australia. Both Eco Marine Power and the Wind Challenger are Japanese projects, the latter by the University of Tokyo. Eco Marine Power has built strategic relationships with three engineering companies – KEI System, Corvus Energy and Aspin Kemp & Associates (Eco Marine Power n.d.). SolarSailor receives financial support from the publicly funded Australian Greenhouse Office and is assisted in its international marketing and promotion by the Australian Technology Showcase. It also works together with Solar Choice, a solar energy broker, Schneider Electric and Enersys which supply electric motor systems and batteries, respectively (SolarSailor 2012). Propelwind cooperates closely with several actors in the field of sail racing in order to translate innovations from sport sailing to merchant shipping. These include HDS, VPLP Yacht Design, Mer Forte and Jean Luc Nelias. It is further supported by the Dutch hydrodynamics research institute MARIN and the Von Karman Institute for Fluid Dynamics and connected to the engineering companies Safran Engineering Services, Sofresid Engineering and Actiflow. In January 2013, the company has officially announced the formation of a windship lobbying group which also includes the wind propulsion technology providers Greenheart Project and Energy Ship as well as the environmental NGO Carbon War Room (Englebert 2012; Englebert 2013). For the other entrepreneurs, no information on partnerships and alliances was available.

On the one hand, the identification of TIS actors has shown that there is a lack of actors both on the demand and policy side. On the other hand, some technology suppliers are well-connected to intermediary actors and knowledge providers. Furthermore, some collaboration between the technology providers was evinced, i.e. between the Greenheart Project, FairTransport and B9 Shipping, as well as between the Greenheart Project, Propelwind and Energy Ship. Given that both partnerships involve the Greenheart Project, one could assume that the environmental organization is a node in the TIS network linking different actors together. The collaboration between technology providers could potentially accelerate TIS development because it might foster knowledge diffusion among actors, the creation of legitimacy and stimulate other function fulfillment as well.

6.2.2 Institutions

The institutions that are important for the TIS for sails are the same than those for kites. Therefore, please see chapter 4.2.2 for more information on the institutional infrastructure.

6.3 Narrative

After their replacement with steam engines and diesel motors in the late 18th/ early 19th century, sails started being investigated for merchant shipping again in 1984. That year, Japan launched a 31.000 ton cargo ship assisted by wing sails[6] (Tucker 1984). Seagoing trials of the ship showed that fuel savings of 25% or more are possible on certain routes which triggered great expectations and led to the belief that wing sails “will transform the appearance and the economics of large ships” (ibid.). The same year, the British company Walker Wingsail Systems started tests with a 3.000 ton ship equipped with wing sails. The tests were meant to see if the fuel savings of 20 to 28% resulting from modeling exercises could be translated into practice.[7] The company was supported by a large European carrier of refined products and initially backed up financially by a British Business Startup Scheme, ye experienced financial struggles throughout its whole existence. In the mid 1980’s, oil prices fell which meant that the company retreated from the merchant shipping market and instead focused on yachts (Bowan 1994).

In 1989, naval architects in West Germany started with a research project to explore the potential of modern sailing ships and designed a clipper for transporting raw materials

[6] Prior to this, Japan had brought six other sail-assisted cargo ships into service, yet it is not reported when this happened.
[7] The results of these practical tests are not known.

between Indonesian islands. They believed that on wind alone, the ship could run at between 12 to 14 knots and added that “any normal freighter or container ship could be fitted with backup sail equipment which would save between 10 to 25 % on fuel (‘Sailing cargo ship soon for Indonesia’ 1989).

Six years later, the Danish Environmental Protection Agency started financing a major research project into wind ships. For the following nine years, a team of naval architects in Copenhagen looked into the possibilities of re-introducing sails into commercial shipping. During this time, they developed a completely new design for sail-assisted cargo ships, came up with the idea of replacing canvas with aerofoil, investigated the type of cargo to be carried by sail-assisted ships and selected optimum courses according to weather forecasts. However, they found that over its lifetime, the wind ship would be about 10% more expensive than a conventional ship when including the extra costs of construction. These negative results resulted stop of the research project in 2000. Yet given the rising oil prices, it was believed in 2005 that building and operating the windship would be profitable and the Danish research team expected to start full-scale trials of their design within the coming three years.[8] (Hamer 2005)

In 2005, Wallenius Wilhelsen, a Stockholm-based shipping company, resented their own take of a sail-assisted cargo vessel. They designed a concept car carrier that would run on renewable energy only by harnessing the power of the sun, wind and waves. In this design, the vessel is equipped with three sails, each of which is lined with photovoltaic panels. Even though there are currently no plans to build such a vessel in the foreseeable future, this concept car provides the shipping industry with a vision of where it could be in 20 years, showing that ships could theoretically run on renewable energy only and thereby contributing to knowledge development in this area. (‘Green power the wave of the future on high seas’ 2005).

The idea of solar-powered sails is not completely new, though. The Australian firm Solar Sailor produces and sells this type of sail and has entered the merchant shipping market in 2008 when it signed an agreement with China’s biggest shipping firm COSCO to retrofit solar-powered sails on two of its ships in 2010. It claims that the sails can reduce fuel costs by 20-40% and use the sun to meet about 5% of the ship’s energy needs. (Hong Liang 2008; Huck 2009). Similarly, the Japanese company Eco Marine Power decided to proceed with the development of an advanced rigid sail concept that incorporates solar panels and energy storage units after it had conducted an extensive feasibility study in 2010 which found that wind and solar energy could be harnessed by ships cost-effectively (‘Eco Marine Power Proceeds with Development of Aquarius Solar and Wind Power System for Ships’ 2011). Consecutively, another comprehensive study project which focused on optimizing a large ocean going ship to harness wind and solar power was conducted. (‘Eco Marine Power Launches Eco Ship Study’ 2011) This study informed the design of a concept ship – the Aquarius Eco Ship – which was unveiled in 2012. (‘Eco Marine Power Proceeds with Development of Aquarius Solar and Wind Power System for Ships’ 2012) Another company who wants to harness power from both the wind and the solar, but also from waves, is Sauter Carbon Offset Design. In 2011, they announced the development of a 4.000 ton solar hybrid vessel which would reduce GHG emissions by 75 to 100% while maintaining an average speed of 10 knots (Einemo 2010a).

Another company made its appearance in the merchant sailing scene in 2008: French shipping company Compagnie de Transport Maritime à la Voile (CTMV). The company wants to transport wine and other cargo from France to most European countries by traditional sailing ships (Luttmer 2008a). The company delivered its first environmentally friendly shipment of wind to Dublin in July 2008, followed by a second and third one in 2009 to Bristol and London respectively (Sage 2008; Tang 2008). Despite this success, the company had to declare insolvency in October 2010 as a result of the economic crisis and the unwillingness

[8] It is unknown whether this research project was continued.

of banks to provide further loans (Mokhtari 2011). Two other companies are trying to bring traditional sailing back to merchant shipping: TransOceanic Wind Transport (France) and FairTransport (Netherlands). Both companies have already successfully delivered merchandise. While the former relies on wind only, FairTransport is currently working on the Ecoliner, a hybrid vessel taking advantage of both high-tech sails and engine power (Bruckner-Menchelli 2012b; Jameson 2011a).

Just like Fairtransport, B9 Shipping is working on a wind-assisted shipping solution. It wants to introduce carbon neutral vessels to the market that can run on wind and biofuels alone (Einemo 2009). In 2012, the company started tests on a full-scale demonstration vessel to check if the engineering and economic assumptions of the initial vessel design could be translated into reality (Jameson 2012).

Together with the University of Tokyo, Mitsui OSK Lines (MOL), one of the biggest shipping lines worldwide, is working on a system of large, retractable sails which, according to studies, could cut annual fuel use on ships by up to 30%. The construction of a small prototype is planned for the next few years to prove the concept and to start sea-trials in 2016 (Einemo 2010b: Currie 2012).

Marintek Engineering, a subsidiary of the tanker operator Marinvest, has assessed the possibilities of different types of sail for reducing fuel consumption of its tankers. In 2009, it announced that it has begun designing its own concept involving a rotatable wing mast which “even at today’s bunker prices we [they] think it will pay itself off quick enough” (Eason 2009b). More research is conducted within the Strategic Research Group of the classification society Lloyds Register, yet this research is not exclusively focused on wind propulsion, but also on the viability of other environmentally friendly propulsion technologies (e.g. biofuels and fuel cells) (‘Lloyd's Register teams up with leading Chinese design house’ 2009). In 2012, Lloyds Register joined forces with Totempower Energy Systems and Zodiac maritime Agencies in order to assess the potential of wind-generation devices onboard commercial ships (Bruckner-Menchelli 2012a). The year before, TU Berlin published the results of a five-year study which found that using sails or other wind technologies could achieve fuel savings of up to 44%. Backed up by this study, the Committee on Climate Change which advises the British Government on climate change has called upon the shipping industry to re-introduce wind propulsion technologies into their propulsion systems (Millward 2011).

6.4 Event analysis

The table below shows the yearly allocation of events per function. The re-introduction or re-investigation of sails for commercial shipping started in 1984, yet only few activities followed in the twenty years to come. However, there are also only few years in-between where no activities at all have been reported. Overall, the development of commercial merchant sailing is relatively continuous, even if on a low level. Furthermore, the table shows a higher accumulation of events in recent years, starting in 2008, which indicates an acceleration in the development of the different sailing technologies.

Table 10: Total count of events per function per year - sails

Year	F1	F2	F3	F4	F5	F6	F7	TOTAL
1984	2	3	1	3	0	3	0	**12**
1985	0	0	0	0	0	0	0	**0**
1986	1	1	1	1	0	0	0	**5**
1987	0	0	0	0	0	0	0	**0**
1988	0	0	0	0	0	0	0	**0**
1989	0	1	0	1	0	0	0	**2**
1990-94	0	0	0	0	0	0	0	**0**
1995	0	1	0	0	0	1	0	**2**
1996-99	0	0	0	0	0	0	0	**0**
2000	0	0	0	1	0	0	0	**1**
2001-04	0	0	0	0	0	0	0	**0**
2005	1	1	0	3	0	0	0	**5**
2006	0	0	0	0	0	0	0	**0**
2007	1	0	0	0	0	0	1	**2**
2008	4	1	2	4	0	1	0	**12**
2009	2	3	1	3	0	0	0	**9**
2010	4	4	3	8	0	1	0	**20**
2011	2	4	2	4	0	1	1	**14**
2012	5	10	6	12	0	2	0	**35**
TOTAL	**23**	**29**	**16**	**40**	**0**	**9**	**2**	**121**

F1: Entrepreneurial activities; F2: Knowledge development; F3: Knowledge diffusion; F4: Guidance of the Search; F5: Market formation; F6: Resource mobilization; F7: Creation of legitimacy

In the previous examples, it was suggested that the development pattern was largely influenced by fuel prices. To see if this might also be the case for the different sailing technologies, the number of events is plotted against the fuel price development.

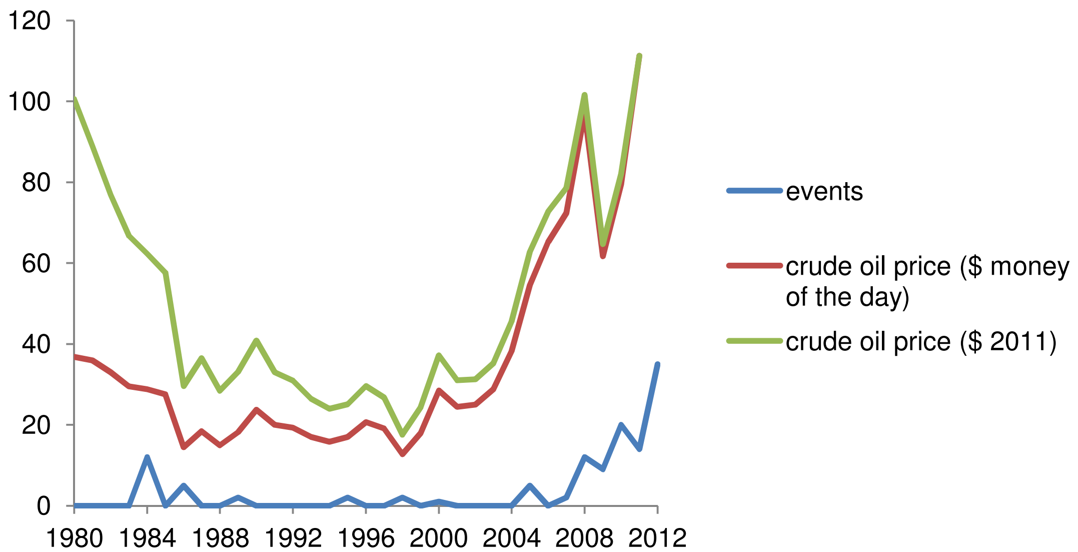

Figure 17: Comparison of oil price development and temporal event pattern - sails
Source: BP (2012)

The figure shows that the decrease in activities after 1984 indeed coincides with drops in oil prices just like the increase in activities as of 2008 does with the rising oil prices. It is therefore suggested that the oil prices are a major driver for the development of the TIS related to commercial sailing technologies.

6.4.1 Fulfillment of individual system functions

The review of newspaper articles on sailing technologies to be used in merchant shipping resulted in the identification of 119 events that have impacted the TIS of these technologies in the period 1984 to 2012. According to the specific content of the event, each of the events was mapped on a particular system function. The overall allocation of events to the individual system functions is shown in the figure below. The figure also shows the number of events contributing positively to the TIS in question, as well as those contributing negatively.

Table 11: Function fulfillment - sails

	F1	F2	F3	F4	F5	F6	F7
Positive	21	29	16	35	0	6	2
Negative	2	0	0	5	0	3	0
TOTAL	**23**	**29**	**16**	**40**	**0**	**9**	**2**

F1: Entrepreneurial activities; F2: Knowledge development; F3: Knowledge diffusion; F4: Guidance of the Search; F5: Market formation; F6: Resource mobilization; F7: Creation of legitimacy

As a first observation regarding the spread of the events over the several categories, significantly more positive (109) than negative events (10) were identified. Furthermore, for some system functions, more events were mapped than for other system functions. Most events were linked to Guidance of the Search (40), Knowledge development (29) and Entrepreneurial activities (23). 16 and nine events were identified for the functions Knowledge diffusion and Resource mobilization, respectively. Only two events were identified for Creation of Legitimacy and none for Market Formation.

In the following paragraphs, each of the functions will be discussed based on the mapping of the events and evaluated by means of the propositions put forward in chapter 2.3.

