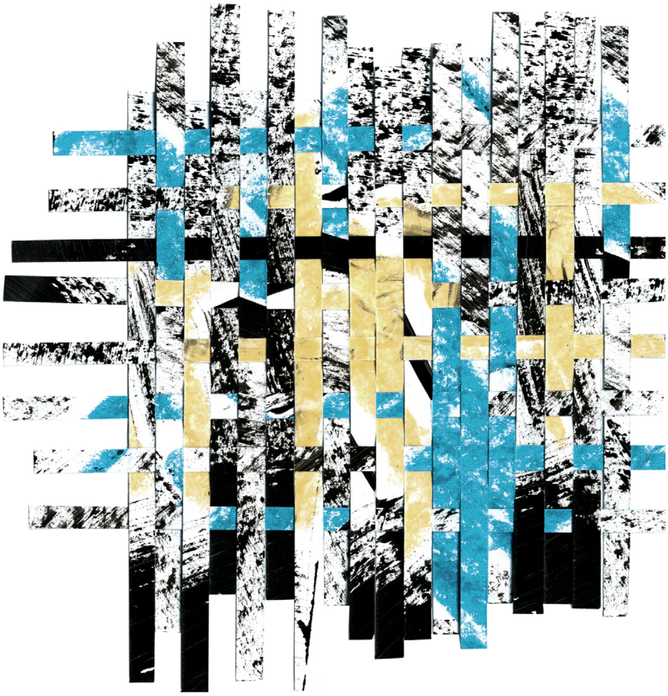
CHALMERS



On national technology policy in global energy transitions
The case of Swedish marine energy

JOHNN ANDERSSON

Department of Technology Management and Economics
CHALMERS UNIVERSITY OF TECHNOLOGY
Gothenburg, Sweden 2017

THESIS FOR THE DEGREE OF LICENTIATE OF PHILOSOPHY

On national technology policy in global energy transitions

The case of Swedish marine energy

JOHNN ANDERSSON

Division of Environmental Systems Analysis

Department of Technology Management and Economics

CHALMERS UNIVERSITY OF TECHNOLOGY

Gothenburg, Sweden 2017

On national technology policy in global energy transitions:

The case of Swedish marine energy

JOHNN ANDERSSON

Licentiate thesis report no. L2017:089

ISSN 1654-9732

Division of Environmental Systems Analysis

Department of Technology Management and Economics

Chalmers University of Technology

SE-412 96 Gothenburg

Sweden

Telephone + 46 (0)31-772 1000

Cover picture by Linn Schildt:

[The cover picture is a suggestive drawing inspired by the author's countless reflections, monologues and arguments about reality and what it ought to be.]

Chalmers Reproservice

Gothenburg, Sweden 2017

economics is all about
how people make choices;
sociology is all about
how they don't have any choices to make

James Duesenberry, 1960

ABSTRACT

Mitigating climate change and achieving sustainable development requires a rapid global transition to a low-carbon energy system. Policymakers therefore promote new renewable energy technologies, while also aiming to create localized environmental and socioeconomic benefits. However, the latter may be challenging in today's globalized economy where innovation is an increasingly international phenomenon.

The purpose of this research is to increase the understanding of how national governments can promote and benefit from the global energy transition. This thesis makes a contribution towards this objective by examining innovation in marine energy technology from a Swedish policy perspective. It takes the technological innovation systems approach as a theoretical starting-point and aims to reveal intra- and transnational innovation dynamics, derive implications for policymakers, and develop theory to account for these insights.

The thesis concludes that an informed political direction was needed to accelerate innovation in Swedish marine energy, and argues that determining the appropriate direction requires assessments of domestic market and export potentials in relation to the policy rationales that motivate public support. By focusing on tidal kite technology, the thesis demonstrates that the presence of critical knowledge and competence has so far favored developments in Sweden. However, the analysis also shows that the location of markets will become increasingly important and create a tendency for industrialization abroad. Therefore, an export-focused political direction should involve strengthened incentives for domestic development. In addition, the results emphasize that there is a need for international policy coordination to promote global innovation in marine energy.

Finally, the thesis makes a theoretical contribution by highlighting the interdependence of problems in the innovation process, suggesting conceptual developments of the technological innovation systems framework and introducing an explicit regional policy perspective to analysis of technological innovation. It also argues that policy-oriented analyses of new technologies should move towards employing spatially sensitive analytical goals and scenario-based thinking.

Keywords: technology policy; innovation policy; energy transitions; sustainability transitions; technological innovation systems; marine energy technology; tidal kite technology

LIST OF INCLUDED ARTICLES

Article 1

Andersson, J., Perez Vico, E., Hammar, L., Sandén, B.A., 2017. The critical role of informed political direction for advancing technology: The case of Swedish marine energy. Energy Policy 101, 52–64.

Johnn Andersson designed and performed the empirical investigation and subsequent analysis in close collaboration with Eugenia Perez Vico, and with support from Linus Hammar, for the purposes of a book chapter. The study was elaborated and refined to a research paper by Johnn Andersson, with support from Eugenia Perez Vico, Linus Hammar and Björn Sandén.

Article 2

Andersson, J., Hellsmark, H., Sandén, B.A., 2017. The spatial nature of innovation: Localized drivers and benefits of tidal kite technology development. Submitted to Technological Forecasting and Social Change in February 2017 (currently under review).

Johnn Andersson designed and performed the empirical investigation and subsequent analysis, and wrote the manuscript, with support from Hans Hellsmark and Björn Sandén.

OTHER PUBLICATIONS BY THE AUTHOR

Perez Vico, E., Andersson, J., Hammar, L., 2014. Marin energi, in: Hellsmark, H., et al. (Eds.), Teknologiska innovationssystem inom energiområdet: En praktisk vägledning till identifiering av systemsvagheter som motiverar särskilda politiska åtaganden. ER 2014:23. The Swedish Energy Agency.

ACKNOWLEDGEMENTS

The work presented in this thesis would not have been possible without the warm, welcoming, dedicated, and intelligent research environment at the Division of Environmental Systems Analysis. In particular, I would like to thank my supervisors Björn Sandén and Hans Hellsmark for providing guidance, advice and encouragement; Eugenia Perez Vico for luring me back to Chalmers and reintroducing me to the sustainability transitions field; and Carina Hedberg for smilingly making things run smoothly. I also gratefully and proudly acknowledge financial support from the general public in Sweden, mediated by the Swedish Energy Agency. Finally, I want to give my unconditional love to the people that challenge my rocksteady preconceptions and principles; to the beings whose eyes teach me the meaning of consciousness and keep my feet firmly on the ground; and to the nature that gives me perspective and energy to keep working for what I believe in. You know exactly who you are.

TABLE OF CONTENTS

1 INTRODUCTION

A growing population and increased material wellbeing, coupled with a strong dependence on fossil energy and technologies with high environmental impacts, have led to a situation where we simply live beyond planetary boundaries (Rockström et al., 2009; Steffen et al., 2009). One of the most pressing sustainability challenges is global warming caused by human carbon emissions, which affect and potentially destabilize the complex climate system upon which both human societies and ecosystems depend (IPCC, 2014). Avoiding the worst consequences of climate change and achieving a more sustainable development requires a rapid transition to a low-carbon energy system within decades (IPCC, 2014; Rockström et al., 2017). This involves replacing fossil energy sources such as oil, gas and coal with renewables, based on solar insolation, winds, waves, water currents, geothermal processes or biological systems, in order to produce heat, electricity, chemicals, materials as well as other goods and services (IPCC, 2012).

An energy transition is not only necessary to limit global warming, but will also contribute to mitigating other global environmental problems such as ocean acidification (Doney et al., 2009) and biodiversity loss (Spangenberg, 2007). In addition, it will result in different types of localized benefits. For example, regions in which renewables are used to replace fossil energy may increase their energy security and reduce local pollution (GCEC, 2015; IPCC, 2012; IRENA, 2017, 2014). Also, industries that develop and produce renewable energy technology will become important drivers of economic development, which for some regions will result in new jobs, increased tax revenues and knowledge spillovers to other industries (ibid).

Among the many actors involved in the energy transition, governments on different levels play a key role by supporting innovation in new technologies that may accelerate the pace of change and facilitate a low-carbon energy system (Mazzucato and Semieniuk, 2017; UNEP, 2017). These efforts are driven by a desire to contribute to the energy transition while appropriating some of the associated localized benefits, which entails that government support to research, development and demonstration (RD&D) leads to domestic technology deployment and/or industrialization (IRENA, 2014; Joas et al., 2016). However, in a globalized economy, where innovation, production and consumption are increasingly international phenomena, it is not certain that new technologies are used and/or produced in the same region from which they originated (Binz et al., 2017; Bunnell and Coe, 2001; De Backer et al., 2017; Ernst, 2002; Lovdal and Moen, 2013; Quitzow, 2015). Instead, early-stage innovation support by public actors in one region may enable the emergence of technologies that are predominantly used and produced abroad as they advance towards large-scale diffusion. This represents a situation where public investments contribute to global developments without leading to any domestic appropriation of localized benefits, which implies challenges for national governments that aim to both promote and benefit from the global energy transition.

1.1 Theoretical point of departure

Analyses that intend to inform policymaking for supporting innovation in new technologies have traditionally been dominated by neoclassical economic theory and the concept of market failure, but this approach is increasingly criticized (Bleda and Del Rio, 2013; Jacobsson and Johnson, 2000; Mazzucato and Penna, 2016; Smith, 2000). Scholars in the sustainability transitions field have instead developed more systems-oriented concepts, models and frameworks, based on a more realistic understanding of innovation and technological change (Coenen and Díaz López, 2010; Markard et al., 2012). One of these is the technological innovation systems (TIS) framework, which focuses on specific technologies. It underlines the collective, cumulative and uncertain nature of innovation, and offers tools for analyzing strengths, weaknesses and dynamics in the innovation process (Bergek et al., 2008a; Carlsson and Stankiewicz, 1991; Hekkert et al., 2007). This makes the TIS framework an appropriate approach for analyzing the development and diffusion of new technologies from a policy perspective (Binz et al., 2014; Jacobsson and Bergek, 2011; Markard et al., 2015; Truffer, 2015), and it is therefore used as a theoretical point of departure for this research.

1.2 Empirical focus

This thesis focuses on marine energy technology that produces power from ocean waves and tides (IPCC, 2012).[1] Marine energy may eventually contribute to a low-carbon energy system, but the technology field is in an early development stage and still dependent on public support to advance towards commercialization (OES, 2015). Many different technology concepts are subjects to RD&D efforts, but there are very few power-producing installations. Moreover, innovation activity is global and involves actors from most parts of the world, although the UK plays a leading role as the host of the majority of testing and demonstration projects. Sweden is one of several countries that have promoted marine energy development through different policy measures and a number of promising device developers have emerged (Corsatea, 2014; OES, 2015). However, the domestic resource endowment and potential market is limited, which has made key actors look abroad to access funding, supportive policy schemes and suitable locations for testing and demonstration. Marine energy technologies

[1] There is no commonly agreed-upon definition of marine energy. In this thesis, however, marine energy refers to energy harnessed from ocean waves and tides, with the latter including both tidal streams and ocean currents. Accordingly, technologies such as offshore wind power, tidal barrage technology, ocean thermal energy conversion, salt gradient energy conversion, and current power from inland rivers are excluded from the concept.

developed in Sweden thus exhibit a high degree of internationalization in the innovation process. This highlights policy challenges related to appropriation of localized benefits (Løvdal and Neumann, 2011), since there is a risk that neither industrialization nor technology deployment occur domestically, even if Swedish technologies are successfully developed and diffused globally. Swedish marine energy is therefore an interesting case to explore for learning more about how national governments can combine an ambition to contribute to the global energy transition with a desire to appropriate localized benefits.

1.3 Purpose and aims

The general purpose of this research is to increase the understanding of how national governments can promote the global energy transition by supporting innovation in new renewable energy technologies, while at the same time appropriate some of the localized benefits. This thesis makes a contribution towards this objective by examining innovation in marine energy technology from a Swedish policy perspective, using the TIS approach. It aims to unfold intra- and transnational innovation dynamics, derive implications for policymakers, and develop theory to account for these insights. There is accordingly an empirical dimension in which knowledge about innovation in marine energy and associated policy challenges is developed in a predominantly Swedish context, as well as a theoretical dimension where these findings are used to develop and critically discuss the TIS framework.

The research is presented in two appended articles. Article 1 analyzes the development and diffusion of marine energy in Sweden up until 2014. It adopts a conventional TIS approach and focuses on identifying and analyzing problems in the innovation process. Article 2 concerns tidal kite technology, which is a specific marine energy technology concept that is developed by Swedish actors. It analyzes the global emergence of this technology from a Swedish policy perspective, focusing on how the resources provided by domestic and foreign regions have influenced its development in the geographical dimension. To enable this analysis, Article 2 also develops and demonstrates a variation of the TIS framework.

1.4 Scope and limitations

The thesis concerns innovation in marine energy technology, which refers to technologies used to produce electricity from ocean waves and tides. Renewable energy technologies that use the ocean in other ways, such as offshore wind power and ocean thermal energy conversion, are not included in the analysis. Moreover, the research concerns innovation and associated policy challenges, which implies that detailed analyses of marine energy technology as such, and the natural resources they exploit, are beyond the scope of this thesis. In addition, the research is performed from a Swedish policy perspective, which means that although other geographies are included in the analysis, there is a stronger focus on developments in Sweden.