Entrepreneurial activities

The development of entrepreneurial activities is depicted in the figure below. First attempts to reintroduce sails into modern merchant shipping were made by Walker Wingsail Systems in the mid 1980's, yet with plunging oil prices, the payback time for wing sails was too long for the merchant shipping market, so the company retreated from this market segment and turned to yachts[9] (Bowan 1994). After almost twenty years, other entrepreneurs appeared on the scene and entrepreneurial activities increased, peaking in 2012. The activities relate to the market entrance of start-ups both in Europe, Australia and Japan and the acquisition of their first customers, but also to established shipping operators (Marinvest, Mitsui O.S.K. Lines, Wallenius Wilhemsen) who start investigating the possibilities of using sails (Brooymans 2007; Bruckner-Menchelli 2012b; Eason 2009b; 'Eco Marine Power Proceeds with Development of Aquarius Solar and Wind Power System for Ships' 2011; Einemo 2009; Einemo 2010a; Einemo 2010b; 'Green power the wave' 2005; Hillmer 2008; Jameson 2011; Tang 2008; 'WWL unveils $100,000 green technology grant' 2011). Since 2005 and 2012, only one negative event has been reported: the insolvency of the Dublin-based sailing company Compagnie de Transport Maritime à la Voile which fell victim to the economic crisis (Mokhtari 2011). Yet judging from the number of positive events, the economic crisis did not have a major impact on entrepreneurial activities, with activities only slightly decreasing during 2009 and 2011. On the one hand, this might have to do with the fact that many actors are new and have not surpassed the prototype stage yet. On the other hand, one could

[9] The success in the yachting market, however, was not much bigger and after a lot of struggle, the company declared bankruptcy in 1998.

argue that the mix of new and established actors taking an interest in sailing technologies have provided the TIS with a certain resilience against external shocks.

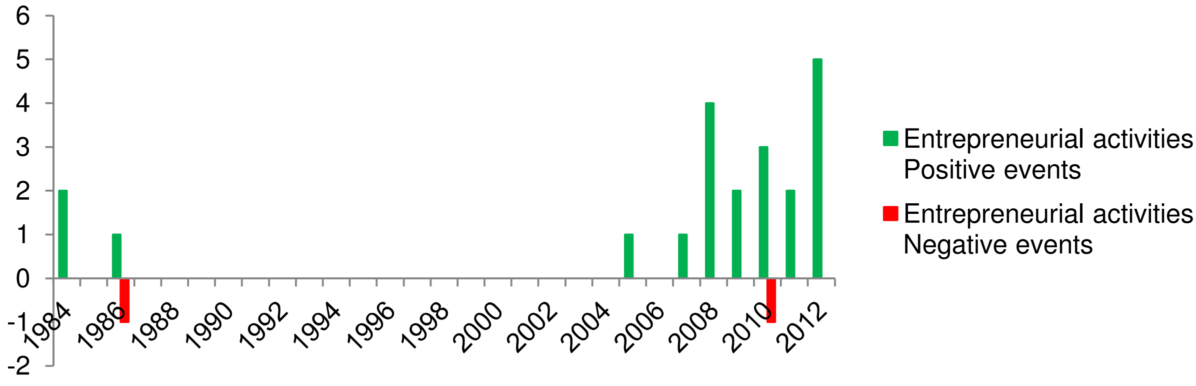

Figure 18: Activity pattern of Entrepreneurial activities - sails

This, coupled with the positive development of activities in the past seven years, indicates that function fulfillment is medium to high.

Knowledge development

Until 2008, Knowledge development activities have only taken place irregularly, with some events reported in the 1980's, in 1995 and 2006. As of then, activities have increased and peaked in 2012.

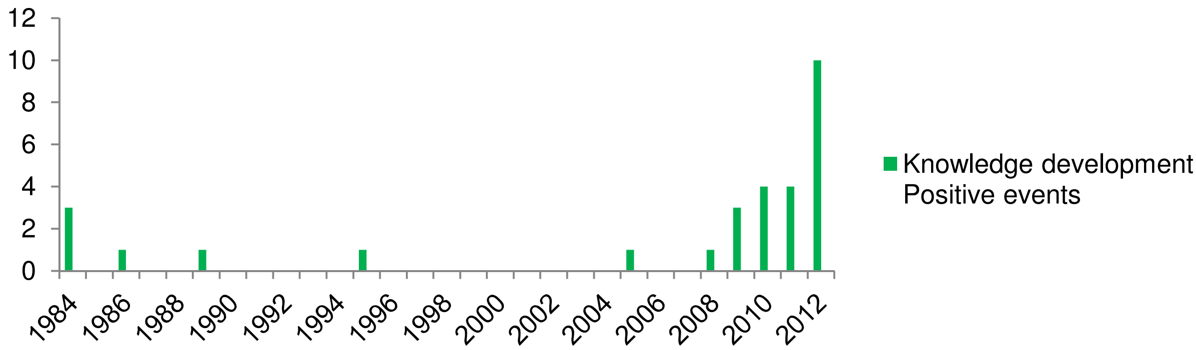

Figure 19: Activity pattern of Knowledge development – sails

For the most part, knowledge development is driven by entrepreneurs who are investigating the potential of different types of sails. However, there is also involvement of public research institutes and institutes who either lead research projects or support entrepreneurial-driven research. The University of Tokyo, for example, leads the "Wind Challenger Project" and, together with industrial partners, has developed retractable wing sails (Currie 2012; Lui 2010). The Technical University of Berlin has conducted a five-year study on modern merchant sailing ships (Millward 2011) and the University of Southampton is supporting B9 Shipping in a fundamental testing program of their technology (Jameson 2012). Furthermore, two research consortia have been formed in 2012 independently from one another to investigate the potential of different wind propulsion technologies (see 4.4.1 'Knowledge development'). So on the one hand are the positive aspects like the upward trend observed since 2008 and the mix of actors involved in Knowledge development, on the other hand the irregular development of the function until 2008 which is considered negative. Therefore, function fulfillment is considered low to medium.

Knowledge diffusion
Similarly to Knowledge development, the spread of events related to Knowledge diffusion is uneven. Two events were reported in the 1980's, followed by a more than 20 years long period of inactivity. Most events took place between 2008 and 2012, with a peak in 2012.

The long period of inactivity can be explained by the absence of entrepreneurial activities during this phase. Due to their absence, hardly any knowledge was generated during this phase, so there was no knowledge to share.

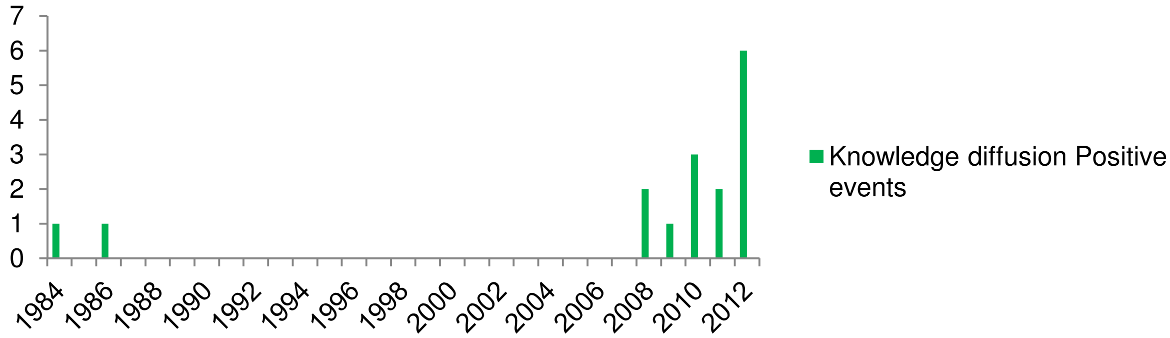

Figure 20: Activity pattern of Knowledge diffusion - sails

The majority of events relate to the formation of partnerships between actors which allow for a more intense exchange of knowledge between the partners (Bruckner-Menchelli 2012b; 'Eco Marine Power Proceeds' 2011; Einemo 2009; 'Groundbreaking Solar and Wind Energy Initiative' 2011; Huck 2009; Jameson 2010; Lui 2010). However, the knowledge generated through this exchange is mostly inaccessible to the wider industry which is why a stronger presence of technology providers at workshops and conferences would be helpful for increasing knowledge exchange.

Overall, function fulfillment is considered low to medium due to the long period of inactivity and the low accessibility of knowledge for actors not involved in any partnerships,

Guidance of the search
The distribution of events related to Guidance of the search is very similar to those of the previous functions: some activity in the 1980's, little activity over the following twenty years and an acceleration of events starting in 2008.

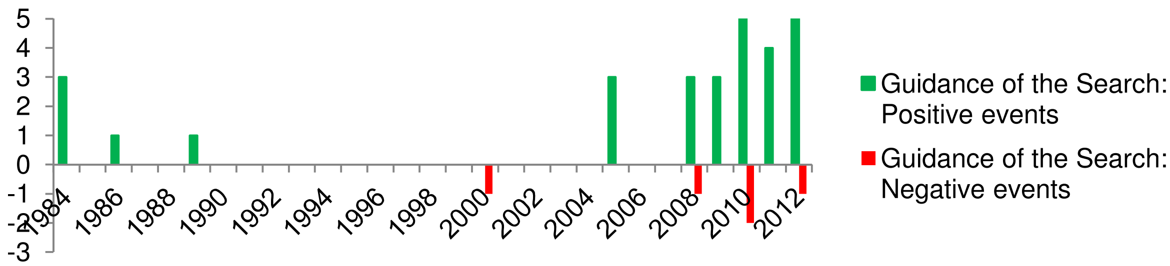

Figure 21: Activity pattern of Guidance of the search - sails

The majority of events relates to positive research outcomes or to technology providers voicing positive expectations (Bruckner-Menchelli 2008b; Bruckner-Menchelli 2012b; Cacnio 2012; Currie 2012; Eason 2009b ; 'Eco Marine Power Proceeds' 2011; 'Eco Marine Power Unveils' 2012; Einemo 2010a; Hillmer 2012; McKenzie 2012; Michelsen 2012, Sage 2008; Watt-Pringle 2012; Webster 2010). The function is thus driven by entrepreneurial activities and knowledge development which explains the temporal event distribution. Only little people have raised doubts over sailing technologies and these doubts relate more to the economic viability and how sailing would fit into the current economic paradigm rather than technological feasibility (Alexander 2010; Kan 2012; Webster 2010; wee 2008). Proponents of sailing technologies argue that with rising oil prices, sailing will make economic sense again. Furthermore, modern technologies can remedy some of the negative factors which led to the transition to steam ships in the past: modern sails require less crew and weather forecasts increase the reliability of schedules (Hamer 2005).

Just like with kites and Flettner rotors, only three events relate to policies which all aim at reducing air pollution from shipping (Geoghegan 2012; Knauer 2012; Otzen 2011) (see section 4.2.1). Even though these instruments could promote the use of sails as a means to reduce air pollution, they are not aimed specifically at incentivizing them, but rather set targets to be achieved by the industry, no matter how. Therefore, the use of sails is only promoted in a very indirect way.

The majority of events is positive and the function has shown an upward trend in the future, yet there has been a long period of inactivity which means that overall, function fulfillment is medium.

Market formation

No events have been reported for the function Market formation. There are no financial incentive schemes which could create a niche market for kites and shield technology development from market pressures. The function is thus absent.

Resource mobilization

The temporal pattern of the function Resource mobilization is very similar to those of the other functions, with some activity in the 1980's, almost none for the coming twenty years and some events reported as of 2008.

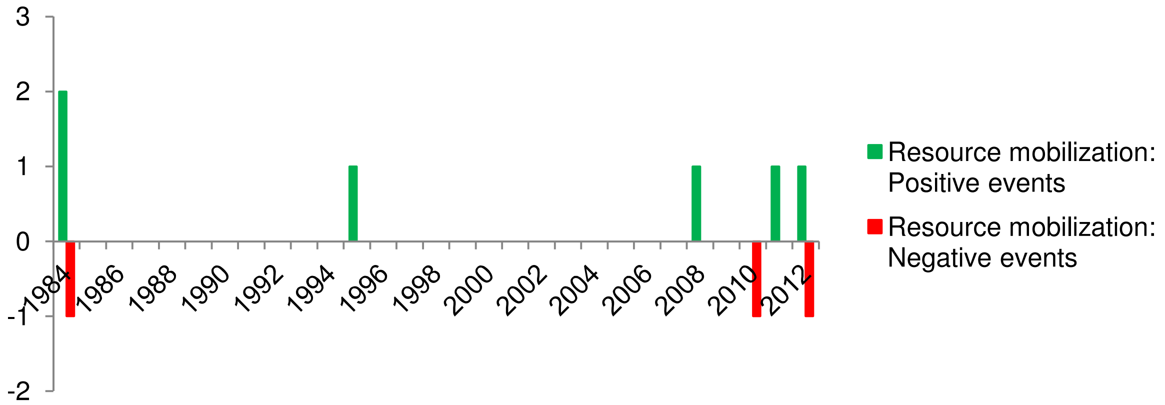

Figure 22: Activity pattern of Resource mobilization - sails

The few positive events either relate to public funding from the British and Danish governments (Tucker 1984; Hamer 2005), purchase agreements with customers (Hong Liang 2008; Bruckner-Menchelli 2012c) or price money ('WWL unveils $100,000…' 2011). Yet the positive events are alternated with negative ones linked to technology providers experiencing difficulties in acquiring finance (Tucker 1984; Mokhtari 2011; Werner 2012). It is difficult to deduce from this information only whether enough financial, human and physical resources are available for the development of the emerging technology and whether actors within the TIS have access to these resources. Judging purely from the low number of positive events, and the comparatively high number of negative ones, is concluded that this function is poorly fulfilled.

Creation of legitimacy

Only two events were reported for creating legitimacy for the different sail technologies. In the first instance, a member of the European Parliament urged the IMO for the introduction and promotion of renewable energies for shipping, such as wind (Bruckner-Menchelli 2008a). In the second case, an advisory group to the British government has recommended to fit ships with sails or other wind propulsion technologies again (Millward 2011). However, there are no coordinated actor groups exerting pressure on actors in power to change institutions which complement the emerging technology as is postulated in proposition 7. In conjunction with the low number of events reported, this means that the function is only poorly fulfilled.

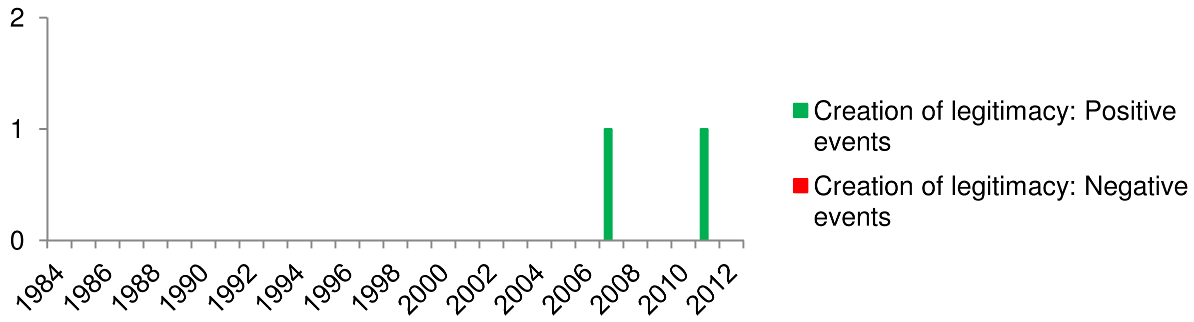

Figure 23: Activity pattern of Creation of legitimacy - sails

6.4.2 Interaction of system functions

The interaction of system functions is very similar to that identified in both the TIS for kites and Flettner rotors.

Knowledge development is primarily driven by entrepreneurs, yet in contrast to the previous TISs, public research institutes are slightly more involved. The development of knowledge is a prerequisite for sharing it which explains why knowledge diffusion has stopped during 1986 to 2008: there were hardly any entrepreneurial activities which could have spurred knowledge development. Knowledge development also impacts on Guidance of the search as research outcomes contribute to generating positive expectations. However, these positive function interactions came to a halt when oil prices fell and the use of sails was not considered economically viable anymore.

6.5 Conclusion

The table below shows the evaluation of the different propositions according to which the development of the TIS is being judged. It shows that overall, the development of the TIS is poor to medium which suggests that there are few drivers in place that could accelerate the development of the TIS, but instead many barriers that obstruct it. In order for the TIS to flourish, these barriers need to be alleviated and the drivers accelerated.

Table 12: Overview of system function fulfillment – sails

Proposition No.	Content of proposition	Evaluation
1	The function 'Entrepreneurial activities' is considered well developed if many experimentation projects are conducted and if these are diverse in terms of exploring different technological options, possible applications and different market segments.	M/H
2	The function 'Knowledge development' is considered well developed if many different knowledge activities of both 'learning by searching' and 'learning by doing' are undertaken.	L/M
3	The function 'Knowledge diffusion' is considered well developed if there are many occasions (e.g. partnerships, workshops and conferences) where actors can meet and exchange knowledge.	L/M
4	The function 'Guidance of the search' is considered well developed if there are clear positive signals in place pushing actors towards entering and contributing to the development of the TIS. These signals may take the forms of clear policy targets or measures in favor of the technology and the voicing of positive expectations regarding the future development of the technology.	M
5	The function 'Market formation' is considered well developed if public support schemes are in place that effectively incentivize the use of the emerging technology.	-
6	The function 'Resource mobilization' is considered well developed if enough financial, human and physical resources are available for the development of the emerging technology and if actors within the TIS have access to these resources.	L
7	The function 'Creation of legitimacy' is considered well developed if coordinated actor groups exert pressure on actors in power to change institutions which complement the emerging technology.	L

L = low; M = medium; H = high; - = absent

7 Meta-analysis of the TIS development for wind propulsion technologies

In the previous chapters, the performance of the TIS for kites, Flettner rotors and sails has been assessed separately. This chapter will seek to combine these findings, thereby arriving at an overall estimation of the performance of wind propulsion technologies. These findings are assessed against those resulting from an expert survey. This will either substantiate the findings or discredit them. Furthermore, the survey shows which functions would benefit mostly from policy interventions and contribute mostly to accelerating TIS development.

7.1 Meta-analysis of the event analyses of the three TIS on wind propulsion

The event analysis has shown that fulfillment of the function Entrepreneurial activities is low to medium for both kites and Flettner rotors and medium for sails. Even though the TIS for kites is most advanced in terms of technology development, the whole TIS is dependent on just one company (Skysails) and the function has shown a downward trend in the past few years which is mainly due to the economic crisis. While several companies have been involved in entrepreneurial activities in the TIS for Flettner rotors, these activities have been highly discontinuous over the years which meant that none of the companies could become established. The reason why entrepreneurial activities scored slightly higher for sails is because both new and established actors are active in the TIS, providing it with a certain resilience which might partly explain why this TIS seems to be relatively unaffected by the recent economic crisis.

Knowledge development is low for kites and Flettner rotors and low to medium for sails. This mainly relates to the fact that the development of knowledge has been so dependent on entrepreneurs. This implied that activities related to this function were often not continued when entrepreneurs experienced set-backs or left the TIS in question. Especially in the TIS for Flettner rotors, this proved to be a problem as it prevented the creation of a knowledge base. For sails, function fulfillment was considered slightly more positive due to higher involvement of public research institutes and the recent upward trend shown by this function.

For all three technologies, fulfillment of the function Knowledge diffusion is considered to be low or low to medium. The reason for this is twofold. On the one hand, the long periods of absence of any knowledge development activities in the TIS for Flettner rotors and sails meant that there was simply no knowledge to share. On the other hand, it was argued that because knowledge is diffused primarily by means of partnerships, actors outside these partnerships cannot access this knowledge.

Compared to the other functions, Guidance of the search is relatively well fulfilled. The function is considered medium for both kites and sails and medium to high for Flettner rotors. Many positive expectations have been voiced on the potential of the three technologies and at times, it was expected that the invention of the Flettner rotor would revolutionize commercial shipping. Yet positive expectations were often absorbed by influential actors expressing concerns or skepticism. Furthermore, there are no policies which directly promote the uptake of any of these technologies.

The function Market formation is completely absent for all three technologies. No events have been reported related to this function which means that wind propulsion technologies have to openly compete with more established and proven technologies.

Across all three technologies, the function Resource mobilization is poorly fulfilled. Even though some financial support has been provided for technology development, primarily by public innovation funds, actors are reported to struggle for financial resources. The economic crisis has further aggravated this struggle. This is especially the case for the TIS on kites whose main actor experienced severe financial difficulties due to the economic crisis which resulted in the dismissal of staff. Other than this one occurrence, no events were reported on the availability or lack of human and/or physical resources.

Hardly any activities related to the creation of legitimacy were reported. The few that were did not target any wind propulsion technology in particular, but were linked to the promotion of wind propulsion in general. These were single, unrelated occurrences so they did not build up on each other. In the reviewed articles, there was no mention of any coordinated actor groups lobbying for wind propulsion technologies.

Table 13: Overview of TIS development for kites, Flettner rotors and sails and overall evaluation

Proposition	Brief description	Kites	Flettner	Sails	Overall
1	Many and diverse experimentation projects	L/M	L/M	M/H	**M**
2	Many 'learning by searching' & ' learning by doing' activities	L	L	L/M	**L**
3	Many occasions to exchange knowledge	L/M	L	L/M	**L/M**
4	Clear positive signals, both policy and expectations	M	M/H	M	**M**
5	Effective public support schemes	-	-	-	**-**
6	Enough financial, human and physical resources	L	L	L	**L**
7	Coordinated lobbying activities	L	L	L	**L**

L = low; M = medium; H = high; - = absent

Overall, the event analysis has shown that the performance of the three TIS's is poor. The majority of the functions is underdeveloped or even absent and only two functions (Entrepreneurial activities and Guidance of the search) have been judged medium fulfilled.

7.2 Analysis of survey results on the performance of the TIS for wind propulsion

As a way of triangulating the results obtained in the event analysis, the performance of the TIS for wind propulsion technologies was assessed by professionals working in the field of wind propulsion. In a survey, they were asked to assess the state of function fulfillment on a Likert scale from one to five, one meaning low function fulfillment, five meaning high function fulfillment. In order to arrive at a more nuanced understanding of the fulfillment of each function, some function indicators were assessed separately. Those were knowledge development (a) scientific knowledge and b) practical knowledge); knowledge diffusion (a) exchange of knowledge between actors active in the TIS for wind propulsion and b) knowledge exchange on wind propulsion within the shipping industry), and mobilization of resources (a) financial, b) human resources and c) physical infrastructure). Furthermore, they were asked how important they thought each function (or function indicator) was for the further development and diffusion of wind propulsion. The discrepancy between function fulfillment and importance for further technological development and diffusion can be used as an indicator for the necessities of regulatory or other intervention. The figure below shows the results of the survey:

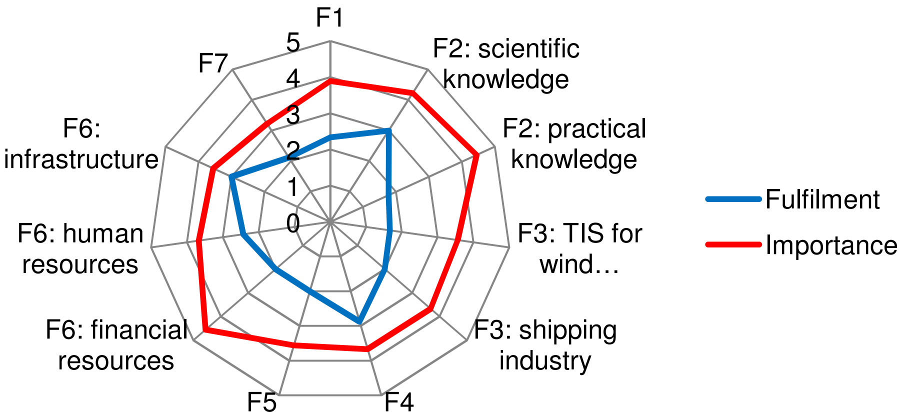

Figure 24: Overview of system function fulfillment based on expert survey

The function Entrepreneurial activities scores 2,33/5 so function fulfillment is estimated to be medium. This corresponds to the findings of the event analysis. The availability of scientific knowledge was judged to be 3/5, so medium again. However, there seems to be a severe lack of practical knowledge on the technologies (1,78/5). The average of both indicators is 2,38/5 which suggests that function fulfillment is medium. Even though the overall judgment of function fulfillment does not deviate significantly from the event analysis, the explanation for it does. In the event analysis, it was mainly due to a lack of involvement of public research institutes that the function was considered poorly fulfilled. The survey, however, indicates that it is mainly practical knowledge that is missing. Further discrepancies can be found in the outcomes of the function Knowledge diffusion. Even though the average rating for both function indicators (1,83/5) corresponds well to the finding of the event analysis which is that function fulfillment is low to medium, the explanations for these outcomes do not match. In the event analysis, it was concluded that knowledge exchange worked better among actors in the field of wind propulsion compared to the overall shipping industry, whereas the survey shows the reverse. However, the difference of the survey scores for both indicators is only small (1,67/5 for knowledge exchange with actors inside the TIS versus 2/5 for knowledge exchange with actors outside of it). The discrepancy between the results of the event analysis and the survey is thus negligible. Among the seven functions, Guidance of the search scored highest in the survey (2,88/5) which matches the result of the event analysis. The fulfillment of the function Market formation was found to be low – 2/5 – in the survey which again, corresponds well with the finding of the event analysis. With regard to Resource mobilization, survey respondents report a lack of financial resources (2/5) but, to a lesser extent, also of human resources (2,43/5) and physical infrastructure (3/5).Given that the event analysis was not indicative of the presence or absence of these last two function indicators, but only reported on the availability of financial resources, its result on Resource mobilization can only be compared to the survey score on financial resources. It follows that both event analysis and survey report low function fulfillment. The same is the case with the seventh function – Creation of legitimacy – which scores poorly in both event analysis and the survey (2,11/5).

With regard to the importance allocated to each function or function indicator, the survey shows that almost all of them are considered important or very important. Least importance is allocated to the function Creation of legitimacy (3,22/5), whereas the generation of practical knowledge is given highest importance (4,44/5). Because all indicators are considered somewhat important, it is more interesting to identify the difference between function importance for TIS development and its current fulfillment. It is assumed that closing the gap between the two scores will accelerate TIS development. This can be achieved, amongst others, by means of policy interventions. In the TIS for wind propulsion, all function indicators show a difference between the score of function importance and function fulfillment. In order to identify priority areas where policy interventions would be most effective, the ones with the highest difference thus need to be identified. This is shown in the figure below:

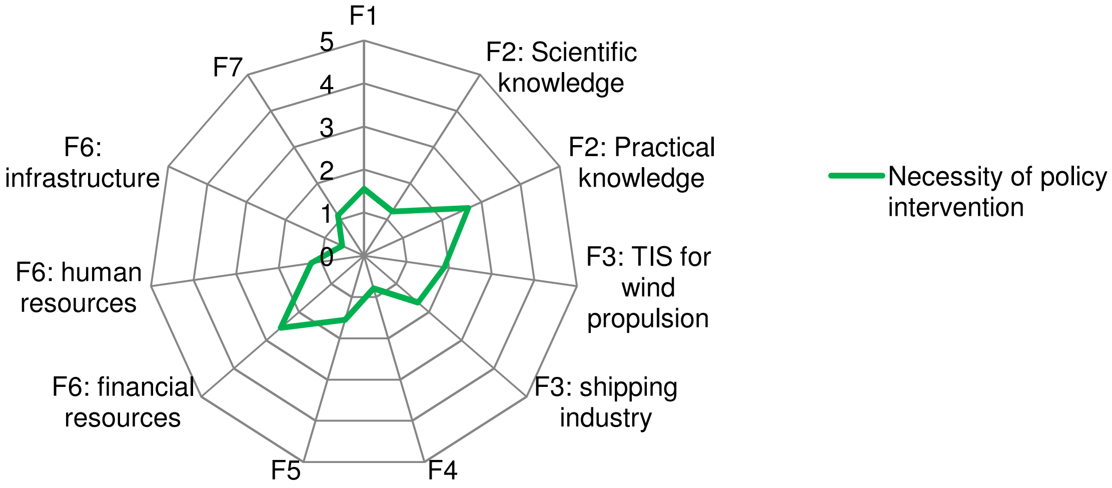

Figure 25: Necessity for policy intervention

The functions (or their indicators) with the highest difference in both scores are the generation of practical knowledge, the mobilization of financial resources and knowledge diffusion, especially among actors inside the TIS for wind propulsion. Consequently, highest priority should be accorded to interventions aiming at stimulating these indicators.

7.3 Conclusion

In this chapter, the findings of all three TIS' analyses of the previous chapters have been compared and contrasted to each other. In general, function fulfillment across all three technologies was found to be fairly similar; most functions are underdeveloped and only two functions were considered to be medium fulfilled. The overall performance of the TIS for wind propulsion technologies is therefore poor. This finding was also reflected in the survey which in particular highlighted a lack of practical knowledge and of knowledge diffusion among actors involved in the field of wind propulsion. By comparing the current fulfillment of function indicators with their importance for future TIS development, priority areas were identified in which policy interventions should be taken first. These relate to Knowledge development (especially of practical knowledge), Knowledge diffusion (in particular among actors inside the TIS for wind propulsion) and Resource mobilization (with a focus on financial resources).

Overall, the performance assessment of the TIS for wind propulsion technologies resulting from the event analysis corresponds well to the survey findings. This shows that generally, both methods are valid for assessing TIS performance. If in doubt, e.g. when discrepancies between both findings exist, the expert assessments should be considered more credible as they generally have more insights into the system functioning than it is usually expressed in newspaper articles. This is especially the case if data availability in terms of newspaper articles is low, as was the case in this study. The fact that all system functions could be used in the event analysis to explain system performance and that all of them were considered important for further TIS development by the experts shows that all functions have their place in the analysis of TIS performance evaluation.

8 Analysis of structural drivers and barriers to the uptake of wind propulsion

The previous chapter has shown that overall the performance of the TIS for wind propulsion technologies is poor. By means of an interview analysis, the reasons for this poor performance will be identified, thereby answering the following sub-question:

> *Which mechanisms hamper or stimulate the development and diffusion of wind propulsion technologies?*

Due to the fact that the overall performance is poor, it is assumed that there are more structural barriers than drivers which is why the barriers obstructing the fulfillment of each function will be considered first, followed by the structural drivers if any could be identified.