As a case of an emerging technology field for which it may be difficult to appropriate localized benefits, Swedish marine energy is an appropriate research focus for building knowledge about how national governments can promote and benefit from the global energy transition. However, an important limitation of the thesis is the extent to which the generated knowledge is valid for other technologies and geographical contexts. This issue is further discussed in Chapter 5.

1.5 Thesis outline

After this introduction, the thesis unfolds in six chapters. Chapter 2 presents the theoretical foundations that the research builds upon. Chapter 3 introduces the research design by elaborating on marine energy technology as an empirical domain as well as by describing the research idea, analytical framework and methodology. Chapter 4 summarizes the appended articles and highlights their main results. Chapter 5 discusses empirical findings and policy implications as well as theoretical contributions and future research. Finally, Chapter 6 summarizes main conclusions.

2 THEORETICAL FOUNDATIONS

This research is concerned with *innovation,* which is a concept that is used extensively in many contexts to describe either the process of introducing something new or the novelty itself (OECD, 2005; Schumpeter, 1961). In this thesis, though, it will only be used in reference to the development and diffusion of new technology. *Technology*, in turn, is defined broadly as a set a procedures and tools, available to a culture, and used to fill a human purpose (Arthur, 2009). Any given technology thus consists of interconnected technical and social components with a common purpose, and may be conceptualized as a sociotechnical system (Sandén and Hillman, 2011). The terms 'technology' and 'sociotechnical system' are therefore used interchangeably. This broad definition of technology implies that innovation can happen on different scales; from improvements in minor components to large-scale transformations of societal infrastructure such as the power grid or the entire energy system.

Furthermore, innovation is examined from a policy perspective. The notion of *policy* is used to capture how publicly controlled resources are allocated in society as well as the rules and regulations that emerge from the democratic process. Policy is the result of complex and collective processes that involves actors on different levels, ranging from parliaments and government agencies, to research institutes and publicly owned companies (Flanagan et al., 2011). These policymakers differ in the objectives they pursue and the roles they play, and their interactions are governed by regulations, norms, values and beliefs that are specific to the policy context in which they are embedded (ibid.). This implies that the design and implementation of policies is highly situational and characterized by a multitude of specific interests. However, policy can still be conceived of as a systemic phenomenon that, through a complex process of negotiation, transforms public beliefs and values to policies that govern societal development (Sabatier, 1991). Being able to aggregate the interests of different policymakers to a higher level, and for instance talk about 'national policy' for a specific matter, is arguably necessary for the democratic system to function. After all, it is in local, regional, national and in some cases supranational elections that the public will is expressed, and not in relation to individual policymakers. When this thesis uses notions such as 'policymaking' and 'policymakers', it therefore refers to an aggregated system on a national or regional level, rather than to specific policy actors. The remaining part of this chapter describes the theoretical foundation upon which this research is built.

2.1 Drivers of national technology policy in renewable energy

Policymaking that aims to stimulate innovation in specific technologies can be referred to as technology policy[2], and may involve interventions such as funding RD&D, supporting market deployment, facilitating network formation and adapting the education system (Sandén and Azar, 2005). Technology policy thus consists of a mix of policy instruments that differ in their objectives, type, design and implementation (Borras and Edquist, 2013; del Rio and Howlett, 2013; Flanagan et al., 2011; Rogge and Reichardt, 2016). Moreover, there may be different reasons for why policymakers and other actors wish to promote a specific technology. In the renewable energy context, technology policy is at least in part motivated by a desire to contribute to the global low-carbon energy transition, in order to mitigate climate change and create other benefits that have a positive impact on the entire planet (EU, 2009; Joas et al., 2016). However, an additional driver, that may arguably dominate in many cases, is the possibility of appropriating some of the associated localized benefits, including strengthened energy security, reduced local pollution and economic development (EU, 2009; IRENA, 2014; Joas et al., 2016). It is also possible to distinguish between benefits that are created as a result of the utilization of a new technology[3] and benefits that relate to the enabling industrialization (i.e. development, production, installation and maintenance of technology). Table 1 provides a typology based on these two dimensions and summarizes potential benefits from successful innovation in new renewable energy technology.

Table 1. A typology and summary of potential benefits from successful innovation in new renewable energy technology.

	Benefits related to industrialization	**Benefits related to utilization**
Global impact	Strengthened global knowledge-base and economic development	Mitigation of climate change and related global environmental problems
Local impact	New jobs, tax income, knowledge spill-overs to other industries	Improved energy security, compliance with international agreements and mitigation of local pollution

[2] It should be noted that industrial policy, that aims to stimulate the growth of particular industries or economic sectors, is a subset of technology policy given a broad definition of technology, since an industry can be conceived of as a sociotechnical system that fulfills a human purpose (i.e. a technology). However, innovation policy in its pure sense is arguably different since it aims to enhance general innovation capability rather than to stimulate the growth of specific technologies.

[3] Or more specifically, at least in some situations, as a result of replacing an old technology.

2.2 Benefits appropriation and the localization of new industries

As a result of globalization, production processes are increasingly organized in global value chains, in which extraction of raw materials, production of intermediate and final products, and end-user consumption are dispersed across countries (De Backer et al., 2017). It is the geographical composition of these value chains that determines the distribution of localized benefits associated with a specific technology. However, since products, services, capital, knowledge and people are increasingly moving across national borders, it is not certain that new technologies are used and/or produced in the same region from which they originated (Binz et al., 2017; Bunnell and Coe, 2001; De Backer et al., 2017; Ernst, 2002; Lovdal and Moen, 2013; Quitzow, 2015). This implies that national technology policy may enable the global development and diffusion of a new renewable energy technology, while industrialization, utilization, or both, mainly occur abroad. In this scenario, there is limited domestic appropriation of localized benefits, even though public support has contributed to the global energy transition. This is clearly undesirable from a national policy perspective and poses additional challenges for national policymakers interested in promoting new renewable energy technologies; ideally, policy interventions should not only promote the development and diffusion of a new technology, but also stimulate domestic appropriation of localized benefits.

The issue of benefits appropriation has been discussed in relation to the German Energiewende and its extensive market deployment subsidies to photovoltaics. A common argument is that support policies have unintentionally led to industrialization in China, and that policymakers might fail to achieve objectives related to domestic economic development (Buchan, 2012; Grau et al., 2011; Paris Innovation Review, 2012). Although other scholars dismiss this reasoning as oversimplified, emphasize more complex transnational dynamics and highlight that the Energiewende has led to domestic industrialization as well (Pegels and Lütkenhorst, 2014; Quitzow, 2015), the German case still illustrates how emerging global value chains can follow unintended and unexpected spatial development trajectories that are not in line with national policy objectives.

The nature and composition of global value chains is studied in economic geography and related research fields (Krugman, 1991). A part of this literature tries to understand what determines the localization of economic activity in space, and often emphasizes the occurrence and importance of spatially concentrated agglomerations of firms, universities and other actors in an industry (see Malmberg and Maskell (2002) for a review). Although debated (Boschma, 2005; Hansen, 2015; Malmberg and Maskell, 2006), it is commonly accepted that geographical proximity is important for learning processes and increases the access to collective resources such as infrastructure, skilled labor pools and specific educations (Boschma, 2004; Howells and Bessant, 2012; Jaffe, 1993; Krugman, 1991; Malmberg and Maskell, 2002; Porter, 1998). This suggests not only that actors will locate their activities close to existing industrial agglomerations, but also that actors within them are more likely to be successful. In addition, new firms tend to emerge from within these agglomerations, as spinoffs from universities and established firms (Boschma and Lambooy, 1999). The result is spatial path dependencies that makes new industries "sticky"; once an industrial agglomeration has formed around an emerging technology, further industrialization tends to gravitate towards it. This effect is more pertinent for knowledge-intensive economic activities such as research and development (R&D) and advanced manufacturing (Howells, 2002), and may also depend on the type of knowledge that different industries build upon (Asheim et al., 2011). It has, for instance, been argued that industries based on synthetic knowledge (i.e. wind power), characterized by recombination of prior experience-based knowledge and competence, are spatially stickier than industries more based on analytical knowledge (i.e. photovoltaics), characterized by scientific principles and codification (Binz et al., 2016). Similarly, Huenteler et al. (2016) demonstrates the importance of technology deployment and user-producer relationships for innovation in complex products and systems, due to the localized nature of learning processes.

Although this research provides important insights about the spatiality of global value chains, it does generally not make an explicit connection between the localization of new industries and the regional appropriation of benefits from successful innovation. Benefits appropriation is instead mainly discussed from a firm perspective and particular attention is given to the distribution of returns from investments in R&D, patentability and intellectual property. (Jacobides et al., 2006; McGahan and Silverman, 2006; Milesi et al., 2013; Ritala et al., 2015; Teece, 1986).[4] A large body of literature also attempts to understand what makes firms and industries in particular regions successful, by identifying the key drivers of competitive advantage (see for example Porter, (1990)). However, the focus is most often on innovation within established industry sectors rather than the emergence of new technologies. An important exception is the recent work by Mariana Mazzucato and colleagues (Lazonick and Mazzucato, 2013; Mazzucato, 2016, 2015a; Mazzucato and Penna, 2016). By studying historical cases of large-scale technological change, they show that government intervention is an essential enabler for the development and diffusion of new technologies, highlight that the financial rewards from successful innovation tend to be appropriated by private actors, and argue that policy interventions should be designed to promote a stronger connection between risks and rewards. However, though this part of the literature is very much in line with the topic of this thesis, it focuses on an intra-national context and only discusses the international distribution of benefits in passing.

---

[4] The distribution and spillover of policy-related benefits are also discussed in welfare, development and international economics (Ali and Fan, 2007; Arze del Granado et al., 2012; Bibi and Duclos, 2007; Buys et al., 2004; Canning and Vroomen, 1996; Lin and Jiang, 2012), but the focus is generally not on benefits related to technological innovation.

2.3 Systems-oriented approaches to understanding technological innovation

Designing policymaking aimed at promoting new technologies involves identifying 'problems' in the innovation process (Borras and Edquist, 2013). They may be formulated as weaknesses, blocking factors or failures, but essentially refer to something that stands in the way of enhanced innovation performance. By implementing policies that target these issues, policymakers can, potentially, promote innovation. Until fairly recently, the dominating rationale for identifying problems in the innovation process and justifying policy intervention has been the market failures approach, which implies that the role of policy should be to create efficient markets (Smith, 2000). It has, however, been criticized for its unrealistic assumptions about the nature of knowledge and learning processes, and for downplaying the crucial role of policymakers in the development and diffusion of new technologies (Bleda and Del Rio, 2013; Jacobsson and Johnson, 2000; Lazonick and Mazzucato, 2013; Metcalfe, 1994; Smith, 2000).

As a response, alternative approaches to analyzing technological innovation have been proposed in the sustainability transitions literature, which attempts to understand fundamental transformations of sociotechnical systems. They commonly view the economy as a dynamic system, characterized by increasing returns and positive feedback (Bergek et al., 2008b; Geels, 2005a). Innovation is understood as a collective endeavor, involving a multitude of actors that engage in complex and cumulative learning processes (Bergek et al., 2008a; Markard and Truffer, 2008). The influence of institutions on the innovation process is emphasized and often put central to the analysis, and phenomena such as interdependence, path dependency and lock-in are widely acknowledged (Arthur, 2009; Carlsson et al., 2002; Geels, 2005a; Unruh, 2000). In addition, they do not only view policy intervention as justified and desirable for successful innovation, but are also often geared towards informing policymaking, by offering a broader systems failures approach to identifying problems in the innovation process for specific technologies (Bergek et al., 2008a; Jacobsson and Johnson, 2000; Klein Woolthuis et al., 2005; Weber and Rohracher, 2012).

Four interrelated and somewhat overlapping analytical frameworks have so far achieved some prominence (Markard et al., 2012; Markard and Truffer, 2008). The *multi-level perspective (MLP)* (Geels, 2005b, 2002; Geels and Schot, 2007; Kemp et al., 1998) is concerned with how innovation leads to large scale transitions, and focuses on the tension between existing and emerging sociotechnical configurations. It conceptualizes sociotechnical transitions in terms of a regime that refers to the established sociotechnical system, a landscape that constitutes an exogenous context, and niches in which new technologies develop. The fundamental idea behind the MLP framework is that landscape forces and niche developments may destabilize the regime, disrupt tendencies for incremental innovation along established development paths, and allow for the emergence of new technologies (Geels, 2002). Based on this conceptualization of sociotechnical transitions, the *strategic niche* *management (SNM)* framework (Kemp et al., 1998) is a more policy-oriented approach. It suggests the deliberate creation and support of niches in which new technologies can develop and gain momentum so that they may eventually compete with the prevailing regime. In the same vein, *transitions management (TM)* (Kemp and Loorbach, 2006) prescribes reflexive and inclusive policy approaches, by emphasizing the complex, evolutionary and multi-stakeholder characteristics of existing and emerging economic sectors. Finally, the *technological innovation systems (TIS)* framework focuses on innovation activity in specific technologies (Bergek et al., 2008a; Carlsson and Stankiewicz, 1991). This means that slightly less attention is given to their sociotechnical context (i.e. the regime), which instead enables a more refined analysis of the dynamics, strengths and weaknesses in the innovation process. The TIS framework is accordingly a suitable starting-point for the research presented in this thesis, although MLP provides an insightful conceptualization of the wider transition context in which the technologies in focus emerge.