8.1 Entrepreneurial activities

Entrepreneurial activities are at the core of each TIS because entrepreneurs turn theoretical knowledge into commercial applications. However, the event analysis and the survey have shown that this function is not fulfilled satisfactorily. This finding is supported by the interviews conducted. Before discussing this function, it should be noted that a lack of entrepreneurial activities is often caused by low fulfillment of other functions. Hekkert et al. (2007:421) argue that

> "when entrepreneurial activity lags behind, causes may be found in the other six functions. We expect that the odds of a firm successfully developing an innovation, primarily depend on how the innovation system is developed in terms of functions 2 to 7; a well-functioning system will probably lead to a climate in which entrepreneurial activities blossom"

So as not to anticipate the findings related to the other functions, only those findings most pertinent to Entrepreneurial activities will be discussed.

The first observation is that not many entrepreneurs are involved in wind propulsion technologies, especially when considering the large size of the potential market for wind propulsion systems (Interviewees 2, 5 and 7).

> "I would like to see more activities. After all, only a handful of ship owners have seriously investigated wind propulsion. (…) Less than ten ships of more than 400 gross tonnage are equipped with wind propulsion systems. Of about 5.000." (Interviewee 7)

Besides the number of entrepreneurs, it is noteworthy that the majority of them are small start-up companies. While the merits of start-ups are said to lie in their flexibility and adaptability to changing circumstances, they lack the resources, experiences and market standing of incumbents. According to Luo et al. (2012:42) "incumbents accelerate the system development, are less vulnerable to changing political winds in the country and are more stable financially." The lack of incumbents thus makes the TIS for wind propulsion relatively instable and vulnerable to external shocks, such as the economic crisis which, as an example, led to Skysails' dismissal of half of its staff.

The main problem underlying entrepreneurial activities is the lack of consumer demand:

> "There's more entrepreneurial activity than there is uptake. I think this is the frustration. (…) There is no point in innovating unless somebody is going to put it on the ship." (Interviewee 6)

However, this lack of demand cannot be explained by a single factor, but is rather the result of barriers encountered within the other functions, e.g. lack of knowledge development and resources, so it will be discussed where appropriate.

Despite the overall small number of entrepreneurs, several actors have entered the market in the past few years which indicates that the pace of TIS might be accelerating:

> "Just lately, there has been increased activity in the field of wind propulsion for ships. This shows that we're on the right track."(Interviewee 12)

The drive behind all entrepreneurial activities is the great commitment and determination of the entrepreneurs:

> "One thing I will say about this field is it's still very personality driven, so there's strong personalities, groups of small innovators who are pushing through, want to be first movers in this field" (Interviewee 13)

Despite all difficulties, actors are not willing to give up and continue pushing their idea forward. This drive should not be underestimated because without it, the TIS would simply not exist.

8.2 Knowledge development

According to the survey, 'Knowledge development' is one of the most weakly fulfilled functions, but one that is deemed crucial for the further development of the TIS for wind propulsion technologies. This finding is confirmed by the interviews. Most importantly, interviewees stressed the lack of practical and objective knowledge.

Practical knowledge relates to knowledge gained from testing the technology in reality and from demonstration projects. The only demonstration projects carried out with wind propulsion technologies so far are from the towing kites from Skysails and the Flettner rotor from Enercon. While Skysails has made the results of the demonstration projects public, Enercon did not release any data. Even though trials with Flettner rotors have been conducted in the past, the highly disruptive development of the technology meant that no knowledge base could be built up. The problem with the lack of practical knowledge is that ship owners are not willing to employ a technology until it was proven in real-life conditions that it works:

> "Nobody is going to buy these things without understanding completely how they operate and how they function. (…) If the product works, people will buy it. So we need to prove that the product works, and to do that, we need to experiment. (…) Everything is a bit theoretical, and we need some practice. (…) We need to put these things on ships and make sure that they work." (Interviewee 9)

More precisely, ship owners want to see hard facts on fuel savings and know more about the operational consequences resulting from using the technology. At this point, it is not clear how the different technologies behave in rough weather, how fast they can be retracted, if they could cause safety issues, how easily they can be operated, if they cause additional crew requirements, how reliable they are and if there any additional costs involved in employing them (e.g. for maintenance) (Interviewees 1, 4, 9, 10, 11).

The knowledge requirements of ship owners for investing in a new technology can be extensive, as witnessed by one interviewee:

> "Ideally, ship owners would like to see data on costs and fuel savings for a minimum of five years on a minimum of 100 ships." (Interviewee 12)

In light of the huge investments needed to finance a ship – containerships and tankers can cost up to USD 150 million each (Stopford 2009), these requirements seem justified. However, in order to get the practical knowledge required, ship owners need to participate in trials, yet many are unwilling to do so unless the technology is relatively proven:

> "What we would like to see before we see ourselves as the tester of technology and before we might test it on-board of our ship especially with such a technology that has a lot of operational consequences you want to see facts on the savings and facts on the operational consequences." (Interviewee 1)

This creates a vicious circle where "no one wants to be first" (Interviewee 1), "everybody wants to be second" (Interviewee 8). This vicious circle can only be interrupted by the initiative of brave frontrunners. However, in the current market environment, trying out radical technologies is particularly challenging. The shipping industry is deeply interwoven with the global economy and dependent on the flow of goods which explains the severe damage caused to the industry by the recent economic crisis. Many actors are struggling for commercial survival and currently do not have the financial means to invest in new technologies (Interviewees 6, 8, 9). In this market environment, liquidity is more important than profitability which explains why no investments are made that only pay for themselves after a couple of years (Interviewee 12). So the competitive advantage that, over the long-term could arise from investing in wind propulsion technologies cannot be realized due to shortage in financial means.

> "The market situation currently (…) is extremely challenging. There is a lot of overcapacity in the market. Basically there are too many ships for too few cargo holds, so it's an extremely competitive environment. And that's generally speaking not a fruitful market environment to try out wild and new things." (Interviewee 1)

This lack of liquidity is all the more regrettable because – given the low freight rates due to the market's overcapacity – it would have been a perfect time to retrofit ships and experiment with new technologies:

> "What's in their favor of course is that if they're not able to charter out a ship, that's just lying idle, you may as well spend that time doing something with it, because half the cost of getting something done is having your ship not working, not carrying cargo. (…) But if you're not carrying cargo anyway, because there's no cargo to transport, you might as well put your ship in, and then it's going to be cheaper."(Interviewee 6)

The second problem related to data is the lack of objective and verified data. Currently, most of the available information comes from technology providers. They are not perceived as an objective source of knowledge and hence, their information provided is not trusted.

> "There are lots of players out there (…) all saying 'we can save you emissions, we can save you fuel costs'. The difficulty is how do you measure that? If you're a ship owner (…), how do you know which one is credible? So I think that's a big problem for the industry." (Interviewee 3)

Proving and verifying of the technologies by independent third party testing are thus key and a clear framework is needed for appraisers and people that need appraisal (Interviewee 8). The problem is who populates this framework?

> "There is a bit of a vacuum at the moment for companies that can with authority provide information about the fuel savings." (Interviewee 10)

So in order to establish trust in the technologies, companies with more credibility for the third party verification are needed. Furthermore, it was pointed out that standard practices should be defined on how to present and justify a technology's fuel savings in order to increase comparability between technologies and enable an informed purchasing decision (Interviewee 10).

In order to counter the lack of knowledge, several initiatives have been started in recent years. In March 2012, seven North Sea countries have launched the NSR Interreg SAIL project, bringing together 19 partners from academia and the public, private and civil society sectors. Over the next three years, several activities with regard to knowledge development are planned, e.g. evaluating the potential and economic viability of different wind propulsion systems, developing hybrid sailing concepts optimized for specific routes and wind conditions, and conducting (social) cost-benefit analyses and environmental impact assessments for wind propelled ships (NSR SAIL 2013). Another ongoing project is led by the Sustainable Shipping Initiative whose overall goal it is to promote sustainable shipping practices. Under its energy technology work stream, the organization, together with a cross-industry group representing different stakeholders in the shipping industry, builds business cases for wind propulsion technologies with a view to piloting them from April 2013 onwards (SSI 2013b). More research on the potential of wind propulsion is conducted by the joint strategic research initiative formed by Lloyd's Register's Strategic Research Group, Totempower Energy Systems and Zodiac Maritime Agencies. Real time wind data is collected in field trials, enabling an assessment of the feasibility of wind power systems to be deployed on board commercial ships. ('Zodiac, Totempower and Lloyd's Register embark on project to monitor wind energy as marine industry looks to improve its fuel efficiency', 2012)

8.3 Knowledge diffusion

Knowledge diffusion has been identified as another barrier to the further development of the TIS for wind propulsion technologies. There are different levels at which knowledge diffusion can be assessed: between technology providers, between technology providers and ship owners as well as amongst ship owners.

There is hardly any knowledge exchange between providers of wind propulsion technologies. They are mostly operating within their own microcosm without sharing information and experiences with each other. Even though stronger collaboration and pooling of knowledge and resources would probably help all participants to build up a strong knowledge base and conduct practical trials, technology providers rather hope they can make it by themselves. Thus, weak ties and a lack of trust between technology providers are hindering knowledge diffusion.

The knowledge of wind propulsion technologies does not only have to be diffused amongst the technology providers, but in order to acquire customers, also between technology providers and ship owners. Sales presentations are a common way of diffusing knowledge between these two actor groups, yet they are usually not convincing for ship owners. They only allow to have a first glimpse at the technology and are often 'empty' content-wise in that they fail to deliver facts on fuel savings, costs and operational consequences that ship owners need to build trust in the technology (see 'knowledge development') (Interviewee 1). Furthermore, these presentations are unidirectional because they do not allow for a true knowledge exchange between both parties. However, such an exchange could benefit both in that they could learn from each other's knowledge and experiences.

Collaboration with suppliers is seen as a more successful way of exchanging knowledge:

> "Our knowledge build-up and knowledge diffusion is primarily by testing and verifying together with suppliers. I think that's the most important part of our knowledge diffusion. The other one is joint industry projects where we – together with other ship owners and institutes like MARIN – test energy saving devices on sort of more fundamental steps. I'd say collaboration with suppliers and collaboration in joint industry projects with sort of knowledge institutes are the most important parts of diffusion."(Interviewee 1)

The problem with this type of knowledge exchange is that ship owners are generally only willing to participate in trials and collaborate with technology providers once the technology is quite far developed (see 'knowledge development'). Furthermore, trust needs to be built up between technology providers and ship owners given that participating in trials is an expensive and risky activity. What is missing is an intermediary form of knowledge exchange, one that bridges the gap between mere sales presentations and expensive and risky collaboration projects. There is currently no platform which brings wind propulsion technology providers and potential customers together to engage in open communication and discussions, create a network and build up trust. Such a knowledge exchange platform would enforce the weak ties between the supply and demand sides which are currently preventing effective knowledge diffusion.

The last level of knowledge diffusion mentioned is amongst ship owners. Ship owners participating in trials are not willing to provide detailed information on how the trial went and do not share data related to costs and fuel savings. The rationale behind employing these technologies is to gain a competitive advantage by driving operating costs down. Sharing data would mean giving this competitive advantage away (Interviewee 6). As a consequence of this lack of data-sharing, no knowledge base can be built up and time and resources are wasted researching the same technology repeatedly:

> "Nobody is sharing data, so everybody is just reinventing the wheel every time they invest in something. And also, nobody's going to say if it didn't work. So they might've spent two million quid on it, they might have a ship that's going on very nicely, but there's not really a proper forum for going like 'how did that work for you, because we want to do that'. So the knowledge diffusion amongst the players is very, very limited."(Interviewee 6)

A lack of trust and the fear of losing a competitive advantage thus prevent a more efficient knowledge exchange and build-up within the shipping industry. This is due to the fact that it is mostly left to industry players to test the technology and its applicability on their own risk, rather than public research institutes whose mandate it is to generate and disseminate knowledge. There is a need for publicly financed, joint industry research projects, the results of which could be freely disseminated to the wider benefit of the shipping industry, yet without inflicting harm on the testing parties.

The recently established joint research projects (see 7.3.2) could provide a means to improve knowledge diffusion amongst all actor groups. By bringing different stakeholders together, they facilitate the exchange of knowledge and experiences among them. Given that the partners of these initiatives have agreed to the same goals and objectives, an atmosphere of trust is created which enables open discussions. Furthermore, the involvement of public research institutes, as is the case in the Interreg Sail project, ensures that knowledge is diffused beyond the project parameters as they have to fulfill their public mission of generating and disseminating knowledge.

8.4 Guidance of the search

Guidance of the search relates to the existence of a clear vision regarding the technological pathway. Such a vision can be created by both policy targets and expectations related to the technology.

The event analysis has shown that there are no specific regulations targeting wind propulsion technologies. Indirectly, however, these technologies could be promoted by the recently adopted IMO regulations on preventing air pollution by ships: the EEDI and SEEMP. On the one hand, these instruments point the way towards low-carbon shipping, on the other hand, they allow for the inclusion of wind propulsion technologies:

> "With IMO regulations regarding the EEDI entering into force on 1 January 2013, wind energy could get a boost because existing designs that just miss the EEDI target can be equipped with a Skysails quite easily, get a bonus and get through the EEDI hurdle." (Interviewee 7)

The interviewees showed mixed feelings with regard to the effectiveness of the IMO instruments in promoting low-carbon shipping generally, or the use of wind propulsion more specifically. While some actors perceived the instruments to be the most reasonable and direct measures to reduce GHG emissions from shipping (Interviewees 1, 11), others thought that they were too incremental, complicated or toothless to be effective (Interviewees 2, 4, 13). It was pointed out that their biggest value might lie in putting out information about the efficiency of new built ships and thereby addressing some of the information barriers (Interviewee 10). Furthermore, issues of compliance and enforcement were brought up because lack thereof can lead to non-compliance and thereby make the regulations ineffective:

> “”For us, it is extremely important that everyone is crystal clear about the regulations and how to comply and how it’s going to be enforced. Our main concern is that we have now recently seen a couple of measures that are unclear about technical details and are unclear about the enforcement at the date. (…) If compliance is not clear, then the playing field is not levels, and that is, for a competitive industry, a nightmare.” (Interviewee 1)

> “You also need proper enforcement which we don't have. Enforcement is pretty terrible at the moment.” (Interviewee 6)

So not only is there a lack of hard institutions specifically promoting wind propulsion, but also are the existing policies not stringent enough in the set targets. It is likely that weak compliance and enforcement mechanisms will further hinder effective GHG emissions cuts.

Besides policies, expectations can contribute to establishing a clear vision with regard to the technological transition pathway. Regarding wind propulsion, expectations differ significantly. On the one hand are the avid believers that are convinced that wind propulsion will play a major role in the future:

> “The industry would be crazy not to do it because there’s a lot of wind, we’ve got the capacity to harness that wind and all. It’s about getting a solution that works. (…) So I think the potential for that is enormous, absolutely massive.” (Interviewee 6)

> “I think their [wind propulsion technologies] potential is massive. I think they’re very desirable. (…) There are probably about 50% of the world fleet for which wind assistance – whether that’s a kite or a sail or a Flettner rotor – could have a very significant impact.” (Interviewee 10)

> “We all have the vision that it [wind propulsion] will come. (…) If you tell the industry that the time frame we’re talking about goes beyond the next 20 years, I’m sure they will agree.” (Interviewee 5)

On the other hand, a lot of actors are skeptical and have doubts about the potential of wind propulsion:

> “There are a lot of people – truth-be-told – that don’t think that wind will play any part of it because of all the operational consequences and the difficulties of implementing it.” (Interviewee 1)

Generally speaking, positive expectations were mostly voiced by actors actively involved in the TIS, while skepticism mainly came from people outside of it. The same was found in the event analysis. The vision of using wind power for propulsion has thus not sufficiently penetrated the boundaries of the TIS. This points to the lack of ties between actors inside and outside the TIS through which knowledge, expectations and experiences could be communicated, leading to the creation of a common vision.

8.5 Market formation

There are currently no financial incentive schemes that promote the uptake of wind propulsion. Protected niche markets which would shield the technologies from mainstream market selection do not exist. The result is that wind propulsion technologies are in direct competition with other, more developed, maritime technologies.

The problem with this is that wind propulsion is not yet developed enough to openly compete with other technologies, both on a cost and performance basis.

> "If you include downtime, maintenance and risk costs next to all other costs, wind propulsion is very often not (yet) viable. Or at least not as viable as other measures which are then, reasonably, being taken up first." (Interviewee 7)

Just like with other immature technologies, wind propulsion technologies need to be developed, tested and refined in order to become competitive. It can also be expected that, just like with any other technology development, costs will decrease due to economies of scale, which, however, presupposes market-uptake (Interviewee 7).

As a counter-argument one could say that probably many other maritime technologies have not been publicly incentivized. Yet the problem with renewable energies is that they compete with energy sources which are not correctly prized, i.e. negative externalities are not included. This in itself puts renewable energy at a disadvantage compared to conventional energy sources. In order to make up for this disadvantage and help renewables become competitive, governments around the world have introduced financial incentives in various forms, yet this has not happened in the shipping industry.

The introduction of an MBM by the IMO could fundamentally change this by, simply speaking, putting a price on either fuel consumption or GHG emissions, so it has great potential to promote the uptake of wind propulsion. Several proposals are being discussed at this point in time which means that there is uncertainty on how the MBM will look like. However, it is not clear when it will be introduced, pushing back the much needed investment decisions:

> "My main concern is: it is clear, is it going to be enforced, and is the date of introduction clear? Because we've seen now in many of these regulations that sometimes it pays to wait, basically, and not do anything because if everyone waits, then the date will be postponed. And that is to nobody's good. That creates a lot of uncertainty and an unleveled playing field in the market." (Interviewee 1)

Even though the specific design and date of entry into force of a MBM are not decided yet, it is generally acknowledged that at some point, an MBM will be introduced:

> "at some point there will be cost levied on shipping, right now we don't know what it's going to look like and when it's going to be implemented […], but you can be sure it will. (…) Yes, it [market-based mechanism] is coming, it has to come, it's not possible for it not to come." (Interviewee 3)

Once in force, ship owners have strong financial incentive to consider more radical fuel saving technologies and deviate from their current approach of incremental technology uptake:

> "But the market-based measures might change that incrementalism, they could potentially change the market fundamentals." (Interviewee 8)

The MBM could thus become a strong driver for the uptake of wind propulsion technologies by increasing the costs of fuel consumption. Aside from the introduction of such a mechanism, the costs for fuel consumption are very likely to increase in the future. Fuel prices have risen sharply in the past years and are likely to keep on rising. Because fuel consumption accounts for about 50 per cent of the costs for operating a ship, reducing the fuel consumption can help ship operators to drive down their expenses, increase their profit margin and provide them with a competitive advantage. Ship operators therefore have a strong incentive to invest in energy efficiency technology. All interviewees stated that currently, these commercial considerations provide the biggest incentive for using wind propulsion technologies:

> “In the current market, costs [drive the uptake of wind propulsion]. In the current market, and maybe that's – from a sustainability point of view – a good thing, the fuel price is now so high that a lot of technologies that were previously not worth it are now being considered, and I think that will remain. I think that the cost saving initiatives from shipping companies will still drive a lot of energy efficiency measures.”(Interviewee 1)

> “So the impetus (…) is fuel prices are rising and unpredictable, and that's their main cost. If they can reduce those by ten percent, their competitors are the ones that will go bust, not them.” (Interviewee 6)

It is thus likely that interest in wind propulsion will grow further as fuel prices continue to increase:

> “The rising fuel prices have considerably promoted the interest in wind propulsion. Beforehand, it was not an issue at all. Now, it is always mentioned, though rarely implemented."(Interviewee 7)

The rising fuel price could thus make wind propulsion more profitable and thereby increase interest in and uptake of these technologies. Another driver which is starting to emerge is increasing pressure of cargo owners on the shipping industry to become more energy efficient:

> “There’s always been a very dysfunctional link between customers for shipping and the shipping industry themselves. So the customers don’t tend to put any pressure on the shipping industry to be more efficient because they don’t really understand the sector and they don’t really want to understand some of the drivers behind the sector so that link is probably becoming stronger in the container sector and companies that demand logistics services are increasingly going back to the shipping lines and saying “well, how could you do this more cheaply?”. I think the side of that’s been going on more recently but it’s still gradual.” (Interviewee 10)

The demand for more energy efficient and environmentally friendly shipping services is part of corporate initiatives to green their supply chains which, in light of the increased environmental awareness of society, has become more important for businesses (Interviewee 3). In order to improve information flows on vessel efficiency between ship owners, cargo owners and freight forwards, several voluntary benchmarking tools have been developed. These include, but are not limited to, the Green Award[10], the Clean Cargo Working Group[11], the Environmental Ship Index[12], the Clean Shipping Index[13] and shippingefficiency.org[14]. Even though these initiatives use different methodologies to assess environmental performance and have different reward mechanisms, they are based on the same underlying idea: By providing information on vessel efficiency to the cargo holder who usually pays for the fuel, the likelihood is increased that he charters an energy efficient ship. The ship owner thus has a higher incentive to invest in energy efficient technologies as it is likely to secure him more business. While the focus of these initiatives is not on wind propulsion, they all aim to promote sustainable shipping by rewarding good environmental ship performance. This can create an incentive for ship owners to invest in energy efficiency, such as using wind propulsion technologies. Moreover, they contribute to creating an awareness of the environmental impacts of shipping within the shipping industry, but potentially also throughout society which, in turn, can further increase customer demand for environmentally-friendly shipping services.

[10] http://www.greenaward.org/
[11] http://www.bsr.org/en/our-work/working-groups/clean-cargo
[12] http://esi.wpci.nl/Public/Home/ESIFormulas
[13] http://www.cleanshippingindex.com/
[14] http://shippingefficiency.org/

8.6 Resources

The survey showed that there is a lack of resources which significantly hinders the further development of the TIS.

First, financial resources are missing, both on the side of technology providers and of ship owners. For a proof-of-concept, technology providers need to produce and subsequently test a prototype and for that have high capital requirements. Yet they experience difficulties in securing start-up finance for putting out a prototype:

> "Actually, the problem we've got is simply building the first ship. We've got two to three million euro applications for funding already out there, and we've had banks coming in and say 'we want to go to production. We could give you sort of 10 million plus outlines'. So, the funds are there, we have to get over the hump of getting the first ship in the water. I think that that is the case with all of the groups, to varying degree." (Interviewee 13)

> „We need more public support and innovation research. It is always being announced, 'once you build, then…' But there is no start-up funding in the sense of giving us twenty millions and leaving us to it." (Interviewee 5)

So in order to secure funding for further developing the technology, investors require a proof-of-concept:

> "You need hard facts, demonstration of economic viability. Otherwise no investor will buy into it. (…) To me the most important aspect is to proof that our model is economically viable. If we succeed in doing so with our pilots, we will find the way to money." (Interviewee 5)

Again, we can observe a vicious circle where actors experience a shortage of R&D spending to build prototypes which in turn would be required to obtain more funds from commercial banks or investors. Furthermore, it was pointed out that the lack of cooperation between wind propulsion technology providers makes it even more difficult to secure finance (Interviewee 13). The pooling of knowledge and resources could help convince investment companies of the merits and potential of wind propulsion.

This same lack of finance is experienced by shipping companies. In the current market situation, banks are unwilling to lend money for shipping (Interviewee 7, Interviewee 9, Interviewee 5). So any investments in new built ships or retrofits have to come from equity which most ship owners do not have at the moment:

> "The investment capital really has to come from principals as equity. Most people are worried about how much equity they've got. I mean, frankly, a lot of people in our industry don't have any equity anymore. So they don't have any to spend on this type of thing." (Interviewee 9)

Investments thus cannot be made as a consequence of the economic crisis which has left ship owners with no financial means to invest in innovations and made banks reluctant to do so. If at all, banks are only willing to invest in proven technologies, but in order to prove them, technology providers lack the required R&D and start-up funds. This points to severe problems in the financing infrastructure and to the unwillingness of public actors to recognize shipping as an important R&D field.

Furthermore, investments into the technologies are obstructed by the so-called split incentive problem. It describes a situation where somebody other the investor appropriates the benefits from the investments made. In shipping, ship owners and ship operators are often distinct actors. While the ship owner has to pay for any adjustments of his ship that could yield energy efficiency improvements, such as the installation of wind ship propulsion technologies, the ship operator or charter party benefits from having to pay less fuel costs (Interviewees 6, 8 and 13). The split incentive is a typical market failure problem. In order to overcome it, alternative financing mechanisms or other ways to reward ship owners who invest in energy efficiency have to be found.

The Sustainable Shipping Initiative is currently working on creating such an alternative financing mechanism. In collaboration with industry partners and the University College London, they have developed the ‘Save As You Sail’ financing model which financially rewards ship owners, charterers and financiers while spreading the investment risks between them. This way, all parties involved benefit from retrofitting fuel saving technologies. It is planned to pilot this financing mechanism during 2013 and evaluate and communicate its performance with a view to help the entire shipping industry finance energy efficiency retrofits (SSI 2013a).

With regard to human resources, the survey as well as the interviews show mixed results. In general, it does not seem to be a major problem at the moment even though it has been mentioned that with more staff, the technological development could be accelerated significantly (Interviewees 12 and 13). However, human resources could become a problem as the technologies become more widely used. Some of the technologies require specific capabilities and knowledge on behalf of crews and captains, such as how to launch and retract the technology, how to select optimum courses according to the best wind conditions, etc.

> “If you hope that this becomes a global topic, well then, we still have some things left to do. Nobody has ever sailed a 250m long ship.” (Interviewee 5)

So in the future, the build-up of a knowledge infrastructure to teach this knowledge will probably be needed.

Finally, port infrastructure has been mentioned as problematic for some types of ships. Except for tankers and Ro-ro ships, the (un)loading of vessels is currently being done by cranes. This would be prohibitive to the use of non-retractable Flettner rotors and sailing masts.

> “If you’re operating a bulk carrier, then you need a clear space above your deck, and masts get in the way. (…) They will collide with loading arms and various other things.” (Interviewee 9)

> “I think for container shipping, Flettner rotors will be prohibitive. I think there’s not a lot of space on deck to manage it and it’s too difficult to operate or it has too much impact on the loading and unloading of containers.” (Interviewee 1)

The (un-)loading procedures would have to be modified, requiring investments in port infrastructure (Interviewee 5). The problem is that

> “ports have investment horizons of 50 to a 100 years, (…) you're investing in a 50 to a 100 year paradigm that will not change.” (Interviewee 13)

Due to these long investment horizons, ports effectively lock-in existing technologies and it will be difficult for new technologies to break through. An example for this is LNG, an alternative fuel which has already gained widespread acceptance in the industry:

> “If you look at the number of LNG ships – who are not carriers of LNG, but have propulsion from LNG –, there's very, very few still and we've been talking about it for years. The infrastructure is not there. It’s probably going to be another five years, that's what I can see. If you look at that – and that's a tiny change in the shipping industry – if you look at sail, that would be a dramatic change in the industry.” (Interviewee 13)

The likelihood is thus very low that port infrastructure will be changed in the near future to accommodate for wind propulsion technologies.

8.7 Creation of legitimacy

The function 'creation of legitimacy' scored very low in both the event analysis and the survey. The low function fulfillment is also reflected in the skeptic attitude of the shipping industry towards wind propulsion.

One of the frequently mentioned reasons why wind propulsion is not encountered with more enthusiasm is the conservative character of the shipping industry (Interviewees 1, 2, 8, 10 and 13):

> "Look, we're pretty conservative, old-fashioned people, and there aren't many ship owners out there who would seriously consider putting sails on their ships." (Interviewee 9)

This conservatism is understandable when considering that technology failure at sea could put human lives at risk (Interviewee 1). However, it prevents many ship owners from seriously considering using wind for propulsion purposes. Instead, wind is perceived as romantic and nostalgic, but not suitable for efficient industrial use nowadays (Interviewee 2).

> "Sail has been denigrated for many, many years. If you are poor, you use sail, which is really interesting because the only people who really use sail are rich yacht owners. (…) If you look at the popularity of heritage fleets (…), it's unbelievably popular. If you then talk to someone and say 'Well, we'll move your Christmas gifts – or whatever – by sail, everyone start coming up with a problem: 'you see, it's not going to be possible'. There's a lot of collective consciousness that sees sail as a romantic, oldy-worldy thing." (Interviewee 13)

So while wind propulsion evokes nostalgic feelings, it is not considered to be appropriate under the current economic paradigm. Instead, it is considered a step back, rather than forward:

> "This is a male oriented industry. (…) Wind isn't sexy to these guys. (…) What would be really sexy to these guys 'Let's put nuclear reactors onboard the ships'. (…) That would be a step forward in their view. Bigger, heavier." (Interviewee 13)

The technological or operational measures that have lately or will shortly be introduced in the shipping industry – e.g. slow steaming, weather routing, LNG – are all incremental steps that did not require any substantial changes to the current shipping paradigm. The situation is different with wind propulsion technologies that are generally regarded as the more radical, game changing technologies that might be implemented in the more distant future. Their introduction could fundamentally alter the current face of shipping, not only by the looks of it, but also by the way the industry operates. Currently, ships and shipping operations are accurately tailored to one another, whereas incorporating wind would imply disturbances on various aspects such as time of arrival, costs, and routing and navigation:

> "One of the pillars of modern day trade is predictability. You have to have it, you have a contract and you know the goods are coming then and then. If you could change that into something more flexible or in another way, where it is not so important, then of course wind could become a little more important for ships." (Interviewee 4)

All these aspects are currently highly predictable yet the inclusion of wind would decrease this predictability and require room for maneuver. However, accepting and embracing this uncertainty is challenging:

> "We're all very much afraid of change. We've always done it like that, it's always worked for us, let's carry on. (…) I think it's a human condition which is not specifically related to shipping. I think there's so much uncertainty that we like to feel secure in our area of comfort, the way

> that we know how to do things. So we know how to run an engine on a ship and even if the price of bunkers keeps on going up we still know how to do it, it just gets harder but we're still within our comfort zone." (Interviewee 3)

So the fear of the unknown results in inertia. In order to overcome this fear, people in the shipping industry have to be made familiar with new technologies, such as wind propulsion. Educational structures are needed to make the unknown known and evoke a sense of curiosity rather than resistance. This role should be taken on by an objective, trusted knowledge broker.