2.4 The TIS framework

The TIS framework is based on evolutionary economic theories (Markard and Truffer, 2008) and has strong linkages to other innovation systems approaches that focus on nations (Lundvall, 1992), regions (Cooke et al., 1997) and sectors (Malerba, 2002). Building on the notion of technological systems proposed by Carlsson and Stankiewicz (1991), a TIS is commonly defined as a sociotechnical system focused on the development, diffusion and use of a particular technology (Bergek et al., 2008a, 2008b; Hekkert and Negro, 2009; Jacobsson and Bergek, 2004).[5] It exists in a context consisting of other emerging technologies, established industry sectors and broader societal systems such as the political, financial and education systems (Bergek et al., 2015). Defining a TIS thus involves setting a system boundary in the sociotechnical dimension, apart from specifying its geographical and temporal reach.

As a sociotechnical system, a TIS consists of social and technical components that can be categorized and described in different ways (Bergek et al., 2008a; Geels, 2002; Hughes, 1987; Sandén and Hillman, 2011). The conceptualizations available in the literature arguably attempt to capture the same underlying phenomenon; namely that the world seemingly consists of physical objects that are either inert (i.e. artifacts) or have some kind of individual or collective agency (i.e. actors). These physical objects interact systemically under the influence of rules that may be socially constructed (i.e. institutions), and exist as beliefs and values embedded in actors or as mechanisms and codes embedded in artifacts, or constitute fundamental characteristics of nature (such as the force of gravity). This thesis therefore adopts the view that artifacts, actors and rules are the fundamental structural components of a TIS (see

[5] The literature is somewhat vague about whether a TIS is a system that delivers the function of the technology in focus (i.e. electricity or transport) or merely describes the innovation activities within such a system (see Bergek et al. (2008b)).

Sandén and Hillman (2011) for a similar view). Artifacts include physical objects that constitute or enable the development of the technology in focus (i.e. machine components, testing infrastructure etc.) as well as ones in which codified knowledge is embedded (i.e. papers, hard drives etc.). Actors comprise firms, universities, research institutes, governments, public agencies and other organizations, but also individuals that may act as entrepreneurs, experts or parts of larger groups. Finally, rules consist of fundamental forces and characteristics of nature together with socially constructed regulative, normative and cognitive procedures. The latter are embedded in formal laws, regulations and standards as well as in informal norms, values and beliefs. In addition, it should be noted that system properties such as knowledge, networks and institutions are often highlighted as structural components in the literature (Bergek et al., 2008a; Jacobsson and Johnson, 2000). Here, however, they are viewed as properties that emerge from the interplay of artifacts, actors and rules, which is by no means intended to downplay their importance for the innovation process.

A central proposition in the TIS literature is that few of these structural components are in place when a new technology emerges (Bergek et al., 2008b). Analyses of TISs therefore tend to be geared towards understanding how their structure develops over time through the entry, accumulation and alignment of artifacts, actors and rules (Bergek et al., 2008a, 2008b; Hekkert et al., 2007; Hekkert and Negro, 2009). To better capture the multifaceted and dynamic nature of this process of structural build-up, the TIS approach includes analyzing the performance and interdependence of a set of sub-process, commonly referred to as functions (Bergek et al., 2008a; Hekkert et al., 2007). Although functions can be defined, grouped and interpreted somewhat differently (Markard and Truffer, 2008), they tend to revolve around processes that describe the creation, development, mobilization and availability of essential innovation elements such as knowledge, financial capital, infrastructure, legitimacy and markets (Bergek et al., 2008a; Hekkert and Negro, 2009).

Structure and functions can thus not be separated but rather highlight the composition and performance of the system as two different aspects of the same phenomenon. Analyzing a TIS from these two perspectives makes it possible to describe the emergence of new technologies as well as to reveal strengths, weaknesses and dynamics in the innovation process (Bergek et al., 2008a). This may in turn inform the design of policies aimed at stimulating technological innovation.

The TIS literature has, however, been criticized for paying too little attention to the geographical dimension of innovation (Binz et al., 2014; Coenen et al., 2012; Markard et al., 2012; Raven et al., 2012; Truffer and Coenen, 2012), even though TISs fundamentally, and in contrast to national and regional innovation systems approaches, transcend territorial boundaries (Bergek et al., 2008a; Carlsson et al., 2002; Carlsson and Stankiewicz, 1991). As the research presented here will show, this is particularly problematic when analyzing technologies from the perspective of regional policymaking that aims to appropriate localized benefits of successful innovation, but also something that opens opportunities for theoretical contributions.

3 RESEARCH DESIGN

Guided by the theoretical foundation established above, this chapter provides an overview of marine energy technology[6] and describes the more specific methodology used for analyzing this empirical domain.

3.1 Marine energy technology as an empirical domain

Marine energy technologies are intended to produce electricity from ocean waves and tides, with the latter including both tidal streams and ocean currents. Accordingly, other technologies associated with the marine environment, such as offshore wind power, tidal barrage technology, ocean thermal energy conversion, salt gradient energy conversion and current power from inland rivers, are excluded from the concept.[7] Marine energy has a physical resource potential estimated at about 90 000 TWh per year, but only a minor part can be exploited due to technical, economic, social, and ecological constraints (Sandén et al., 2014a). The realistically expected level of deployment is highly uncertain (IPCC, 2012) and has been estimated at a few hundred (Sandén et al., 2014a) or thousand (Carbon Trust, 2012) TWh per year. While the global potential is not very impressive compared to solar and wind energy, it is quite substantial in some coastal regions (IPCC, 2012; Rourke et al., 2010). For example, marine energy is estimated to be able to meet 20% of the current UK electricity demand (Carbon Trust, 2011).

A distinguishing feature of the marine energy resource is that it is localized in several respects. Firstly, deploying the technology requires access to a part of the ocean, which for countries usually implies having a coastline. Secondly, this part of the ocean must have suitable waves or currents that can be harnessed with available technologies. And thirdly, the sites where these waves or currents exist should be accessible, in the sense that it is physically, economically, socially and ecologically feasible to deploy marine energy power plants. This localized nature of the resource is to some extent shared with renewables in general, but the differences in resource potential between regions are larger for marine energy than for solar, wind and bioenergy technologies (IPCC, 2012).

The Swedish potential for marine energy is limited relative to several other European countries. Still, a number of promising technology concepts are developed by Swedish actors, there are world-class research activities, domestic industries offer relevant capabilities and competences, and policymakers offer quite substantial innovation support. Innovation activity has been dominated by Uppsala University and its spin-off company Seabased. These actors engage in the development of a specific

[6] For a more thorough description of the marine energy technology field the reader is referred to Article 1.

[7] It should be noted that there is no commonly agreed-upon definition of marine energy.

technology concept for wave power, which has been tested extensively in Swedish waters. Minesto, an industry spin-off, develops a technology concept for tidal power, which has also come quite far in its development. What makes this concept particularly interesting is that Sweden completely lacks a suitable resource endowment. This rules out not only a domestic commercial market, but also ocean testing and demonstration activities. Minesto has therefore established a test center in the UK, although most R&D activities are located in Western Sweden. In addition to these leading Swedish actors, a number of other technology concepts have attracted funding and engage researchers and entrepreneurs, although at a substantially smaller scale.

Worldwide, hundreds of marine energy technology concepts are being developed and technological diversity is high (EMEC, 2014; Magagna and Uihlein, 2015; OES, 2015). Most technology concepts undergo conceptual development and small-scale sea trials, and only a handful have been tested and demonstrated at full scale. There are accordingly very few power-producing installations; the total installed capacity only amounted to about 13 MW in 2014 (OES, 2014), which is less than 1% of that for offshore wind the same year (IEA, 2016). However, with consented projects exceeding 200 MW, it can be expected to increase significantly in coming years (see Figure 1 in Article 1).

Despite the early development stage, many national governments promote the sector by setting national deployment targets, making detailed resource assessments, providing market incentives such as feed-in tariffs, establishing open test centers, and supporting RD&D (OES, 2015). However, the support offered to marine energy constitutes a very small fraction of the resources dedicated to other renewables (UNEP, 2017). The UK is widely considered the world leader in terms of RD&D activity with over two-thirds of both installed and consented capacity, many involved actors, and a large number of scientific publications (Corsatea, 2014; OES, 2015). At the supranational level, the EU has highlighted its commitment to marine energy in its Blue Energy communication, and provides extensive funding for RD&D through various funding mechanisms (European Commission, 2014). This has led to strategic initiatives and collaborative RD&D projects with actors from several European countries including Sweden (Ingmarsson, 2014). Moreover, Ocean Energy Systems, an initiative under the International Energy Agency, promotes the sector by coordinating the activities of national governments, facilitating multinational R&D projects, and disseminating knowledge (OES, 2015).

Marine energy is accordingly an immature technology field. This is reflected in the global innovation activity, which is focused on conceptual development, testing and demonstration, and the active support by governments on different levels. Sweden seems to have a quite strong position as a technology developer with several globally leading actors, but the domestic market potential is small compared to other regions in Europe and beyond. This highlights policy challenges related to the issue of benefits appropriation, which makes Swedish marine energy an appropriate research case for building knowledge about how national governments can promote and benefit from the global energy transition.

3.2 Research idea and analytical framework

Although both articles in this thesis examine marine energy from a Swedish policy perspective, and use the TIS approach as a theoretical starting-point, the respective analyses differ in their research focus, system delineation and analytical framework. This is due to a learning process where results from Article 1 have not only informed the conclusions put forward in this thesis, but also inspired the research design and methodology used in Article 2, see Figure 1.

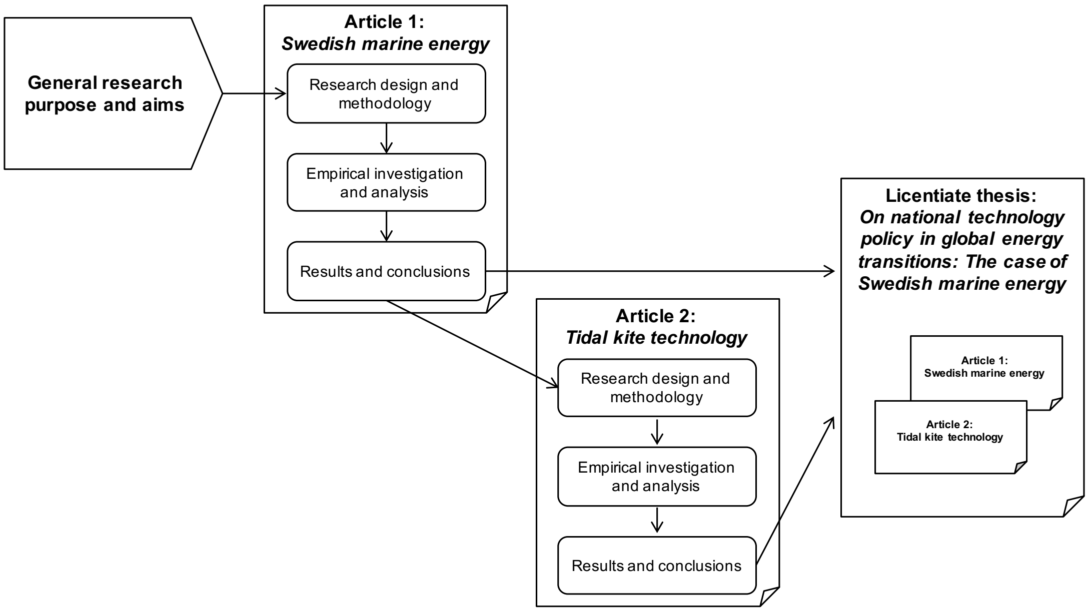


Figure 1. The relationship between the thesis, Article 1 and Article 2 in terms of research design and methodology.

As a quite general and empirically oriented starting-point, Article 1 aims to identify factors that block the development and diffusion of Swedish marine energy and discuss related policy issues. The analysis thus concerns the entire marine energy technology field, although its geographical scope is limited to Sweden. In Article 2, a step further is taken by limiting the scope to one specific marine energy technology concept, namely tidal kite technology. The reason is that a narrower system delineation in the technological dimension enables an analysis of the global innovation system, and also reveals more detailed transnational dynamics, than what is possible when looking at a broader technology field. Moreover, tidal kite technology further emphasizes the issue of benefits appropriation from a Swedish policy perspective, since a domestic resource endowment is lacking completely (and not just being very small which is the case when including wave power technologies). Finally, Article 2 has a more historical and narrow research focus, where the aim is to understand how the resources provided by domestic and foreign regions have influenced developments in the geographical dimension.

The two articles also employ slightly different analytical frameworks. Article 1 is based on a conventional TIS framework following Bergek et al. (2008a), whereas Article 2 develops and demonstrates a variation tailored for the specific research case and focus. The main difference is that an explicit regional policy perspective is introduced by defining domestic and foreign sub-systems within the global innovation system. In addition, TIS functions are interpreted and used to describe how new system structures are built-up through the development of key resources, and a somewhat simplified typology of functions/resources is used. Table 2 summarizes the research focus, system delineation and analytical frameworks used in the appended articles.