Furthermore, no lobbying structures are in place that could promote the uptake of wind propulsion and establish trust in this new-old technology. Technology providers do not cooperate enough and instead, promote their own technology on their own. However, all the different claims voiced on each single technology create confusion rather than conviction. The shipping industry is just too big, risk-averse and conservative to be won over by a single start-up. Therefore, technology providers need to collaborate, pool resources and knowledge and speak with a stronger, unified voice. Once wind propulsion has attained a certain level of legitimacy and market acceptance, the existing players will probably not have the required capacities to even satisfy this demand:

> "If you consider how big the market will be in 40 years - we cannot even build that much." (Interviewee 5)

Even though currently, no formal lobbying structures are in place, they are started to be developed. In January 2013, the establishment of a Windship Lobbying Group was formally announced. The association has been initiated by three wind propulsion technology providers – Energy Ship, Greenheart Project and Propelwind – and is supported by the environmental NGO Carbon War Room (Englebert 2013). Its primary objective is

> "to facilitate and promote wind propulsion for commercial shipping worldwide and to bring together all parties in the development of a wind-ship sector to shape industry and government attitudes and policy." (Allwright 2013)

Towards this end, the group intends to create a clear sectoral approach with like-minded organizations, promote the economic value of wind propulsion within the shipping industry, assist in securing funding streams, act as a central information hub for the wind-ship sector and lobby legislative bodies on policies, activities, funding and incentives required to realize uptake of wind propulsion technologies on a larger scale (Allwright 2013). Further lobbying activities can be expected to come from the Interreg SAIL project. Besides aiming to generate more knowledge on wind propulsion, it also intends to increase awareness on wind propulsion, interact with political decision makers from the IMO, the European Union and North Sea riparian states and issue policy recommendations and build public-private partnerships to promote the uptake of wind propulsion (NSR SAIL 2013)

8.8 Conclusion

To conclude, there is a lack of practical and verified data which prevents ship owners to invest in wind propulsion technologies. Practical data can be generated from trials of the different technologies. However, in addition to the fact that ship owners are afraid to test a relatively unproven technology, there currently are not enough financial resources to do so because of the economic crisis which left ship owners struggling for economic survival and banks unwilling to finance investments in shipping. Another problem preventing ship owners to invest in wind propulsion is the lack of trust in data provided by the technology providers themselves. Data needs to be verified by independent third parties so as to ensure objectivity, but interviewees have pointed to a lack of organizations to do this.

Knowledge diffusion takes place at different levels, but is insufficient at all of them. Technology providers mostly prefer to operate on their own rather than collaborate with each other because of a heightened sense of competition and a lack of trust in each other. Knowledge exchange between technology providers and ship owners is impeded by the lack of joint research projects which represent the most effective form of knowledge exchange. Engaging in these research projects is a risky and costly endeavor for ship owners, so a there needs to be a considerable amount of trust between the two parties before a ship owner would be willing to do so. However, there are too few occasions where both parties can meet and establish a relationship so platforms need to be created where they can engage in open communications and discussions. Even if these trials or other knowledge development activities take place, data is not shared within the shipping industry out of fear of losing a competitive advantage. R&D activities are mostly financed by ship owners themselves, so they hope to reap the benefits of their research themselves. This suggests a lack of publicly financed research projects, the results of which could be publicly shared and thereby benefit the whole industry.

With regard to Guidance of the search, there a lack of hard institutions specifically promoting wind propulsion. Existing policies to combat air pollution and GHG emissions from shipping are not stringent enough in the set targets and weak compliance and enforcement mechanisms could hinder their implementation. So far, no common vision shared by both actors inside and outside of the TIS has been created yet, suggesting that there is not enough interaction and exchange of experience between these actors.

Furthermore, there are no financial incentive schemes promoting the uptake of wind propulsion, yet these would be needed to develop the technologies up to a point where they can openly compete with existing technologies both on a cost and performance basis. What makes matters worse is the severe lack of finance experienced by both technology providers and ship owners. While the former experience a shortage of start-up finance and R&D investments which keeps them from trialing their technologies, the latter cannot invest in new technologies because of the economic crisis which left many struggling for economic survival. Moreover, the split incentive problem prevents ship owners to invest in energy efficiency technologies as they cannot appropriate the benefits from their investments. Market-uptake of wind propulsion is also obstructed by ill-suited port infrastructure. For a lot of ships, cargo handling is currently done by cranes which are prohibitive with most wind propulsion technologies.

Finally, wind propulsion technologies are not perceived as legitimate, but rather as a nostalgic thing of the past that does not fit in today's economic system. Conservatism and fear of change lead to inertia which can only be overcome by educating actors within the shipping industry and creating curiosity in the technology. The current fragmentation between technology providers is a further barrier in that it leads to confusion over the potential of wind propulsion. Instead, suppliers should cooperate and together lobby for the uptake of wind propulsion.

Despite these structural barriers, there is some reason for optimism. Interviewees agreed that the most important driver were rising and fluctuating oil prices which provide an incentive to invest in energy efficiency. This will be even more true once an MBM is introduced as this instrument would increase the costs of emitting GHGs. In order to develop more knowledge on wind propulsion and generate practical and objective data, three knowledge initiatives have recently emerged. They could also provide a means to improve knowledge diffusion amongst all actor groups because by bringing different stakeholders together, they facilitate the exchange of knowledge and experiences among them. Along the same lines is the recent formation of a Windship Lobbying Group among some wind propulsion technologies. This initiative can increase public awareness of wind propulsion and contribute to making the technologies being perceived as legitimate. As a means to mitigate the split incentive problem, alternative financing mechanisms are being developed and will shortly be trialed.

Furthermore, there is an increasing demand for environmentally friendly shipping services as sustainable supply chain management becomes more and more important for businesses. Finally, the great Drive, commitment and passion of entrepreneurs active in this field need to mentioned. Without their relentless efforts to bring wind propulsion technologies to the market, no TIS would exist at all.

An overview of the different structural barriers and drivers is shown in the figure below.

Table 14: Overview of structural barriers and drivers influencing TIS development of wind propulsion

	Structural barrier	**Structural driver**
External factors	• Economic crisis	• Rising fuel prices
Hard institutions	• Lack of policies promoting wind propulsion • Lack of stringency of air pollution and GHG emission reduction policies • Weak compliance and enforcement mechanisms • Lack of financial incentive schemes • Lack of start-up finance • Lack of public finance for R&D activities • Split incentive	• Future introduction of MBMs • Development of alternative financing mechanisms • Emergence of voluntary benchmarking tools
Soft institutions	• Lack of trust among actors • Conservative & risk-averse industry	• Great entrepreneurial drive • Increasing demand for environmentally-friendly shipping services
Knowledge infrastructure	• Lack of demonstration projects & practical trials • Lack of independent 3rd party testing	• New research consortia
Interaction	• Little collaboration between technology providers • Lack of knowledge exchange platforms • Weak network between actors in- and outside of TIS	• Emerging collaboration and lobbying activities among technology providers
Physical infrastructure	• Ill-suited port loading and unloading equipment	

When comparing the number of drivers and barriers, it becomes more clear that structural barriers outweigh the drivers by far. Furthermore, most drivers are only emerging, whereas many of the barriers have existed for a long time. The severity of barriers thus also outperforms that of the drivers. This shows all the more how important it is that the IMO intervenes by mitigating the structural barriers and promoting the drivers. The next chapter will analyze its capacities and possibilities to do so.

9 The IMO's potential to influence drivers and barriers

In this chapter, the fourth and final sub-question will be answered:

> *How and to what extent can these factors be influenced by the IMO as the main regulatory body?*

In order to answer this question, we first need to understand the IMO's potential to exert influence on the identified drivers and barrier better. Based on the theoretical framework outlined in chapter 2.8, the governing capacities of the IMO will be assessed. Based on this assessment, we can give policy recommendations on what the IMO could realistically do to mitigate barriers and promote drivers. Thereby, the main research question will be answered:

> *What possibilities does the International Maritime Organization have to promote the uptake of wind propulsion in international shipping?*

9.1 Assessing the IMO's governing capacities

9.1.1 Formal competences

The Intergovernmental Maritime Consultative Organization (IMCO) was established by a UN treaty in 1948, yet this treaty only came into force in 1958. This delay can be explained by the skepticism of the large maritime nations towards governmental involvement in the commercial aspects of shipping (Tan 2005). Given the vital importance of shipping to most economies, these states were afraid of a high degree of external regulation which would have made shipping much more costly and so could only agree to governmental involvement in technical matters (DeSombre 2006). This explains the inclusion of the word 'consultative' within the organization's name. Rather than becoming a political body with far-reaching authorities vis-à-vis its member states, IMCO's competence was to be restricted to purely advisory and technical matters (Tan 2005). The purpose of the organization is summarized by article 1(a) of its founding Convention:

> "provide machinery for co-operation among Governments in the field of governmental regulation and practices relating to technical matters of all kinds affecting shipping engaged in international trade; to encourage and facilitate the general adoption of the highest practicable standards in matters concerning the maritime safety, efficiency of navigation and prevention and control of marine pollution from ships" (IMO 1958).

The focus of the organization is thus on safety, efficiency and prevention of marine pollution from ships, and again, its technical nature is stressed. Activities that go beyond this mandate are rare (Campe 2009).

Despite the changes that the organization underwent – its name was changed to IMO in 1982 and its membership base grew from a modest 21 member states to about 170 – the work of the IMO is still very much restricted to advisory and technical work (Leeuwen 2010; Tan 2005). To this day, the work of the IMO is driven by its member states, and the IMO does not push towards a political direction, but rather provides a forum for negotiations amongst its members (Campe 2009). The lack of competence vis-à-vis its member states is also reflected in the IMO's monitoring and compliance mechanisms. Even though data on enforcement is available, the IMO has a weak record in processing this data and monitoring compliance. Furthermore, the IMO does not have the power to enforce compliance with its rules or to impose sanctions for non-compliance on member states. It also has not used soft sanctioning mechanisms such as the publishing of enforcement data to its full capacity. For these reasons, the IMO has often been criticized for lacking 'teeth' in ensuring compliance. (Campe 2009; Tan 2005)

This lack of competence can be viewed both positively and negatively. While Biermann (2009) hypothesizes that the more competences an organization has, the more influential it is, Campe (2009) argues that it is the certainty that the organization cannot act against the will of its member states which has earned the IMO the trust of its member states. Because of its perceived neutrality, its submissions are generally regarded as a good basis for negotiation.

9.1.2 Organizational structure

The IMO currently has 170 member states and three associate members. The membership base of the IMO is broad and rather heterogeneous in that both industrialized and developing countries are included. Contrary to the global power distribution, it is the developing nations who have the upper hand in the IMO's decision-making process. This was not originally envisioned, but can be explained by the growth in flag-of-convenience ship registration which mostly takes place in developing states. Thus, a tension exists between the globally powerful European and North American states and the developing nations who do not have much international influence, but are centrally important in determining international shipping standards. (DeSombre 2006)

In addition, a number of inter-governmental and non-governmental organizations, representing a wide variety of interests ranging from ship owners to environmental groups, have consultative status with the Organization and can attend meetings.

The IMO's secretariat is based in London, UK and comprises a staff of around 300. The organization is composed of seven organs. Its main ruling body is the Assembly which consists of all member states. In its biennial meetings, it decides on the work program and budget, elects the Council and approves the secretary-general. The Council is the executive organ of the IMO and is responsible for supervising its work. It is made up of 40 member states, representing the ten largest shipping nations, the ten largest seaborne trading nations and 20 countries with a maritime interest covering all major world regions (Art. 17, IMO Convention). As a consequence of this allocation mechanism, coastal states which are the most vulnerable to marine pollution are underrepresented whereas the large flag states possess a de facto veto (Campe 2009). The technical work of the IMO is carried out by five main Committees: the Maritime Safety Committee (MSC); the Marine Environment Protection Committee (MEPC); the Legal Committee; the Technical Co-operation Committee and the Facilitation Committee (IMO 2013a). The MSC is the highest technical body of the IMO and is concerned with any issue related to maritime safety. The MEPC, which deals with any matter related to the prevention and control of pollution from ships, was not only created later than the MSC, but was also first established as a subsidiary body of the Assembly until raising to full constitutional status in 1985 (IMO 2013a). This reflects the IMO's evolving mandate: the initial focus of the organization was on safety at sea and efficiency of navigation (Tan 2005). Both MSC and MEPC are open to all member states and their work is supported by nine sub-committees of which the Ship Design and Equipment (DE) and Bulk Liquids and Gases (BLG) are the most important with regard to regulating GHG emissions from shipping. Often, working or correspondence groups are established for working on complex issues at a highly technical level (Brown 2012). By means of informal sessions or e-mail correspondence, these groups do a lot of preparatory work and even undertake "in-principle decisions" (Tan 2005:99) prior to Committee meetings.

The Legal Committee, Technical Co-operation Committee and Facilitation Committee deal with legal matters, implement technical co-operation projects and harmonize shipping procedures as well as streamline internal bureaucratic procedures, respectively.

The work of the IMO is characterized by highly formalized and hierarchical decision-making procedures and responsibilities are clearly communicated to the staff (Campe 2009). While these factors are likely to contribute to an efficient organization of work, they provide little space for proactive engagement of staff (Biermann et al. 2009).

9.1.3 Embeddedness

The IMO is a UN specialized agency and largely independent of the UN system (Campe 2009). This is different with regard to the issue of climate change. Overall, the UNFCCC and its Kyoto Protocol form the supreme international regime to tackle climate change and there is "no specific institution or specialized agency that might challenge the UNFCCC for 'institutional' ownership over international climate-related agreements" (Strong 2011:14). However, the Kyoto Protocol excludes emissions produced within international waters (and airspace) from national targets and instead, charged the IMO with addressing these 'international' emissions from shipping (Article 2.2, Kyoto Protocol) (Gilbert and Bows 2012). However, a clear regulatory hierarchy between the UNFCCC and IMO could not be determined (Oberthür 2003) which is why one could speak of a "co-equal international institutional interaction" (Strong 2011:14). The problem with this interaction is that these two institutions are based on two contradictory core principles. The IMO is based on the principle of "no more favorable treatment" (IMO 1958), whereas the UNFCCC climate regime is based on the principle of "common but differentiated responsibilities" (CBRD) (Hackmann 2012). While the former means that IMO regulations apply to all ships regardless of the country of registry, the latter recognizes the specific needs of developing countries (non-Annex I countries) and places the heaviest burden for fighting climate change on developed countries (Annex I countries). This contradiction creates institutional tensions and has led to a deadlock in the negotiations on how to tackle the issue of climate change since member states cannot agree on which principle to apply (Hackmann 2012). On the one hand, there are the industrialized nations who urge all members to reduce CO2 emissions from ships, noting that the vast majority of the world tonnage is registered in developing countries and that ships currently registered in Annex I countries would likely change their flag to a non-Annex I country to avoid stricter regulation, if the CBRD principle were to be applied. This would render the efforts to reduce CO2 from ships useless (Wang 2010). On the other hand, developing countries led by China, India and Brazil argue that the CBDR principle must be fully respected because CO2 emissions from their ships ensure economic growth and because the CBDR is a widely accepted principle and should be regarded as binding international law. (Wang 2010) They are afraid that making concessions in this discussion would undermine their position in the UNFCCC as it weakens its underlying core principle and that international shipping could become a role model for future discussion in other sectors (Hackmann 2012).

Even though the IMO is largely independent from the UN family, this is not the case for GHG emissions where it shares institutional responsibility with the UNFCCC. The contradictory core principles underlying these two institutions paralyze the negotiations on an effective policy response to climate change.

9.1.4 Resources

The IMO's budget is mostly derived from membership fees that depend on the tonnage of the Member State's merchant fleet. Accordingly, the top five contributors in 2012 were Panama, Liberia, the Marshall Islands, the United Kingdom and the Bahamas; four out of five are developing countries (IMO 2013a). This explains why the IMO has experienced temporary cash shortages in the past, even though overall, the IMO budget is relatively stable and has not undergone any nominal cuts which is interpreted as a general approval of IMO's work by the member states (Campe 2009). The budget is adopted by the IMO Assembly which, for the biennium 2012-2013, agreed on a total appropriation of £62,206,200 (IMO 2013a). Campe (2009) considers the financial resources of the IMO to be scarce and as a consequence, vacancies can often not be filled.

9.1.4 Organizational expertise

The IMO's work is highly technical in nature and thus requires a high level of expertise. The IMO can draw from both in-house and external knowledge sources. Its staff has predominantly seafaring or naval engineering backgrounds and is thus highly qualified to work in such a technical environment. The most important source of expertise, however, are the classification societies which serve as technical advisers to the IMO. (Campe 2009) More external expertise is brought in by industry representatives (e.g. ship owners, marine insurers), but also by environmental NGOs who can follow IMO meetings, submit papers and participate in working and correspondence groups. According to Interviewee 13, this can be quite effective:

> "One of the important aspects with the IMO is that most of the decisions of the IMO are based on science and information and so the more you can communicate to the IMO, the better it is for your work. So if you communicate, for instance, there is an environmental issue, (…) then people will start to talk about it, people will start to think about it and that's the way people think about regulation." (…) And for us, the ammunition in our work is arguments and information. So if we have the best arguments, if we have the best information available, people will start listening to us and then we start to be credible and if we are credible and we bring information, then people will start considering the information we bring into the debate. So being involved in a debate, having the arguments and information, I mean this – in policy terms - is power." (Interviewee 13)

So by submitting information and participating in meetings and working groups, NGOs (but also industry) can exert a significant influence on the IMO's decision-making process (Strong 2011). Even though the influence of environmental NGOs has grown over the past years, industry presence is still dominant (Harrison 2011). This is also explained by the fact that industry representatives often have more technical knowledge and/or capacities, e.g. in terms of time to follow meetings and participate in working or correspondence groups (Interviewee 13).

While the IMO disposes over strong technical expertise, it lacks environmental knowledge which manifests itself both in-house and in the predominance of shipping industry representatives over those from environmental NGOs. With regard to climate change issues, the IMO could draw on the expertise of the UNFCCC. While the two institutions exchange knowledge and participate in each other's relevant meetings, forums to exchange expertise outside the negotiation process currently do not exist (Hackmann 2012).

Another important aspect in this category is the potential of the IMO to process and disseminate information. Two of the major tasks of the secretariat are to collect and review technical information on ships as well as to inform on legal issues. With regard to the first task, the IMO performs rather poorly given that no proper reporting system had been established for a long time and that only recently it has increased its efforts in database management. The dissemination of legal knowledge, however, works well: the IMO publishes a great amount of manuals on IMO regulations and codes, the demand for which has grown steadily. (Campe 2009) Concerning the creation and dissemination of environmental knowledge, the IMO is relatively inactive. The MEPC itself does not undertake any scientific research, yet hosts the Joint Group of Experts on the Scientific Aspects of Marine Environmental Protection, which – through publishing in peer-reviewed journals - has enlarged the knowledge base on marine pollution. The issue of air pollution from ships was largely ignored within the MEPC and if only decided to commission a study on GHG emissions in 1998, as a reaction on the growing international debate (Campe 2009; Oberthür 2003).

Furthermore, the IMO is involved in training students and professionals. Under its auspices, three institutions have been founded: the International Maritime Law institute to educate maritime law experts, the International Maritime Academy to train professionals and government officials in short-term courses, and the World Maritime University as a center of excellence for maritime post-graduate education and research (Campe 2009; IMO 2013h). Financed by the IMO, the World Maritime University has developed a training course to promote energy efficient operation of ships and the implementation of the SEEMP (IMO 2013g).

To conclude, the IMO avails over strong technical expertise, disposes over a good information network and has well-functioning knowledge dissemination mechanisms in the form of its large publication department and the establishment of three knowledge institutions. However, its knowledge base is biased towards seafaring, naval engineering rather than environmental science and incorporates more expertise from maritime industry representatives than from environmental NGOs.

9.1.6 Organizational culture

The IMO is very technical in its nature and rather than perceiving itself as a political actor, views itself as a neutral broker:

> "Perceived as neutral broker loyal to its member states without the ability to act against the will of its principals, the secretariat is trusted by the member states and its submissions are regarded as a good basis for negotiations." (Campe 2009:154)

So instead of furthering its own political agenda, it provides a space for international negotiation and cooperation and facilitates this cooperation by providing technical knowledge. Even though the provision of knowledge to its members is so important within the IMO work, this is not the case internally where no formal learning mechanisms exist and no internal staff workshops take place. (Campe 2009)

It could be assumed that the IMO is a rather conservative organization. This is due to its great exposure to the maritime industry which is well known for its conservatism (Leeuwen 2010). It maintains close relations with the shipping industry, exchanges knowledge with industry representatives on a regular basis and employs many people with a seafaring background. This conservatism was shown in the 1990s, when the IMO denied incorporating the precautionary principle into its work. Instead of integrating environmental concerns into its daily work, the IMO wanted to maintain the status quo, referring to two outdated resolutions which mandated to avoid structural change. This episode shows that

> "the organizational culture of the bureaucracy tends to favor efficient shipping over sustainable development goals, and the dominating professional culture of seafarers promotes this culture" (Campe 2009:160).

To conclude, the culture of the organization is characterized by pragmatism, a lack of vision as manifested by the desire to be as neutral as possible, a resistance to change and, presumably, conservatism. It seems like this organizational culture leaves little room for environmental concerns, as shown by the reluctance to incorporate the precautionary principle into the IMO's work.

9.1.7 Organizational leadership

To date, eight individuals have held the post of Secretary-General to the IMO: Ove Nielsen (Denmark; 1959-61), William Graham (UK; 1961-63), Jean Roullier (France; 1964-67), Colin Goad (UK; 1968-73), Chandrika Prasad Srivastava (India; 1974-89), William O'Neil (Canada; 1990-2003); Efthimios Mitropoulos (Greece; 2004-2011) and the incumbent, Koji Sekimizu (Japan; 2012-) (IMO 2013a). Since the 1970s, the terms for the IMO secretary-general have been quite long, providing for some stability within the organization. Unfortunately, no data about the leadership style of the secretary-generals could be found, however, the existence of 'small kings' who protect their small sphere of influence within IMO has been reported (Campe 2009).

9.2 What could the IMO do to alleviate barriers and reinforce drivers

The previous chapter has shown that many structural barriers impede better function fulfillment. In particular, the functions Knowledge development, Knowledge diffusion and Mobilization of resources were shown to be poorly fulfilled while at the same time being deemed crucial to further TIS development. Therefore, the urgency to act is highest with these functions. These functions correspond best to the cognitive and executive areas of influence which is why these will be discussed only.

9.2.1 Cognitive influence

The previous analysis of the IMO's governing capacities has shown that the IMO perceives itself as a neutral knowledge-broker that provides a space for international negotiation and cooperation while facilitating this cooperation by providing technical knowledge. This technical knowledge resides both internally within the organization, but the IMO also has access to a well-developed information network through which it can access external expertise. The organization has a large publication department though which it can effectively disseminate knowledge. It also contributes to generating and disseminating knowledge through the three knowledge institutes set up under its auspices. Overall, the IMO is trusted by its member states and because of its perceived neutrality, its submissions are generally regarded as a good basis for negotiation.

These factors make the IMO well suited to intervene in the low fulfillment of the functions Knowledge development and Knowledge diffusion and exert its cognitive influence.

In order to promote knowledge development and diffusion on wind propulsion technologies, it is recommended that the IMO establishes a working or correspondence group on the topic. This would have several advantages: by discussing and working on the topic, the theoretical knowledge base would be enhanced. Due to the fact that participation in working and correspondence groups is open to all IMO delegations (both governments and organizations) that are interested in the topic and can provide sufficient expertise on it, a platform for knowledge exchange would be established. A prerequisite for the participation of wind propulsion providers would be for them to obtain consultative status with the IMO. This could be achieved either by setting up an internationally operating NGO (perhaps in the form of the recently established Wind Ship Lobbying Group) or by joining an established NGO with consultative status.

Furthermore, the establishment of a working or correspondence group would probably send out a strong signal to the maritime industry that wind power is worth considering for ship propulsion or even that it expects these technologies to enter the market. This would change the discourse and increase the legitimacy of the technologies which means that the IMO would indirectly exert normative influence on the industry as well.

While the establishment of a working or correspondence group within the IMO would not help overcome the lack of practical knowledge in the strict sense of the term, the combination of enhanced, more widespread theoretical knowledge and increased legitimacy could convince ship owners more easily to trial the technologies and banks and ship financers to finance the trials. This would then contribute to the generation of practical knowledge as well.

9.2.2 Executive influence

In contrast to the cognitive area of influence, the IMO is less suited for exerting an executive influence. This is mainly due to the fact that the IMO itself has scarce financial resources and because it is mainly financed by developing countries, has experienced temporary cash shortages in the past. Furthermore, it does not perceive itself as a political actor, but rather as a technical advisor which entails that it does not usually push towards a political direction. It will thus be difficult for the organization to help promote the development of the functions Market formation and Resource mobilization. Nonetheless, there

It is recommended that the IMO intensifies its efforts for introducing an MBM. Despite disagreements on the design of such a policy instrument, the fundamental idea is to place a price on GHG emissions and thereby increase costs of fuel consumption. As both the event and the interview analysis have shown, rising fuel prices are the prime motivation to the uptake of wind propulsion which is why it can be expected that the introduction of an MBM would accelerate the uptake of these technologies. Furthermore, MBMs can generate funds which could be used for different purposes. In the current proposals, it is mainly suggested to use revenues from the MBM either for building capacities in developing countries or for research and development activities (MEPC 2010). With regard to the latter, thought should be given to financing research and development for radical low-carbon technologies – such as wind propulsion – which would help the maritime industry in significantly cutting fuel consumption and thereby GHG emissions.

So far, IMO member states have failed to agree on the design of an MBM which is mostly due to the contradictory core principles underlying the work of the IMO ('no more favorable treatment') and the UNFCCC ('common but differentiated responsibilities') (see 8.1.3). In theory, there are ways to reconcile these principles (e.g. Faber et al. 2010; Kågeson 2011; Miola et al. 2010), but they need to be translated into practice for the MBM to become a reality.

Another possibility for the IMO to exert influence in the field of wind propulsion is to establish a fund similar to a Multi-Donor Trust Fund (MDTF)[15] As of April 2011, the IMO had six MDTFs and 17 financial arrangements in operation (IMO Technical Co-operation Committee 2011). Amongst others, IMO projects have been financed by the World Bank, the Global Environment Fund (GEF) and the United Nations Environment Program (UNEP) all of which place climate change mitigation high on their agendas (IMO 2008). In the absence of an MBM, it is suggested to establish a maritime low-carbon technology fund under the auspices of the IMO and with the financial support of international institutions such as the above-mentioned, national governments and industrial parties. Such a fund could be used to finance research and development activities on radical low-carbon technologies (e.g. wind propulsion) and would bridge the time until the introduction of an MBM.

9.3 Conclusion

The analysis of the IMO's governing capacities has shown that the organization does not perceive itself as a political actor but rather as a neutral knowledge broker. It disposes over a lot of technical expertise and has good dissemination mechanisms. This make it well-suited to intervene in the areas of knowledge development and diffusion and it was suggested to establish a working or correspondence group within the IMO to generate and exchange knowledge on wind propulsion. Because the IMO is perceived as a neutral knowledge broker by its member states, this would probably also increase the legitimacy of these technologies. While the IMO is well-suited for exerting cognitive influence, it is less so for executive influence, amongst others because it does not possess great financial resources itself. Nonetheless, it was suggested that the organization intensifies its efforts on introducing an MBM as this would most likely increase the economic viability of wind propulsion and because it would allow to establish funds to finance R&D activities on low-carbon ship propulsion technologies, e.g. wind propulsion. Until its introduction, it could establish a multi-donor trust fund for the same purpose, with the financial support of international donor organizations, maritime states and industrial parties.

[15] MDTF's are so-called pass-through fund management models established by the UN system, national authorities and other contributors and partners. This means that Donors agree to channel the funds through one UN agency. MDTFs aim to support the achievement of national and global priorities such as the Millennium Development Goals. MDTFs are currently only used in context of humanitarian, transition, reconstruction and development programs (The Global Mechanism 2013; UNDP 2013). This is why the suggestion was to establish a funding scheme similar to a MDTF to make sure it could be set up for the achievement of environmental rather than social goals.

10 Conclusion and discussion

This final chapter provides an answer to the main research question, followed by a reflection on the methods used to research it. It will conclude in providing recommendations to further research.

10.1 Conclusion

The aim of this research was to provide policy recommendations to the IMO on how to promote the uptake of wind propulsion technologies in international shipping. Accordingly, the main research question was formulated as follows:

What possibilities does the International Maritime Organization have to promote the uptake of wind propulsion in international shipping?

In order to answer this research question, four sub-questions were formulated, which are discussed in the following.

The first sub-question asked *which factors account for the development and diffusion of innovations?* A review of the academic literature on technological transitions has shown that the most suitable theoretical approach for identifying these factors is provided by the perspective of Technological Innovation Systems. The central idea underlying this approach is that the innovation process takes place within a system comprised of different actors who contribute to the development and diffusion of the innovation in question. The relationships between these actors and the institutional infrastructure in which they are embedded represent the structural components of the system and together form the TIS. In order to account for the fact that systems are not static but evolve over time, seven functions have been identified in the literature on innovation science to represent the dynamics underlying technological change. These are Entrepreneurial activities, Knowledge development, Knowledge exchange, Guidance of the search, Market formation, Resource mobilization, and the Creation of legitimacy. It is assumed that in order to develop properly, the TIS should positively fulfill all seven functions. In turn, a poorly fulfilled function can form an obstacle to TIS development. Both positive and negative function fulfillment are caused by structural drivers and barriers, respectively. These are linked to hard or soft institutions, knowledge and physical infrastructure, networks and external factors. Identifying the structural drivers and barriers is a prerequisite to providing policy recommendations on how to foster technological change. When recommendations are targeted at a specific actor, it is useful to understand its capacities to bring about change to make sure the recommendations could be realistically implemented. For international organizations, seven governing capacities are relevant to exert influence, ranging from their formal competences to organizational culture. Together, these factors create a framework which allows a) evaluating the performance of a TIS by means of assessing function fulfillment, b) understanding its performance by identifying the underlying structural drivers and barriers and c) promoting its performance by formulating policy recommendations tailored to the recipient's governing capacities.