Table 2. Summary of the research focus, system delineation and analytical framework used in the appended articles.

		Article 1: Swedish marine energy	**Article 2: Tidal kite technology**
Research focus		Identifying factors that block the development and diffusion of Swedish marine energy	Revealing how resources provided by domestic and foreign regions have influenced the development of tidal kite technology
System delineation			
	Technological	Marine energy technology	Tidal kite technology (i.e. a specific marine energy technology concept)
	Spatial	Swedish innovation system	Global innovation system consisting of a domestic and foreign sub-system
	Temporal	Early 1900's to 2014	2004 to 2016
Analytical framework			
	TIS definition	Sociotechnical system that enables the development and diffusion of a new technology.	Sociotechnical system that enables the development, diffusion and utilization of a new technology.
	Structure typology	– Actors – Networks – Institutions – Technology	– Artifacts – Actors – Institutions
	Functions interpretation	Sub-processes that build system structures.	Sub-processes that describe how new system structures are built-up through the development of key resources that emerge from existing structures (in the TIS and its context).
	Functions/resource typology	– Knowledge development and diffusion – Entrepreneurial experimentation – Resource mobilization – Development of social capital – Legitimation – Influence on the direction of search – Market formation	– Knowledge – Competence – Enabling technology – Financial capital – Legitimacy – Markets

3.3 Methodology

As indicated above, the methodology used in this thesis is based on a case-study approach (Flyvbjerg, 2016). Swedish marine energy is chosen as a research domain due to its extreme characteristics regarding the issue of benefits appropriation, which are emphasized even more when focusing on tidal kite technology. The two articles thus constitute nested extreme cases that are used to develop situated knowledge about innovation dynamics and policy implications in their particular contexts. To a certain extent, these insights allow for generalizations and conclusions regarding other technological and geographical contexts, and they also inspire a thorough discussion of more general implications for policymaking and theoretical development.

The analysis is informed by a combination of interviews and desktop research. In total, 40 semi-structured interviews were conducted with entrepreneurs, large and small firms, researchers, interest groups, civil servants representing different policy actors, and other key informants. All interviews followed an open-ended interview guide that allowed for follow-up questions and reflections. They were also recorded and partially transcribed to enable structured analysis. Moreover, most interviews were conducted on the condition of anonymity and no interviewee identities are disclosed in the articles. Interviewees are, however, placed in broad categories and in some cases their more specific affiliation is revealed. In addition, the interviews were complemented with personal communications and direct observations during multi-stakeholder workshops organized as a part of a Swedish policy initiative for marine energy. The desktop research included overviews of relevant academic literature, official documents from public agencies, newspaper articles, press releases, industry reports and other communication materials as well as mappings of RD&D funding, patents and political initiatives.

The obtained data from interviews and desktop research were analyzed through a coding procedure. Categories from analytical frameworks, such as taxonomies of structural components, functions and resources, were used to organize information, identify events and causal links, and build narratives in relation to the research objective. In Article 1, the analysis focused on understanding current TIS structure as well as strengths, weaknesses and dynamics in TIS functions (Bergek et al., 2008a), whereas Article 2 followed an event history approach (Negro et al., 2007; Poole et al., 2000; Reichardt et al., 2016) that formed a narrative of historical structural build-up and its underlying drivers.

4 RESULTS

The results from this research is presented in two appended articles. In this chapter, they are summarized with an emphasis on their empirical findings, while policy implications, theoretical contributions and future work are discussed in Chapter 5.

4.1 Article 1: Swedish marine energy

The purpose of Article 1 is to identify factors that block the development and diffusion of Swedish marine energy and to discuss related policy issues. The analytical framework and methodology largely follow the seminal contribution by Bergek et al. (2008a). First, structural components, conceptualized as actors, networks, institutions and technology, are identified. Then, functions are analyzed in terms of their strengths, weaknesses, interdependencies and interactions with the system's context. The functions are interpreted broadly as sub-processes that build system structure, and a list of seven such sub-processes is used. The analysis identifies a set of interdependent blocking factors, which are further analyzed and used to derive policy issues. Empirically, the article is based on 25 semi-structured interviews, 6 short e-mail communications, direct observations during 3 multi-stakeholder workshops as well as extensive desktop research. The investigation is, however, limited to cover developments up until 2014.

Article 1 reveals that both the Swedish marine energy innovation system, and its global context, was at the time characterized by immature and expensive technologies. Although the domestic market potential is limited, several promising device developers had emerged together with world-class research activities, but established industrial actors and private investors remained passive. Public funding to the technology field had been substantial, although its allocation was questionable; coordination among policy actors was poor; and no visions, strategies, or roadmaps were in place. Among certain actor groups, social networks were strong with highly concentrated knowledge development, but there was a lack of knowledge diffusion, collaboration, and trust in the system as a whole. Finally, market incentives were insufficient to stimulate testing and demonstration.

There were accordingly a number of weaknesses in the functions that build system structure and result in the development and diffusion of Swedish marine energy. The weaknesses can be explained by seven blocking factors: limited test and demonstration activities; lack of knowledge and coordination among public actors; lack of collaboration among actors; passivity of established actors; small and uncertain domestic markets potential; lack of political direction; and insufficient markets incentives. Analyzing interdependencies in these blocking factors shows that the small and uncertain domestic market potential hindered the development of political direction, particularly around the crucial issue of whether policy interventions should aim to deploy marine energy technologies in Sweden or create an industry that can supply the global market. Simultaneously, the absence of political direction likely added to uncertainty regarding domestic market potential since policy had not played an active role in shaping expectations. The uncertainties created by these interrelated blocking factors had a number of dynamic impacts on the system, contributing to other blocking factors and thereby hindering the development of the technology field.

The analysis thus indicates that if policymakers wished to promote marine energy in Sweden in 2014, they primarily needed to address the lack of political direction and reduce uncertainties regarding domestic market potential. If these central blocking factors had been addressed, it is likely that the performance of the innovation system would have been enhanced through increased collaboration and strengthened engagement of established actors, which in turn could have mobilized resources, stimulated RD&D activities, and led to technological advancement.

4.2 Article 2: Tidal kite technology

The purpose of Article 2 is to analyze the emergence of tidal kite technology from a Swedish policy perspective, in order to increase the understanding of how resources provided by domestic and foreign regions influence how a new TIS develops in the geographical dimension. It employs a variation of the conventional analytical framework that usually guides policy-oriented TIS analyses. The main difference is that an explicit regional policy perspective is introduced by defining domestic and foreign sub-systems within the global innovation system. In addition, TIS functions are viewed as sub-processes that describe how new sociotechnical structures are built-up through the development of key resources that emerge from existing structures (Bergek et al., 2008b; Binz et al., 2015). The typology of resources is derived from the lists of functions commonly used in the TIS literature (Bergek et al., 2008a; Hekkert et al., 2007), but adapted for this particular study.

Given this system delineation and analytical framework, the article analyzes the emergence of tidal kite technology from its inception in 2004 until 2016, by adopting an event history approach (Negro et al., 2007; Poole et al., 2000; Reichardt et al., 2016). First, a timeline of events was constructed based on desktop research and 15 semi-structured interviews with key informants. Second, the events were used to map structural build-up over time, which made it possible to formulate a narrative of four episodes. For each episode, factors of domestic and foreign origin that influenced the mobilization of key resources were identified, which also revealed intra- and transnational innovation dynamics. The relative contribution by domestic and foreign regions was also qualitatively assessed for each resource, in order to highlight patterns and illustrate temporal and spatial differences. Finally, these insights were applied to the research question by examining the observed connection between regional structural build-up and resource provision, as well as by analyzing expected future developments.

The analysis shows that tidal kite technology started its development in Sweden, where early conceptual development activities was carried-out by Minesto in collaboration with universities, research institutes and industry. The innovation system then gradually branched out to the UK. Initially through the establishment of an ocean test site in Northern Ireland, but more recently in the form of preparations for a full-scale demonstration project in Wales. Currently, the system also shows signs of spreading to regions beyond Europe through Minesto's market development activities. Although this has implied that a number of international and UK actors have entered the system, including both research organizations and industry, Western Sweden has remained the main location of Minesto's growing R&D and management activities. Accordingly, this is still where the system has its center of gravity in terms of TIS structure.

Initially, the development depended almost exclusively on domestic resources such as knowledge, competence and legitimacy. After a few years, however, foreign regions started playing a role, at first mainly by providing legitimacy, but later by giving access to crucial ocean testing infrastructure. Still, domestic structures remained the main sources of knowledge, competence and financial capital. Finally, towards the end of the investigated period, foreign regions arguably started playing an equally important role as the domestic by providing financial capital, an early niche market as well as other key resources. However, the role of domestic structures was not diminished, since they remained important sources of financial capital, knowledge and competence.

The analysis suggests that the development of TIS structures in one region corresponds to the resources provided by its sociotechnical structures; Sweden has played a major role and this is also where the system currently has its center of gravity. However, when examining the observed dynamics more closely, it is clear that the mobilization of resources from one region does not necessarily mean that TIS structures, building on these resources, will be developed in the same place. For example, legitimacy derived from support by the UK Carbon Trust, as well as from earlier knowledge development and testing in the region around Linköping in central Sweden, mainly led to structural build-up in the Gothenburg area in western Sweden. Also, although Northern Ireland provided access to enabling technology, knowledge and competence in connection to ocean testing activities, which have arguably been key for the development of the system as a whole, this region has only seen limited structural build-up.

It arguably appears as if something has made the development of TIS structures gravitate towards Sweden, even though foreign regions have provided certain key resources. This suggests that knowledge and competence, which have to a large extent been mobilized domestically, are particularly decisive for the spatial development of TIS structure. An additional explanation is that early developments in Sweden, such as the basic invention and the incubation period at Chalmers, shaped the spatial development trajectory by creating early networks that provided access to crucial knowledge and competence, which created a path dependency that hindered the development of TIS structures abroad.

Finally, it should be noted that there is a time lag between the mobilization of resources and structural build-up. Therefore, the full results of the influence of foreign regions are obscured, especially in the latest episode.

Furthermore, the analysis indicates that other factors will play an increasingly important role for the spatial development trajectory as the technology advances. Firstly, the location of sites for further demonstration, up-scaling and commercialization will naturally determine where system structures around site development and installation, site operation, service and maintenance, and power transmission and consumption are built-up. Secondly, as the focus of innovation activity shifts from concept development to more incremental improvements in components and sub-systems, R&D activities tend to become more dependent on user-producer interactions. This might make geographical proximity between different parts of the value chain more important and thus create additional incentives for structural build-up close to deployment sites. Finally, it is likely that different regions will to some extent compete for structural build-up in parts of the value chain that are less bound to deployment sites, for example R&D, production of sub-systems and components, and system integration.

Taking these dynamics into account when designing and implementing policies for promoting new technology is clearly key for regional policymakers. The more specific implications will be discussed in the next chapter.

5 DISCUSSION

In this chapter, empirical findings, policy implications, theoretical contributions and future research ideas are discussed.

5.1 Empirical findings and policy implications

This research has focused on marine energy and developed a number of insights for this technology field. Below, the empirical findings are related to existing literature and their technology-specific and general policy implications discussed.

5.1.1 Determining the political direction

The analysis of the Swedish marine energy innovation system, presented in Article 1, clearly shows that its development has suffered from a lack of political direction. This supports claims in the broader innovation literature, where scholars emphasize the importance of collective priorities and strategic policy approaches, and point to lack of directionality as a common failure in innovation processes (Mazzucato, 2016; Weber and Rohracher, 2012). Although the importance of political direction is an interesting contribution in itself, moving towards more concrete policy recommendations requires a discussion of possible and appropriate policy strategies for Swedish marine energy.

As described in Chapter 2, policymakers support the development and diffusion of new technologies to create benefits that relate to technology deployment or industrialization. Which policies that are appropriate for a specific technology should depend on the potential benefits that successful innovation can bring as well as on the perceived possibility and cost of influencing developments in this direction. Although assessments of this kind are clearly difficult, three broad alternatives for the Swedish political direction for marine energy can be identified.

First, policymakers may conclude that marine energy does not merit any specific political attention. This direction would be based on a belief that the potential benefits do not motivate the expected cost of the public support required for achieving successful innovation. It would logically follow that support policies are consciously withdrawn. Though this direction is likely to meet resistance and give rise to disappointment among involved actors and proponents of marine energy, it cannot be overlooked as an alternative.

Second, policymakers could find that the Swedish resource potential will allow for commercial deployment of marine energy technology and accordingly aim for domestic market development. This direction would probably be driven by a desire to appropriate benefits relating to both technology deployment and industrialization, where the latter may involve supplying technology to domestic installations or to the global market. A key policy challenge is to ensure that support policies lead to domestic industrialization and not a situation where technology is mainly imported from other countries. Relying on imports would still enable the appropriation of benefits relating to technology deployment, but new jobs, tax revenues and knowledge spillovers would mainly be created abroad, which is not desirable from a policy perspective. Experiences from solar power in Germany illustrate this challenge, since market support eventually led to industrial development in China (Binz et al., 2014; Pegels and Lütkenhorst, 2014; Quitzow, 2015). It should be emphasized, however, that German tax payers arguably have and will continue to benefit from the global energy transition as well.

Third, policymakers may adopt an export-oriented direction, which would imply dismissing the possibility of creating a domestic commercial market and thereby appropriating localized benefits associated with technology deployment. It would, however, acknowledge the potential for developing an export industry that supplies components, sub-systems, complete power plants and/or services to the global market. To the extent that the direction would involve public support, a significant policy challenge is to ensure that this leads to industrialization in Sweden, and not to a situation where domestic beneficiaries later create job opportunities, pay taxes and give rise to knowledge spillovers abroad. Introducing support systems that stimulate a domestic testing and demonstration might retain parts of the value chain in Sweden despite an export focus, which is emphasized by experiences from wind power (Lewis and Wiser, 2007). However, this may unintentionally promote technologies adapted for Swedish conditions but not necessarily suitable for export. In addition, for some technology concepts, most notably tidal kite technology, the Swedish resource endowment does not even allow for testing and demonstration.

Although these three alternatives are all possible political directions for Swedish policymakers, there are strong indications that a domestic commercial market is not feasible given the limited resource endowment. Given this view, determining if the technology field merits support (i.e. choosing between alternative one and three above), and designing appropriate support policies, requires an understanding of whether and how industrial development in certain parts of the value chain can be achieved, even though a domestic market is out of reach. The key question is what determines the spatial development trajectory of an emerging TIS, and how policymakers can influence the build-up of domestic system structures that bring localized benefits. This is the focus of Article 2 that analyzes the emergence of tidal kite technology.

5.1.2 Responding to an increased tendency for industrial development abroad

Article 2 finds that the domestic access to knowledge and competence in early development stages has been key for the spatial development trajectory of the tidal kite innovation system. This has seemingly created a path dependency that throughout the subsequent development favored local build-up of system structures. Although these insights have been developed in the context of tidal kite technology, they are likely to be applicable to the marine energy technology field as a whole. Moreover, they confirm the conventional view that knowledge development and learning is facilitated by geographical proximity, and the importance of spatial path dependency for the localization of new industries (Boschma, 2004; Howells and Bessant, 2012; Jaffe, 1993; Krugman, 1991; Porter, 1998; see also Section 2.2). This should not come as a surprise since tidal kite technology, and marine energy technology in general, are technology fields based on synthetic knowledge (Binz et al., 2016; Huenteler et al., 2016). At the same time, however, the findings support claims that knowledge networks are increasingly existing on global and local levels simultaneously (Bathelt et al., 2004). After all, the development of tidal kite technology has benefitted from knowledge mobilized from foreign regions, although learning has been concentrated to Western Sweden.

Furthermore, the analysis suggests that the location of markets will become increasingly important for the spatial development trajectory as tidal kite technology advances towards full-scale demonstration and commercialization. This is in line with Huenteler et al. (2016) which demonstrate the importance of technology deployment and user-producer relationships for innovation and learning in complex products and systems such as marine energy technology. For tidal kite technology, the location of markets is strongly related to the spatial distribution of the highly localized natural resource on which it depends. This is worth emphasizing since few contributions in the sustainability transitions literature deal with the importance of natural resource endowments (Hansen and Coenen, 2015).

The increased importance of markets implies a tendency for structural build-up abroad since a domestic commercial market is out of reach (tidal kite technology) or at least very limited (marine energy technology). It is likely that Swedish policymakers need to respond by increasing the incentives for domestic industrial development if they want to appropriate localized benefits. The passive attitude to the technology field, where policymakers have mainly had an indirect influence by shaping the contextual structures that govern the access to knowledge, competence and private financial capital (i.e. through overarching education and taxation policy), would thus have to be replaced by a more active stance. What this means in terms of more specific policy intervention is a question that lies beyond the scope of this thesis, and the discussion is therefore limited to highlighting a few broad options. The first one is to continue building on what seems to have been key for the system's domestic development so far, namely the access to knowledge, competence and financial capital. Further improving the contextual structures that provide these resources would strengthen the incentives for structural build-up in Sweden, but it is clearly an imprecise policy option (i.e. lowering the corporate tax benefits all firms) that often has its effect over long time horizons (i.e. investments in the education system pays-off after many years). A more direct way of building on the strength of contextual structures is to implement policies that facilitate and promote linkages with research organizations and industry, for example by funding collaborative R&D projects. This policy option is likely to lead to faster and more precise results, in terms of strengthening the incentives for structural build-up in Sweden, and also facilitate knowledge spill-over from the system to its context. Finally, a third policy option would be to provide some of the financial capital needed to advance the technology. This could be done in many ways, including direct support to technology developers, investments in future production facilities, and public procurement of the first commercial installations. However, this type of support has to be designed to create incentives for structural build-up in Sweden, or coupled with mechanisms that retains financial rewards, to ensure that sufficient localized benefits are appropriated domestically (Mazzucato, 2015b). Also, it must comply with EU legislation that often limits the extent to which national governments can subsidize individual companies and technology fields.

5.1.3 Beyond a Swedish policy perspective

Although the purpose of this thesis is to examine innovation in marine energy technology from a Swedish policy perspective, the analysis is relevant from other geographical perspectives as well. In regions with beneficial domestic resource endowments and large market potentials, for example, policy challenges have an interesting resemblance to the situation in Sweden. Here, localized benefits relating to technology deployment are naturally important motivations for public support. However, policymakers are also looking to create new jobs and stimulate economic development, and it is not certain that support to technology deployment will lead to domestic structural build-up in parts of the value chain that are less bound to deployment sites, such as R&D, production of sub-systems and components, and system integration. This mirrors the situation in Sweden and policymakers accordingly face a similar challenge when it comes to stimulating domestic industrialization. However, it is arguably easier to couple support to technology deployment with incentives or even outright demands for domestic structural build-up, than it is for support to technology development. The former has also been observed in the emergence of tidal kite technology, where public funding was coupled with demands for local sourcing in Wales.

The desire among regions to achieve domestic industrialization, and the resulting regional competition, can also be negative for the global development of marine energy technology. When policymakers perceive a risk that public investments in RD&D and support to market deployment may not result in the sought domestic localized benefits, they are likely to become passive and withdraw support. In addition, interventions might focus too much on supporting deployment rather than early-stage R&D, since the immediate benefits of the former are arguably easier to retain domestically. This emphasizes the role of supra-national actors that can implement policies based on a more overarching perspective and the general importance of international policy coordination, which has also been highlighted in the context of wind power (Binz et al., 2017) and photovoltaics (Quitzow, 2015).

Finally, the reasoning above points to an important paradox in the increasingly global and internationalized nature of technological innovation. On the one hand, global value chains tend to increase efficiency by taking advantage of regional differences in resource endowments, capabilities, knowledge and other determinants of innovation performance, and promoting and enabling regional specialization (OECD, 2013). But on the other hand, this makes it difficult to ensure that the regional appropriation of localized benefits is in line with the risky public investments that made successful innovation possible. The importance of connecting risks and rewards when it comes to technology policy has been eloquently put forward by Mariana Mazzucato and colleagues (Lazonick and Mazzucato, 2013; Mazzucato, 2015b), but primarily in an intra-national context. This thesis follows their line of reasoning but broadens the scope to the international arena by focusing on the distribution of public support and localized benefits between national states, rather than between actors and social groups within them.

5.1.4 Policy drivers revisited

The discussion has so far focused to a large extent on how regional policymakers can contribute to successful innovation in new renewable energy technology, while appropriating localized benefits such as strengthened energy security, reduced local pollution and economic development. It should, however, again be emphasized that the development and diffusion of these technologies will create urgently needed global benefits no matter which region that ends up deploying technology or build new industries. This means that public investments in RD&D that lower the cost of renewable energy can be considered a form of global stewardship. Moreover, since the need for clean and affordable energy is particularly pronounced in developing countries, there are parallels to foreign aid policy. How much these concerns are allowed to guide public policy naturally varies both within and between nations, and any assessment regarding the extent to which a desire to create global benefits actually drives policy intervention is far beyond the scope of this thesis. However, the presented research results clearly highlight that promoting new technologies is a broad policy concern that is relevant for policymakers representing different interests ranging from purely economic concerns around growth and competitiveness to energy security, local environmental issues and even foreign aid.

5.2 Theoretical contributions and future research

A part from the described empirical findings, this thesis highlights the interdependence of problems in the innovation process, suggests a potential development of the concept of TIS functions and introduces an explicit regional policy perspective to TIS analysis. Moreover, it identifies the need for spatially sensitive analytical goals, scenario-based thinking and future empirical work that can strengthen the reliability and validity of empirical findings. These theoretical contributions and future research avenues are discussed below.

5.2.1 The interdependence of problems in the innovation process

Article 1 employs a conventional analytical framework, following Bergek et al. (2008a), to identify problems in the innovation process for Swedish marine energy. The result is a set of seven blocking factors with different negative impacts on the innovation system. However, the analysis also show that these problems are not independent but rather highly interrelated. In particular, the lack of political direction together with the small and uncertain domestic market potential seem to have induced the other blocking factors, by creating uncertainties and giving rise to detrimental dynamics. This finding leads to policy recommendations that emphasize these two key problems and argues that they ought to be the focus of any intervention aimed at promoting the technology field.

Kieft et al. (2016) argue that the interdependence of problems identified through the analysis of innovation systems has been somewhat neglected in the literature and show that taking this complexity into account may lead to different, and potentially more appropriate, policy recommendations. The analysis presented in Article 1 supports this argument, by demonstrating interactions among blocking factors in the Swedish marine energy innovation system. There is, however, room for improvement when it comes to how interdependencies among problems in innovation processes are conceptualized and analyzed in the literature. Future research could, for instance, attempt to establish more consistent terminologies that enable a clearer distinction between problems on different levels of abstraction, advance tools and frameworks for analyzing problem interactions, and develop ways of ensuring reliable problem diagnosis and appropriate policy recommendations.

5.2.2 TIS functions as resource-mobilizing processes

As mentioned in Chapter 2, TIS analyses normally focus on sub-process, referred to as functions, that can be defined, grouped and interpreted somewhat differently (Markard and Truffer, 2008). The analysis of Swedish marine energy in Article 1 builds on a conceptualization of functions that largely follows Bergek et al. (2008a), which worked well for the purposes of that study. But when attempting to understand the historical developments of tidal kite technology in Article 2, there was a need to develop an alternative approach. Since the analysis focused on the roles played by domestic and foreign regions in the development of the technology field, functions were conceptualized as resource-mobilizing processes, which is similar to the analytical framework employed by Binz et al. (2015). Moreover, a new typology of six key resources (knowledge, competence, enabling technology, financial capital, legitimacy and markets) is used. This arguably enabled a clearer and more concrete analysis than the conventional functions typologies put forth by Bergek et al. (2008a) and Hekkert et al. (2007), in particular when focusing on transnational innovation dynamics.

Still, the elusive concept of functions would benefit from further development. In principle, it is not necessarily negative that functions are defined and grouped differently in the literature, since adaptations are most often necessary when applying analytical frameworks to specific research inquiries. But when such a fundamental concept is interpreted differently by leading scholars, there is a risk that the progression of theory and diffusion of empirical insights is hampered and that the field becomes inaccessible. Future research may therefore have an important task when it comes to either aligning the TIS community behind a common understanding of the concept of functions or introducing complementary concepts that reflect the observed differences. These efforts should also address the perhaps even more fundamental question of what purpose the interacting structural elements in a TIS really fill; does the system develop and diffuse technology, produce and use technology, or perhaps both?

5.2.3 Introducing an explicit regional policy perspective

Article 1 identifies the need for developing the TIS approach to account for the geographical dimension of innovation when performing policy-oriented analyses. Inspired by this finding, a new way of delineating TISs is demonstrated in Article 2. The novelty lies a distinction is between domestic and foreign sociotechnical structures, both in the global TIS in focus and in its sociotechnical context. This is similar to recent literature that views a global TIS as a collection of spatially delineated sub-systems (Binz et al., 2016, 2014; Quitzow, 2015), but the framework adds an explicit regional policy perspective, which represents 'the domestic', and defines sub-systems accordingly. This makes it possible to analyze the different roles played by domestic and foreign regions in the emergence of a new technology as well as the resulting spatial distribution of structural build-up.

5.2.4 Towards spatially sensitive analytical goals and scenario-based thinking

The analysis in Article 2 only stretches as far as explaining how the innovation system for tidal kite technology has developed to its current state. Although this is highly relevant from a policy perspective, it is not the same as recommending appropriate policies for promoting the technology field. This requires identifying weaknesses or problems in the innovation process (Borras and Edquist, 2013), in relation to an analytical goal of some kind (Bergek et al., 2008a). It seems to have become common practice among analysts to, explicitly or implicitly, adopt goals that only relate to system growth, without considering the different ways in which this growth can be achieved geographically. The results presented in this thesis clearly highlight that this is problematic when TIS analyses aim to inform policymaking that is interested in appropriating localized benefits. In these cases, the desired spatial development trajectory of an emerging TIS differs depending on the geographical perspective of the policymaker. Analytical goals employed when performing policy-oriented TIS analysis must therefore be spatially sensitive by describing not only *which* development that is desirable but also *where* it should take place.