The second sub-question aimed at evaluating the performance of the TIS for the different wind propulsion technologies and was therefore broken down into three questions: *What is the state of play in the development and diffusion of a) towing kites, b) Flettner rotors and c) sails?* Based on a review of newspaper articles, the structural components of each technology were identified and by means of an event analysis, the fulfillment of system functions was assessed. Overall, function fulfillment was shown to be low for all three technologies, but for different reasons. The main problem with the TIS for towing kites is the dependence of TIS development on its main actor (Skysails). This made the system vulnerable to external shocks which came about in the form of the economic crisis, leading to the cancellation of orders and resource shortages. The development of the TIS for Flettner rotors was mainly inhibited by fluctuating oil prices. When these were high, interest in the technology grew and entrepreneurial and knowledge development activities were reported. Once oil prices fell, the technology was not considered economically viable anymore, resulting in a complete halt of all activities. This fluctuating TIS development prevented the build-up of a knowledge base and the diffusion of knowledge. Compared to kites and Flettner rotors, the TIS for sails was considered slightly more developed which is primarily due to the involvement of both established and start-up companies which provides the system with more stability as well as the higher support by public research institutes which facilitates knowledge diffusion. However, the difference in performance is only small and just as the other TIS further development is inhibited by low function fulfillment. In all three TIS, actors suffer from financial resource shortages, the lack of financial incentive schemes and of lobbying activities further slows down TIS development. The overall performance assessment resulting from the event analysis was substantiated by a survey among professionals working in the field of wind propulsion. Except for small deviations, the evaluation of function fulfillment largely matched the one from the event analysis. Furthermore, experts were asked how important they considered each function to be for further TIS development. All functions were considered at least somewhat important if not very important. By comparing the expert scores for function fulfillment and function importance with each other, areas were identified on which to focus policy interventions. These relate to the functions Knowledge development, Knowledge diffusion and Resource mobilization.

By means of the third sub-question the structural drivers and barriers underlying TIS development for wind propulsion were identified: *Which mechanisms hamper or stimulate the development and diffusion of wind propulsion in international shipping?* Even though the event analysis and expert survey were useful to assess the performance of the TIS in terms of function fulfillment and to identify areas for policy interventions, they did not provide sufficient insights into current dynamics which is why several semi-structured expert interviews were conducted. With regard to the structural barriers, there is a lack of policies directly promoting the uptake of wind propulsion. It might be fostered indirectly by recent or upcoming international regulations reducing air pollution or GHG emissions, yet even these were often considered too lax in terms of target-setting and their compliance and enforcement mechanisms. Furthermore, there is a lack of financial incentive schemes, a lack of finance for start-up companies and insufficient public funds for R&D activities which prevent further entrepreneurial, knowledge development and diffusion activities. This lack of financial resources is further aggravated by the economic crisis which severely affected the shipping industry and meant that many ship owners currently do not have the financial means to invest in innovative technologies. Those ship owners with sufficient financial resources have no incentive to invest as they cannot appropriate the benefits of their investment. This is known as the split incentive problem. In terms of soft institutions, it was established that the general conservative and risk-averse character of the maritime industry was preventing technology take-up and that actors both in- and outside the TIS do not trust each other enough to enable collaboration and cooperation. Network ties between these actors are either inexistent or too weak which also has to do with the lack of a knowledge exchange platform where actors could meet, establish relationships, build-up trust and share their experiences. There is also a lack of demonstration projects and practical trials of wind propulsion technologies, as well as a lack of an independent third party appraiser. Both would be needed to convince risk-averse ship owners to test wind propulsion technologies. Furthermore, current cargo handling equipment is ill-suited for most wind propulsion technologies, yet the long investment horizons for ports infrastructure prevent investments into different equipment, thereby effectively locking-in existing technologies. The strongest driver identified in the interviews is the rising fuel prices which could increase the economic viability of wind propulsion technologies. Similarly, the anticipation of tighter emission targets, the future introduction of MBMs as well as growing demand for environmentally-friendly shipping services coupled with the emergence of voluntary benchmarking tools could increase the attractiveness of wind propulsion to potential customers. New research consortia have formed to contribute to knowledge development, some of them involving public research institutes which could foster the diffusion of knowledge within the shipping industry. Alternative financing mechanisms have recently been developed and will be trialed shortly as a means to overcome the split incentive problem. Furthermore, collaboration and lobbying activities among wind propulsion technology providers are emerging which could increase the visibility and legitimacy of wind propulsion in international shipping. Lastly, it should be made clear that without the great drive and commitment of entrepreneurs, no TIS on wind propulsion would exist. Comparing the amount of strength of structural barriers and drivers, it is clear that the former supersede the latter which is not surprising given that the overall TIS performance for wind propulsion was previously estimated to be poor.

The fourth sub-question asked *What capacities does the International Maritime Organization have to influence the factors that hamper or stimulate the development and diffusion of wind propulsion in international shipping?* Based on academic articles and some interview statements, the analysis of the IMO's governing capacities has shown that the work of the IMO is driven by its member states and mainly restricted to advisory and technical work. It perceives itself as a neutral knowledge broker and discussion facilitator rather than a political actor. Even though the IMO is overall largely independent from other UN organizations, it shares institutional responsibility with the UNFCCC on the topic of climate change. The contradictory core principles underlying these two organizations have blocked the negotiations on an effective policy response to climate change. The IMO's budget is tight, but it disposes over great technical knowledge resources both in- and outside the organization. Knowledge dissemination mechanisms exist in the form of a large publication department and three knowledge institutes under the auspices of the organization. It is assumed that the organizational culture is characterized by pragmatism, conservatism and a resistance to change. In a second step, these findings were combined with the previously identified functions which should be accorded highest policy priority - Knowledge development, Knowledge diffusion and Resource mobilization. The analysis has shown that the IMO is well-suited to promote the development and diffusion of knowledge on wind propulsion and it was suggested that it establishes a working or correspondence group where actors could jointly generate knowledge and exchange experiences. This would also increase the visibility and legitimacy of wind propulsion technologies in the maritime industry. However, the IMO is less suited to mobilize resources for TIS actors. Nonetheless, it was argued that the introduction of a MBM would not only increase viability of wind propulsion, but also the funds generated from the MBM could be used to invest in research and development activities on radical low-carbon propulsion technologies. In order to bridge the time until the future introduction of an MBM, it was suggested to establish a fund similar to a Multi-Donor Trust Fund, which would be financed by international donor institutions (e.g. World Bank, Global Environment Facility), national governments and industrial parties and would be used to further finance research and development on radical low-carbon propulsion, e.g. wind power.

Referring back to the main research question, this means that even though the IMO's capacities to promote the uptake of wind propulsion in international shipping are limited, possibilities still exist. The organization can establish a working or correspondence group on wind propulsion and thereby not only foster knowledge development and diffusion, but also the creation of legitimacy. It can also intensify efforts to introduce an MBM as these would increase the viability of wind propulsion and use the funds generated from this instrument to invest in R&D on radical low-carbon propulsion technologies. For the same purpose, it can set up an interim multi-donor fund to bridge the time until an MBM was introduced and started to show the desired effects. If the IMO proves to be willing and able to act on these recommendations, then the answer to the problem of GHG emissions from shipping might be blowin' in the wind.

10.2 Reflections on theoretical approach and research methods

In this research, the development and diffusion of wind propulsion technologies was analyzed by means of the technological innovation system's approach. This theoretical perspective was well-suited to evaluate the performance of the TIS for wind propulsion in terms of function fulfillment and identify the structural drivers and barriers that influence TIS development. This was reflected by the fact that all important developments as well as the structural drivers and barriers could be linked to one of the seven functions. Furthermore, experts working in the field of wind propulsion considered all seven functions to be at least somewhat if not very important to further TIS development.

In order to formulate policy recommendations targeted at a specific actor, the TIS analysis was extended by the governing capacities framework borrowed from the literature on international environmental governance. This is new to TIS research which up until now has provided relatively broad and untargeted policy recommendations. It is believed that such a combined approach can result in policy recommendations that are more likely to be implemented by the recipient because they consider its possibilities and limitations to enable change. The analysis of governing capacities of the IMO provided great insights and allowed to match recommendations with actual actor capacities. However, the biggest challenge encountered with using both the TIS perspective and the governing capacities framework was a lack of theoretical integration. Not all of the governing capacities could be clearly linked to the mitigation of barriers and acceleration of drivers. Furthermore, the transition between both perspectives was not as seamless as it could have been if the perspectives were more integrated.

With regard to the research methods, the event analysis has sown some limitations. While it helped identify the structural components of each TIS and understand the dynamics that have driven or hindered its development in the past, it did not provide sufficient insights into current dynamics of the three TIS in question. Therefore, semi-structured expert interviews were conducted. Another challenge was the allocation of events to functions because the distinction between the different functions was not always sharp. Furthermore, not all events were found to be equally important yet in the event allocation they are given the same weight. A possible solution to this problem could be to rate events according to their importance, e.g. with regard to expectations, it would be possible to analyze the importance of the person voicing them within the TIS. However, the greatest problem encountered was lack of data. This problem relates not so much to the event analysis as such, but rather to the industry to which it was applied. Only few newspaper articles discuss the shipping industry in general or the introduction of innovative low-carbon technologies in particular. This might be explained by the fact that shipping serves businesses (B2B industry) rather than end consumers (B2C) and is therefore of less interest to the general audience of newspapers. If this is the case for other B2B industries as well, it would suggest that the event analysis is less suitable for studying innovations in B2B industries but should be limited to research on technologies emerging in a B2C context. To make sure the evaluation of function fulfillment was not distorted by this lack of data, an expert survey was conducted which matched the function assessment of the event analysis relatively well. Overall it was found that by using this three-pronged research approach, the short-comings of the event analysis could be overcome. However, due to a lack of integration of the different research methods, it proved difficult at times to combine the different findings with each other and create smooth transitions.

10.3 Recommendations for further research

With regard to theoretical research, it is suggested to address the shortcomings and limitations of the theoretical approaches and research methods identified in the previous section. Above all, it would be helpful for further empirical research if both research perspectives were integrated into an overarching theoretical framework that determines which governing capacities are needed to stimulate the fulfillment of specific functions. Similarly, further integration and harmonization of the different methods available to study TIS development would be helpful. Moreover, consideration should be given to improve the allocation of events to functions by sharpening the distinction between function indicators and by introducing importance indicators for events.

As for empirical research, this study has shown that more technical and operational knowledge is needed on wind propulsion technologies. Regarding social sciences, it sought to identify possibilities to promote the uptake of these technologies, yet due to limited time availability, these possibilities had to be confined to one single actor – the IMO. It would therefore be interesting to identify the capacities and thereby possibilities of other TIS actors, e.g. environmental NGOs or maritime states, to promote the uptake of wind propulsion.

Ultimately, wind propulsion technologies are only one means to achieving significant emission cuts in the shipping industry. In order to promote a transition towards low-carbon shipping, it is recommended to conduct similar research for other low-carbon propulsion technologies or energy sources, such as biofuels and hydrogen. Last but not least, the research on low-carbon shipping would benefit from insights into the dynamics underlying the successful market introduction of innovations within the maritime industry. This would allow for the establishment of benchmarks against which the development of radical low-carbon technologies could be assessed.

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Appendices

Appendix A: Survey

Please rate the following statements on a 1 to 5 scale, where 1 means "I strongly disagree" and 5 "I strongly agree".

On a 1 to 5 scale, where 1 means “not important” and 5 “very important”, please tell me how important the following statements are for the development and uptake of wind propulsion technologies.

- There are enough entrepreneurial activities within the development of wind propulsion technologies.
- There is enough scientific knowledge on wind propulsion technologies (e.g. R&D activities, laboratory trials…).
- There is enough practical knowledge on wind propulsion technologies (e.g. practical trials with prototypes).
- The knowledge on wind propulsion technologies is exchanged easily among actors working in the field of wind propulsion technologies.
- The knowledge on wind propulsion technologies is exchanged easily among actors within the shipping industry.
- Clear positive signals generate interest in wind propulsion technologies (e.g. policy measures, voicing of positive expectations regarding technologies).
- Public support schemes exist that effectively incentivize the use of wind propulsion technologies (e.g. tax incentives, subsidies…).
- Enough financial resources are available for the development of wind propulsion technologies.
- Enough human resources are available for the development of wind propulsion technologies.
- The physical infrastructure is sufficient for the development of wind propulsion technologies.
- Coordinated actor groups lobby in favor of wind propulsion technologies.

Appendix B: List of interviewees

Name[16]	Company/Organization
Allwright, Gavin	The Greenheart Project
Bertram, Volker	FutureShip
Boessenkool, Jasper	Maersk Maritime Technology
Coffin, Tim	Global Maritime Investment Group
Englebert, Patrick	Propelwind
Gilpin, Diane	B9 Shipping
Hughes, Edmund	International Maritime Organization
Kedziersky, Antoine and O'Leary, Aoife	Transport & Environment
Kimmins, Sam	Sustainable Shipping Initiative
Kuehl, Henning	Skysails
Manzel, Siegfried	Energy Ship
Smith, Tristan	University College London
Van der Laar, Fer	International Association of Ports and Harbors
Xypolitha, Kalliopi	Zodiac Maritime Agencies

[16] The listing of interviewees does not correspond to the numbering in the text. The number allocation has been done randomly and the allocation scheme remains with the author.

Appendix C: Interview questions

1. Which wind propulsion technology do you think is the most viable?

2. What are the main reasons for ship owners to consider wind energy?

3. What are the main reasons wind is not used much more already/again? What are the barriers to the uptake of the different technologies?

4. How do you think these barriers could be mitigated? And who could help doing so?

5. What is the role of the IMO in mitigating these barriers and in promoting the uptake of these innovative technologies?

6. What do you think about the IMO measures to regulate GHG emissions from shipping?

7. Do you think there are sufficient entrepreneurial activities in the technology field of wind propulsion? Which actors are active in the field of wind propulsion technologies? Is there cooperation between the different actors? If so, what does this cooperation look like?

8. Do these actors have enough resources at their disposal (e.g. financial, human capital, infrastructure, etc.)? Do you think that more resource endowment would accelerate technology development and diffusion?

9. Do you think there is enough knowledge about the different technologies? Where are knowledge gaps and how are actors trying to fill these?

10. Is the existing knowledge diffused among actors, not only within the field of wind propulsion, but also amongst actors within the maritime industry? Are the actors aware of these technologies? How does knowledge exchange happen?

11. What are the expectations of actors within the maritime industry regarding wind propulsion? Is there a clear vision with regard to the technological transition pathway?

12. Are there any financial or other incentives (e.g. specific regulations) in place that promote the uptake of these technologies?

13. Is there a lot of resistance amongst industry actors with regard to the uptake of these technologies? Are there actors trying to break this resistance?