Quite surprisingly, TIS analyses that employ spatially sensitive analytical goals seem to be largely absent from the literature. The only identified study that attempts to broaden the analytical goal dimension is Sandén et al. (2014b), which analyzes the TIS for solar cells in Sweden. Here, a distinction is made between upstream value chain activities (i.e. technology development) and downstream value chain activities (i.e. technology deployment), and specific blocking factors and policy issues are identified from these two perspectives. Although a promising attempt to employ value chain oriented goals in TIS analysis, the study has a strong focus on developments in Sweden and does not account for transnational aspects. Moreover, no attempt is made to describe a more general methodology.

Translating broader policy objectives to spatially sensitive analytical goals for the development of a specific TIS, and employing them for policy-oriented analyses, is an interesting area for future research. On a high level of reasoning, the design of policymaking for promoting the development and diffusion of specific technologies is contingent on a number of critical questions that should form the basis of such efforts. To begin with, one needs to clarify which technology that is of concern and what characterizes its development up until now. Given an understanding of the current situation and its historical embedding, the next intuitive step is to imagine possible futures in the development of the technology and what benefits they would bring. To determine appropriate policy, however, one must also assess the extent to which policy interventions can promote these futures and what the expected cost would be. Finally, weighing benefits in possible futures against the feasibility and cost of policy intervention for reaching them, enables decision-making regarding which future policymakers should aim for and the design of policy interventions that may influence developments in this direction.

The logic of this reasoning is captured well by the backcasting approach in which strategic planning starts with defining a desirable future and then works backwards to identify actions that may connect the future to the present (Holmberg and Robert, 2000; Robinson, 1982). However, in the context of technology policy from a regional perspective, the cost of actions will influence which future that is desirable;[8] it is simply not appropriate to make public investments aimed at creating a domestic industry if the expected cost to reach this objective is too high. It may therefore be fruitful to adopt a scenario-based backcasting approach, where different futures are analyzed in parallel in order to determine the appropriate course of policy action, as discussed above. This implies that policy-oriented TIS analyses should employ a set of analytical goals, corresponding to scenarios describing different possible futures, and not a single predetermined goal.

Developing these thoughts to an operationalizable analytical framework that can guide policy-oriented TIS analysis involves a number of challenges. The desire to engage in strategizing must be balanced with the uncertain nature of innovation and the influence of factors beyond the control of policymakers. Too detailed scenarios, and extensive assessments of benefits and costs, are not likely to add analytical value but rather create a potentially false sense of predictability. Another challenge is to adapt both analytical frameworks and results to the complexity of national and regional policymaking, where policies result from interactions among a wide variety of policy actors that represent different interests (Flanagan et al., 2011). However, to the extent that future research can meet these and other challenges, this thesis argues that integrating a scenario-based backcasting approach and spatially sensitive

[8] In other contexts, most prominently global policy for achieving sustainable development, cost may not be relevant due to the inevitability of reaching a certain future or the existential consequences of failing to do so.

analytical goals would add relevance by aligning the TIS approach with the logic of the policy context it intends to inform.

5.2.5 Potential future empirical work

The empirical findings presented in this thesis are developed in a quite narrow Swedish marine energy context. Although they are likely to hold some general validity, and at least point to certain general mechanisms of interest, additional studies are needed to make broader inferences. This opens up several possible directions for further research. Firstly, the research designs employed in both Article 1 and Article 2 could be applied to other cases focusing on different renewable energy technologies and/or geographies. Combining results from such investigations with the findings in this thesis would contribute to a more robust understanding of the spatiality of innovation and the issue of benefits appropriation, and expand the validity of the research results to other technological and geographical contexts. In particular, it would be interesting to apply a similar analytical framework as in Article 2 to cases of emerging renewable energy technologies with different technological characteristics, such as photovoltaics, since the literature suggests that findings in Article 2 are especially pronounced for complex products and systems (Huenteler et al., 2016) based on synthetic knowledge (Binz et al., 2016). Secondly, the cases analyzed in this thesis could be revisited in the future. This would make it possible to analyze actual developments in relation to the predictions made in this thesis, and thereby test the reliability of its research methodology. Finally, future empirical work could test and demonstrate analytical frameworks that incorporate spatially sensitive analytical goals and scenario-thinking into policy-oriented analysis of new technologies, along the lines of reasoning presented in Section 5.2.4.

6 CONCLUSIONS

The general purpose of this research is to increase the understanding of how national governments can promote and benefit from the global energy transition. This thesis makes a contribution towards this objective by examining innovation in marine energy technology from a Swedish policy perspective. It takes the TIS approach as a theoretical starting-point and aims to reveal intra- and transnational innovation dynamics, derive implications for policymakers, and develop theory to account for these insights. The research is presented in two appended articles that analyze the Swedish marine energy innovation system and the global tidal kite innovation system.

A number of empirical conclusions can be drawn from the results of this work. Firstly, the analysis of the Swedish marine energy innovation system shows that an informed political direction is needed to accelerate innovation. Determining the appropriate direction requires assessments of domestic market and export potentials in relation to the policy rationales that motivate public support. Secondly, the analysis of the global tidal kite innovation system demonstrates that the presence of critical knowledge and competence has so far favored developments in Sweden, but also that the location of markets will become increasingly decisive for the spatial development trajectory as the technology advances towards large-scale diffusion. This will create a tendency for industrialization abroad and an export-focused political direction should therefore involve strengthened incentives for domestic development. Finally, the results emphasize that there is a need for international policy coordination, since regional competition for industrial development may be negative for the global development of marine energy. However, since these empirical findings are developed in a quite narrow Swedish marine energy context, additional studies are needed to make broader inferences. This opens up several possible directions for future research.

Theoretically, the thesis highlights the interdependence of problems in the innovation process, suggests that TIS functions may be viewed as resource-mobilizing processes and introduces an explicit regional policy perspective to TIS analysis. These contributions may to some extent inform future research, but primarily point to interesting areas of further theoretical development. In particular, the thesis argues that policy-oriented analyses of new technologies should move towards employing spatially sensitive analytical goals and scenario-based thinking. Developing analytical frameworks that account for this insight is a formidable challenge that involves assessing not only benefits of highly uncertain future scenarios, but also the feasibility and cost of making policy interventions that turn them into reality.

REFERENCES

Ali, A.A.G., Fan, S., 2007. Public Policy and Poverty Reduction in the Arab Region. The Arab Planning Institute, State of Kuwait.

Arthur, B.W., 2009. The Nature of Technology: What It Is and How It Evolves. Free Press, New York.

Arze del Granado, F.J., Coady, D., Gillingham, R., 2012. The Unequal Benefits of Fuel Subsidies: A Review of Evidence for Developing Countries. World Dev. 40, 2234–2248. doi:10.1016/j.worlddev.2012.05.005

Asheim, B.T., Boschma, R., Cooke, P., 2011. Constructing Regional Advantage: Platform Policies Based on Related Variety and Differentiated Knowledge Bases. Reg. Stud. 45, 893–904. doi:10.1080/00343404.2010.543126

Bathelt, H., Malmberg, A., Maskell, P., 2004. Clusters and knowledge: local buzz, global pipelines and the process of knowledge creation. Prog. Hum. Geogr. 28, 31–56. doi:10.1191/0309132504ph469oa

Bergek, A., Hekkert, M., Jacobsson, S., Markard, J., Sandén, B., Truffer, B., 2015. Technological innovation systems in contexts: Conceptualizing contextual structures and interaction dynamics. Environ. Innov. Soc. Transitions 16, 51–64. doi:10.1016/j.eist.2015.07.003

Bergek, A., Jacobsson, S., Carlsson, B., Lindmark, S., Rickne, A., 2008a. Analyzing the functional dynamics of technological innovation systems: A scheme of analysis. Res. Policy 37, 407–429. doi:10.1016/j.respol.2007.12.003

Bergek, A., Jacobsson, S., Sandén, B.A., 2008b. "Legitimation" and "development of positive externalities": two key processes in the formation phase of technological innovation systems. Technol. Anal. Strateg. Manag. 20, 575–592. doi:10.1080/09537320802292768

Bibi, S., Duclos, J.Y., 2007. Equity and policy effectiveness with imperfect targeting. J. Dev. Econ. 83, 109–140. doi:10.1016/j.jdeveco.2005.12.001

Binz, C., Coenen, L., Truffer, B., 2016. Global Innovation Systems – a conceptual framework for technological innovation in transnational contexts. Accepted to the DRUID conference 2016.

Binz, C., Tang, T., Huenteler, J., 2017. Spatial lifecycles of cleantech industries – The global development history of solar photovoltaics. Energy Policy 101. doi:10.1016/j.enpol.2016.10.034

Binz, C., Truffer, B., Coenen, L., 2015. Path Creation as a Process of Resource Alignment and Anchoring: Industry Formation for On-Site Water Recycling in Beijing. Econ. Geogr. 0, 1–29. doi:10.1080/00130095.2015.1103177

Binz, C., Truffer, B., Coenen, L., 2014. Why space matters in technological innovation systems—

Mapping global knowledge dynamics of membrane bioreactor technology. Res. Policy 43, 138–155. doi:10.1016/j.respol.2013.07.002

Bleda, M., Del Rio, P., 2013. The market failure and the systemic failure rationales in technological innovation systems. Res. Policy 42, 1039–1052. doi:10.1016/j.respol.2013.02.008

Borras, S., Edquist, C., 2013. The choice of innovation policy instruments. Technol. Forecast. Soc. Change 80, 1513–1522. doi:10.1016/j.techfore.2013.03.002

Boschma, R., 2005. Proximity and Innovation: A Critical Assessment. Reg. Stud. 39, 61–74. doi:10.1080/0034340052000320887

Boschma, R., 2004. Competitiveness of Regions from an Evolutionary Perspective. Reg. Stud. 38, 1001–1014. doi:10.1080/0034340042000292601

Boschma, R., Lambooy, J.G., 1999. Evolutionary economics and economic geography. J. Evol. Econ. 9, 411–429. doi:10.1007/s001910050089

Buchan, D., 2012. The Energiewende – Germany's gamble. Oxford Institute for Energy Studies. Oxford, UK. doi:978-1-907555-52-7

Bunnell, T.G., Coe, N.M., 2001. Spaces and scales of innovation. Prog. Hum. Geogr. 25, 569–589. doi:10.1191/030913201682688940

Buys, P., Chomitz, K., Dasgupta, S., Deichmann, U., Larsen, B., Meisner, C., Nygard, J., Pandey, K., Pinnoi, N., Wheeler, D., 2004. The Economics of Regional Poverty-Environment Programs. World Bank Policy Research Working Paper 3267.

Canning, P.N., Vroomen, H., 1996. Measuring Welfare Impacts from Equilibrium Supply and Demand Curves : An Antidumping Case Study. Am. J. Agric. Econ. 78, 1026–1033.

Carbon Trust, 2012. Marine Energy Briefing. Report available at www.carbontrust.com/resources/reports/technology/accelerating-marine-energy

Carbon Trust, 2011. Accelerating marine energy: The potential for cost reduction – insights from the Carbon Trust Marine Energy Accelerator. Report available at www.carbontrust.co.uk/publications

Carlsson, B., Jacobsson, S., Holmén, M., Rickne, A., 2002. Innovation systems: analytical and methodological issues. Res. Policy 31, 233–245. doi:10.1016/S0048-7333(01)00138-X

Carlsson, B., Stankiewicz, R., 1991. On the nature, function and composition of technological systems. J. Evol. Econ. 1, 93–118.

Coenen, L., Benneworth, P., Truffer, B., 2012. Toward a spatial perspective on sustainability transitions. Res. Policy 41, 968–979. doi:10.1016/j.respol.2012.02.014

Coenen, L., Díaz López, F.J., 2010. Comparing systems approaches to innovation and technological change for sustainable and competitive economies: an explorative study into conceptual commonalities, differences and complementarities. J. Clean. Prod. 18, 1149–1160. doi:10.1016/j.jclepro.2010.04.003

Cooke, P., Gomez Uranga, M., Etxebarria, G., 1997. Regional innovation systems: Institutional and organisational dimensions. Res. Policy 26, 475–491. doi:10.1016/S0048-7333(97)00025-5

Corsatea, T.D., 2014. Increasing synergies between institutions and technology developers: Lessons from marine energy. Energy Policy 74, 1–16. doi:10.1016/j.enpol.2014.07.006

De Backer, K., Destefano, T., Moussiegt, L., 2017. The links between global value chains and global innovation networks: An exploration. OECD Science, Technology and Innovation Policy Papers. OECD Publishing, Paris.

del Rio, P., Howlett, M., 2013. Beyond the "Tinbergen Rule" in Policy Design: Matching Tools and Goals in Policy Portfolios. Annu. Rev. Policy Des. 1, 1–16. doi:10.2139/ssrn.2247238

Doney, S.C., Fabry, V.J., Feely, R.A., Kleypas, J.A., 2009. Ocean Acidification: The Other CO2 Problem. Ann. Rev. Mar. Sci. 1. doi:10.1146/annurev.marine.010908.163834

EMEC, 2014. European Marine Energy Centre. Available at www.emec.org.uk

Ernst, D., 2002. Global production networks and the changing geography of innovation systems. Implications for developing countries. Econ. Innov. New Technol. 11, 497–523. doi:10.1080/10438590214341

EU, 2009. Directive 2009/28/EC of The European Parliament and of The Council of 23 April 2009 on the promotion of the use of energy from renewable sources and amending and subsequently repealing Directives 2001/77/EC and 2003/30/EC. The European Parliament and The Council of the European Union.

European Commission, 2014. Blue Energy: Action needed to deliver on the potential of ocean energy in European seas and oceans by 2020 and beyond. Communication from the commission to the European Parliament, the Council, the European Economic and Social Committee and the Committee of the Regions. Available at ec.europa.eu/maritimeaffairs/policy/ocean_energy/documents/com_2014_8_en.pdf

Flanagan, K., Uyarra, E., Laranja, M., 2011. Reconceptualising the "policy mix" for innovation. Res. Policy 40, 702–713. doi:10.1016/j.respol.2011.02.005

Flyvbjerg, B., 2016. Five Misunderstandings About Case-Study Research. Qual. Inq. 12, 219–245. doi:10.1177/1077800405284363

GCEC, 2015. Seizing the Global Opportunity: Partnerships for Better Growth - The 2015 New Climate Economy Report. The New Climate Economy, Global Commission on the Economy and Climate.

doi:978 0 9906845 0 3

Geels, F.W., 2005a. Processes and patterns in transitions and system innovations: Refining the co-evolutionary multi-level perspective. Technol. Forecast. Soc. Change 72, 681–696. doi:10.1016/j.techfore.2004.08.014

Geels, F.W., 2005b. The Dynamics of Transitions in Socio-technical Systems: A Multi-level Analysis of the Transition Pathway from Horse-drawn Carriages to Automobiles (1860–1930). Technol. Anal. Strateg. Manag. 17, 445–476. doi:10.1080/09537320500357319

Geels, F.W., 2002. Technological transitions as evolutionary reconfiguration processes: a multi-level perspective and a case-study. Res. Policy 31, 1257–1274. doi:10.1016/S0048-7333(02)00062-8

Geels, F.W., Schot, J., 2007. Typology of sociotechnical transition pathways. Res. Policy 36, 399–417. doi:10.1016/j.respol.2007.01.003

Grau, T., Huo, M., Neuhoff, K., 2011. Survey of photovoltaic industry and policy in Germany and China, CPI Report. doi:10.1016/j.enpol.2012.03.082

Hansen, T., 2015. Substitution or Overlap ? The Relations between Geographical and Non-spatial Proximity Dimensions in Collaborative Innovation Projects. Reg. Stud. 49. doi:10.1080/00343404.2013.873120

Hansen, T., Coenen, L., 2015. The geography of sustainability transitions: Review, synthesis and reflections on an emergent research field. Environ. Innov. Soc. Transitions 17, 92–109. doi:10.1016/j.eist.2014.11.001

Hekkert, M.P., Negro, S.O., 2009. Functions of innovation systems as a framework to understand sustainable technological change: Empirical evidence for earlier claims. Technol. Forecast. Soc. Change 76, 584–594. doi:10.1016/j.techfore.2008.04.013

Hekkert, M.P., Suurs, R.A.A., Negro, S.O., Kuhlmann, S., Smits, R.E.H.M., 2007. Functions of innovation systems: A new approach for analysing technological change. Technol. Forecast. Soc. Change 74, 413–432. doi:10.1016/j.techfore.2006.03.002

Holmberg, J., Robert, K.-H., 2000. Backcasting — a framework for strategic planning. Int. J. Sustain. Dev. World Ecol. 7, 291–308. doi:10.1080/13504500009470049

Howells, J., 2002. Tacit Knowledge, Innovation and Economic Geography. Urban Stud. 39, 871–884. doi:10.1080/0042098022012835

Howells, J., Bessant, J., 2012. Introduction: Innovation and economic geography: A review and analysis. J. Econ. Geogr. 12, 929–942. doi:10.1093/jeg/lbs029

Huenteler, J., Schmidt, T.S., Ossenbrink, J., Hoffmann, V.H., 2016. Technology life-cycles in the energy sector - Technological characteristics and the role of deployment for innovation. Technol.

Forecast. Soc. Change 104, 102–121. doi:10.1016/j.techfore.2015.09.022

Hughes, T.P., 1987. The Evolution of Large Technological Systems, in: Bijker, W.E., Hughes, T.P., Pinch, T.J. (Eds.), The Social Construction of Technological Systems. MIT Press, Cambridge.

Ingmarsson, P., 2014. Förstudie om havsenergibranschens forsknings och utvecklingsbehov Innehållsförteckning. Report to the Swedish Energy Agency. SP Technical Research Institute of Sweden and ÅF-Infrastructure AB.

IPCC, 2014. Climate Change 2014: Synthesis Report. IPCC, Geneva, Switzerland.

IPCC, 2012. IPCC Special Report on Renewable Energy Sources and Climate Change Mitigation. IPCC, Geneva, Switzerland.

IRENA, 2017. REthinking Energy 2017: Accelerating the global energy transformation. International Renewable Energy Agency. Abu Dhabi. Report available at www.irena.org/Publications

IRENA, 2014. The Socio-economic Benefits of Solar and Wind Energy. International Renewable Energy Agency. Abu Dhabi. Report available at www.irena.org/Publications

Jacobides, M.G., Knudsen, T., Augier, M., 2006. Benefiting from innovation: Value creation, value appropriation and the role of industry architectures. Res. Policy 35, 1200–1221. doi:10.1016/j.respol.2006.09.005

Jacobsson, S., Bergek, A., 2011. Innovation system analyses and sustainability transitions: Contributions and suggestions for research. Environ. Innov. Soc. Transitions 1, 41–57. doi:10.1016/j.eist.2011.04.006

Jacobsson, S., Bergek, A., 2004. Transforming the energy sector: the evolution of technological systems in renewable energy technology. Ind. Corp. Chang. 13, 815–849. doi:10.1093/icc/dth032

Jacobsson, S., Johnson, A., 2000. The diffusion of renewable energy technology: an analytical framework and key issues for research. Energy Policy 28, 625–640. doi:10.1016/S0301-4215(00)00041-0

Jaffe, A.B.., 1993. Geographic Localization of Knowledge Spillovers as Evidenced by Patent Citations. Q. J. Econ. 108, 577–598.

Joas, F., Pahle, M., Flachsland, C., Joas, A., 2016. Which goals are driving the Energiewende? Making sense of the German Energy Transformation. Energy Policy 95, 42–51. doi:10.1016/j.enpol.2016.04.003

Kemp, R., Loorbach, D., 2006. 5. Transition management: a reflexive governance approach, in: Voß, J.-P., Bauknecht, D., Kemp, R. (Eds.), Reflexive Governance for Sustainable Development. Edward Elgar Publishing, Cheltenham, UK and Northampton, MA, USA.

Kemp, R., Schot, J., Hoogma, R., 1998. Regime shifts to sustainability through processes of niche formation: The approach of strategic niche management. Technol. Anal. Strateg. Manag. 10, 175–195.

Kieft, A., Harmsen, R., Hekkert, M., 2016. Interactions between systemic problems in innovation systems: The case of energy-efficient houses in the Netherlands. Environ. Innov. Soc. Transitions 1–13. doi:10.1016/j.eist.2016.10.001

Klein Woolthuis, R., Lankhuizen, M., Gilsing, V., 2005. A system failure framework for innovation policy design. Technovation 25, 609–619. doi:10.1016/j.technovation.2003.11.002

Krugman, P., 1991. Increasing Returns and Economic Geography. J. Polit. Econ. 99, 483–499.

Lazonick, W., Mazzucato, M., 2013. The risk-reward nexus in the innovation-inequality relationship: who takes the risks? Who gets the rewards? Ind. Corp. Chang. 22, 1093–1128. doi:10.1093/icc/dtt019

Lin, B., Jiang, Z., 2012. Designation and influence of household increasing block electricity tariffs in China. Energy Policy 42, 164–173. doi:10.1016/j.enpol.2011.11.062

Lovdal, N., Moen, O., 2013. International Before Commercial:Investigating the Pre-Commercial Phase of International New Ventures. J. Technol. Manag. Innov. 8, 21–34.

Løvdal, N., Neumann, F., 2011. Internationalization as a strategy to overcome industry barriers-An assessment of the marine energy industry. Energy Policy 39, 1093–1100. doi:10.1016/j.enpol.2010.11.028

Lundvall, B.-Å., 1992. National Systems of Innovation: Towards a Theory of Innovation and Interactive Learning. Pinter Publishers, London.

Magagna, D., Uihlein, A., 2015. 2014 JRC Ocean Energy Status Report. European Commission, Joint Research Centre, Institute for Energy and Transport. Report available at setis.ec.europa.eu/system/files/2014 JRC Ocean Energy Status Report.pdf

Malerba, F., 2002. Sectoral systems of innovation and production. Res. Policy 31, 247–264. doi:10.1016/S0048-7333(01)00139-1

Malmberg, A., Maskell, P., 2006. Localized learning revisited. Growth Change 37, 1–18. doi:10.1111/j.1468-2257.2006.00302.x

Malmberg, A., Maskell, P., 2002. The elusive concept of localization economies: Towards a knowledge-based theory of spatial clustering. Environ. Plan. A 34, 429–449. doi:10.1068/a3457

Markard, J., Hekkert, M., Jacobsson, S., 2015. The technological innovation systems framework: Response to six criticisms. Environ. Innov. Soc. Transitions 16, 76–86. doi:10.1016/j.eist.2015.07.006

Markard, J., Raven, R., Truffer, B., 2012. Sustainability transitions: An emerging field of research and its prospects. Res. Policy 41, 955–967. doi:10.1016/j.respol.2012.02.013

Markard, J., Truffer, B., 2008. Technological innovation systems and the multi-level perspective: Towards an integrated framework. Res. Policy 37, 596–615. doi:10.1016/j.respol.2008.01.004

Mazzucato, M., 2016. From market fixing to market-creating: a new framework for innovation policy. Ind. Innov. 23, 140–156. doi:10.1080/13662716.2016.1146124

Mazzucato, M., 2015a. The Innovative State: Governments Should Make Markets, Not Just Fix Them. Foreign Afffairs 94, 1–4.

Mazzucato, M., 2015b. The entrepreneurial state: Debunking public vs. private sector myths. Public Affairs, New York.

Mazzucato, M., Penna, C.C.R., 2016. Beyond market failures: the market creating and shaping roles of state investment banks. J. Econ. Policy Reform 19, 305–326. doi:10.1080/17487870.2016.1216416

Mazzucato, M., Semieniuk, G., 2017. Public financing of innovation: new questions. Oxford Rev. Econ. Policy 33, 24–48. doi:10.1093/oxrep/grw036

McGahan, A.M., Silverman, B.S., 2006. Profiting from technological innovation by others: The effect of competitor patenting on firm value. Res. Policy 35, 1222–1242. doi:10.1016/j.respol.2006.09.006

Metcalfe, J.S., 1994. Evolutionary Economics and Technology Policy. Econ. J. 104, 931–944.

Milesi, D., Petelski, N., Verre, V., 2013. Innovation and appropriation mechanisms: Evidence from Argentine microdata. Technovation 33, 78–87. doi:10.1016/j.technovation.2012.12.001

Negro, S.O., Hekkert, M.P., Smits, R.E., 2007. Explaining the failure of the Dutch innovation system for biomass digestion-A functional analysis. Energy Policy 35, 925–938. doi:10.1016/j.enpol.2006.01.027

OECD, 2013. Interconnected Economies: Benefiting from Global Value Chains – Synthesis Report. OECD Publishing, Paris. doi:10.1787/9789264189560-en

OECD, 2005. Oslo manual. OECD, Eurostat & European Commission doi:10.1787/9789264013100-en

OES, 2015. Annual Report. Ocean Energy Systems. Report available at www.spp.org/documents/28682/ar-2014 04302015.pdf

OES, 2014. Annual Report: Implementing Agreement on Ocean Energy Systems. Report available at report2014.ocean-energy-systems.org/documents/OES-Annual-Report-2014/

Paris Innovation Review, 2012. The German solar energy crisis: looking for the right incentive scheme.

Available at parisinnovationreview.com/2012/04/13/german-solar-crisis/?media=print

Pegels, A., Lütkenhorst, W., 2014. Is Germany's energy transition a case of successful green industrial policy? Contrasting wind and solar PV. Energy Policy 74, 522–534. doi:10.1016/j.enpol.2014.06.031

Poole, M.S., Van de Ven, A.H., Dooley, K., Holmes, M.E., 2000. Organizational Change and Innovation Processes. Oxford University Press, New York, USA.

Porter, M.E., 1998. Clusters and the New Economics of Competition. Harvard Business Review.

Porter, M.E., 1990. The Competitive Advantage of Nations. Harvard Business Review.

Quitzow, R., 2015. Dynamics of a policy-driven market: The co-evolution of technological innovation systems for solar photovoltaics in China and Germany. Environ. Innov. Soc. Transitions 17, 126–148. doi:10.1016/j.eist.2014.12.002

Raven, R., Schot, J., Berkhout, F., 2012. Space and scale in socio-Technical transitions. Environ. Innov. Soc. Transitions 4, 63–78. doi:10.1016/j.eist.2012.08.001

Reichardt, K., Negro, S.O., Rogge, K.S., Hekkert, M.P., 2016. Analyzing interdependencies between policy mixes and technological innovation systems: The case of offshore wind in Germany. Technol. Forecast. Soc. Change 106, 11–21. doi:10.1016/j.techfore.2016.01.029

Ritala, P., Olander, H., Michailova, S., Husted, K., 2015. Knowledge sharing, knowledge leaking and relative innovation performance: An empirical study. Technovation 35, 22–31. doi:10.1016/j.technovation.2014.07.011

Robinson, J.B., 1982. Energy backcasting: A proposed method of policy analysis. Energy Policy 10, 337–344. doi:10.1016/0301-4215(82)90048-9

Rockström, B.J., Gaffney, O., Rogelj, J., Meinshausen, M., Nakicenovic, N., Joachim, H., 2017. A roadmap for rapid decarbonization. Science 355. doi:10.1126/science.aah3443

Rockström, J., Steffen, W., Noone, K., Persson, A., Chapin, F.S., Lambin, E.F., Lenton, T.M., Scheffer, M., Folke, C., Schellnhuber, H.J., et al., 2009. A safe operating space for humanity. Nature 461, 472–475. doi:10.1038/461472a;pmid:19779433

Rogge, K.S., Reichardt, K., 2016. Policy mixes for sustainability transitions: An extended concept and framework for analysis. Res. Policy 45, 1620–1635. doi:10.1016/j.respol.2016.04.004

Rourke, F.O., Boyle, F., Reynolds, A., 2010. Tidal energy update 2009. Appl. Energy 87, 398–409. doi:10.1016/j.apenergy.2009.08.014

Sabatier, P.A., 1991. Toward Better Theories of the Policy Process. Polit. Sci. Polit. 24, 147–156.

Sandén, B.A., Azar, C., 2005. Near-term technology policies for long-term climate targets - Economy wide versus technology specific approaches. Energy Policy 33, 1557–1576. doi:10.1016/j.enpol.2004.01.012

Sandén, B.A., Hillman, K.M., 2011. A framework for analysis of multi-mode interaction among technologies with examples from the history of alternative transport fuels in Sweden. Res. Policy 40, 403–414. doi:10.1016/j.respol.2010.12.005

Sandén, B., Hammar, L., Hedenus, F., 2014a. Are renewable energy resources large enough to replace non-renewable energy?, in: Sandén, B. (Ed.), Systems Perspectives on Renewable Power. Chalmers University of Technology. Chalmers University of Technology, Gothenburg, Sweden.

Sandén, B., Kamb, A., Kushnir, D., Gustafsson, A., Karlsson, S., 2014b. Solceller, in: Hellsmark, H. et al. (Ed.), Teknologiska Innovationssystem Inom Energiområdet. The Swedish Energy Agency.

Schumpeter, J.A., 1961. The Theory of Economic Development: An Inquiry Into Profits, Capital, Credit, Interest, and the Business Cycle, reprint. ed. Oxford University Press.

Smith, K., 2000. Innovation as a Systemic Phenomenon: Rethinking the Role of Policy. Enterp. Innov. Manag. Stud. 1, 73–102. doi:10.1080/146324400363536

Spangenberg, J.H., 2007. Biodiversity pressure and the driving forces behind. Ecol. Econ. 61, 146–158. doi:10.1016/j.ecolecon.2006.02.021

Steffen, W., Noone, K., Lambin, E., Lenton, T.M., Scheffer, M., Folke, C., Schellnhuber, H.J., Wit, C.A. De, Hughes, T., Leeuw, S. Van Der, Rodhe, H., Snyder, P.K., Costanza, R., Svedin, U., Falkenmark, M., Karlberg, L., Corell, R.W., Fabry, V.J., Hansen, J., Walker, B., Liverman, D., Richardson, K., Crutzen, P., Foley, J., 2009. Planetary Boundaries : Exploring the Safe Operating Space for Humanity. Ecology and Society 14.

Teece, D.J., 1986. Profiting from technological innovation: Implications for integration, collaboration, licensing and public policy. Res. Policy 15, 285–305. doi:10.1016/0048-7333(86)90027-2

Truffer, B., 2015. Challenges for Technological Innovation Systems research: Introduction to a debate. Environ. Innov. Soc. Transitions 16, 65–66. doi:10.1016/j.eist.2015.06.007

Truffer, B., Coenen, L., 2012. Environmental Innovation and Sustainability Transitions in Regional Studies. Reg. Stud. 46, 1–21. doi:10.1080/00343404.2012.646164

UNEP, 2017. Global Trends in Renewable Energy Investment 2017. Frankfurt School FS-UNEP Collaborating Centre for Climate & Sustainable Energy Finance/Bloomberg New Energy Finance. Report available at fs-unep-centre.org/sites/default/files/publications/globaltrendsin renewableenergyinvestment2017.pdf

Unruh, G.C., 2000. Understanding carbon lock-in. Energy Policy 28, 817–830. doi:10.1016/S0301-4215(01)00098-2

Weber, K.M., Rohracher, H., 2012. Legitimizing research, technology and innovation policies for transformative change. Res. Policy 41, 1037–1047. doi:10.1016/j.respol.2011.10.015

Paper I

Energy Policy 101 (2017) 52–64

Contents lists available at ScienceDirect

Energy Policy

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

The critical role of informed political direction for advancing technology: The case of Swedish marine energy

Johnn Andersson[a,*], Eugenia Perez Vico[b,c], Linus Hammar[d], Björn A. Sandén[a]

[a] Chalmers University of Technology, Division of Environmental Systems Analysis Department of Energy and Environment, Gothenburg, Sweden
[b] Lund University, Department of Business Administration, School of Economics and Management, Lund, Sweden
[c] Halmstad University, School of Business, Engineering and Science, Halmstad, Sweden
[d] The Swedish Agency for Marine and Water Management, Department of Marine Spatial Planning and Maritime Affairs, Gothenburg, Sweden

ARTICLE INFO

Keywords:
Technological innovation systems
Innovation policy
Ocean energy
Marine energy
Wave power
Tidal power

ABSTRACT

Marine energy technologies can contribute to meeting sustainability challenges, but they are still immature and dependent on public support. This paper employs the Technological Innovation Systems (TIS) framework to analyze the development and diffusion of Swedish marine energy up until 2014. While there were promising device developers, relevant industrial capabilities, and world-class research, the system suffered from weaknesses in several important innovation processes. Finally, the analysis identifies the lack of informed political direction as a critical blocking factor and highlights its connection to domestic market potential.

1. Introduction

Marine energy technologies[1] that produce power from ocean waves and tides can play a role in meeting the urgent climate challenge (IPCC, 2012, 2014; Stern, 2006), but they are immature and remain dependent on public support (OES, 2014a). Sweden is one of several countries that have promoted marine energy development through different policy measures (Corsatea, 2014; OES, 2014a). After an early start in the 1970s (Lindroth and Leijon, 2011; WERG, 1979) followed by decreased interest and activity during the 1990s, the last 15 years have seen the emergence of several device developers and substantial public investments in research, development, and demonstration (RD & D). Nevertheless, many stakeholders perceive policymakers as passive and misguided, which indicates a need for a deeper understanding of the factors that influence the sector's development (Andersson, 2013).

A number of studies address a broad set of policy challenges related to marine energy in countries such as the UK (Dalton and Ó Gallachóir, 2010; Jeffrey et al., 2013; Vantoch-Wood, 2012; Vantoch-Wood and Connor, 2013; Winskel et al., 2006; Winskel, 2007) and Portugal (Hamawi and Negro, 2012). Others focus on specific issues such as social acceptance and industry barriers (Kerr et al., 2014; Løvdal and Neumann, 2011), and some include marine energy in studies encompassing a wide range of renewables (Foxon et al., 2005; Negro et al., 2012; Winskel et al., 2014). However, only one study covers the development of marine energy technology in Sweden (Corsatea, 2014).[2] While the existing evidence highlights many interesting aspects by comparing several European countries, it provides a rather limited understanding of the Swedish case for two reasons. Firstly, it mainly draws on data from 2011, which was not a representative year for Swedish developments.[3] In addition, it mainly relies on quantitative data and therefore fails to capture some of the factors that hinder the field's development.

The purpose of this paper is therefore to identify factors that block the development and diffusion of Swedish marine energy and to discuss related policy issues. As a case of the role of policy intervention in early development stages, it also contributes to more general discussions on technology policy. The study covers developments up until 2014 and applies the Technological Innovation Systems (TIS) framework (Bergek et al., 2008a, 2008b; Hekkert et al., 2007), which has proved useful for

Abbreviations: NGO, non-governmental organization; R & D, research & development; RD & D, research, development, and demonstration; SwAM, Swedish Agency for Marine and Water Management; TIS, Technological Innovation Systems

* Corresponding author.
E-mail address: johnn.andersson@chalmers.se (J. Andersson).

[1] There is no commonly agreed-upon definition of marine energy. In the present paper, however, marine energy refers to energy harnessed from ocean waves and tides, with the latter including both tidal streams and ocean currents. Accordingly, technologies such as offshore wind power, tidal barrage technology, ocean thermal energy conversion, salt gradient energy conversion, and current power from inland rivers are excluded from the concept.

[2] There are also relevant reports from industry networks and public agencies, see for example (Andersson, 2013; VINNOVA, 2009).

[3] In 2010 and 2011, public and private investments were exceptional compared to the years before and after (Section 5.3).

http://dx.doi.org/10.1016/j.enpol.2016.11.032
Received 25 December 2015; Received in revised form 17 November 2016; Accepted 20 November 2016
0301-4215/

identifying blocking factors in a wide range of technology areas (Bergek, 2012) including marine energy (Corsatea, 2014; Hamawi and Negro, 2012; Vantoch-Wood, 2012). The analysis focuses on the Swedish marine energy innovation system but includes influential developments in other sectorial or geographical contexts.

2. Analytical framework, scope and methodology

Based on Bergek et al. (2008b), we define a TIS as the socio-technical system that enables the development and diffusion of a new technology, where 'technology' can be more or less broadly defined. A TIS accordingly consists of four structural component types: actors such as companies, research institutions, government agencies, and non-governmental organizations (NGOs); networks, which can be formal or informal; institutions, consisting of laws and regulations, as well as norms, beliefs, and expectations; and technology including artifacts and knowledge. Few of these components are in place when a new technology field such as marine energy emerges (Bergek et al., 2008b). Thus, the TIS structure must be gradually developed through technology accumulation, actor entry, network formation, and institutional alignment (Bergek et al., 2008b; Hekkert and Negro, 2009).

TISs are commonly analyzed by describing a set of sub-processes that build system structures, referred to as functions (Bergek et al., 2008a, 2008b; Hillman and Sandén, 2008; Markard and Truffer, 2008). These emanate from the combined effect of agency, internal system structure, and influences from the system's geographical and sectorial context (Bergek et al., 2008b; Hillman and Sandén, 2008). The latter include stimuli and obstructions from less technology-specific structures such as established industries and political, educational, and financial systems; spillovers from technological development in other geographical areas; and competition and coevolution with related emerging technologies (Bergek et al., 2015; Sandén and Hillman, 2011). Analyzing strengths and weaknesses in TIS functions, and identifying how they interact in sequences of cumulative causation that either stimulate or obstruct system development, provides a dynamic understanding of the system (Suurs and Hekkert, 2009). This in turn enables the identification of factors that block development and could be targeted by policy (Bergek et al., 2008a). Table 1 lists the seven functions used in this paper.[4]

This study concerns the Swedish marine energy innovation system and thus focuses on the development and diffusion of devices for producing electric power from ocean waves and tides. Less technology-specific activities downstream (e.g., electric power transmission and consumption) and upstream (e.g., production of raw materials and manufacturing technology) of the value chain fall outside the system boundary.[5] The analysis covers activities in the Swedish marine energy innovation system up until 2014, as well as influential developments in other geographical or sectorial contexts. It largely follows the methodology suggested by Bergek et al. (2008a). First, the global context for marine energy technology is reviewed (Section 3). Then, the structural components in the Swedish marine energy innovation system are identified (Section 4). The functions are subsequently analyzed,[6] and a set of blocking factors is identified (Section 5). Finally, policy issues derived from the blocking factors are discussed (Section 6).

[4] The functions can be defined, grouped, divided, and aggregated in many different ways (Bergek et al., 2008a; Markard and Truffer, 2008). This paper follows Bergek et al. (2008a), with additions from Jacobsson and Karltorp (2013) and Perez Vico (2014).

[5] Although these parts of the value chain are placed outside of the TIS, they are still highly relevant for the analysis. It should also be noted that some actors whose main activities fall outside the system boundary are still included because they engage with device developers and have relevant capabilities (and accordingly constitute potential entrants). Moreover, technological systems such as the power grid constitute important infrastructure and are therefore discussed in the analysis.

[6] The analysis of functions will not result in a summarizing valuation of each function's performance since several functions exhibit clear strengths and weaknesses that are hard to weigh against each other.

Table 1
Functions of innovation systems (Bergek et al., 2008a; Jacobsson and Karltorp, 2013; Perez Vico, 2014).

The function…	*is the process of strengthening…*
Knowledge development and diffusion	The breadth and depth of the knowledge base and how it is developed, diffused, and combined in the system.
Entrepreneurial experimentation	The testing of new technologies, applications, and markets whereby new opportunities are created and a learning process unfolds.
Resource mobilization	The extent to which actors are able to mobilize human and financial capital, as well as complementary assets such as infrastructure.
Development of social capital	The creation and maintenance of social relations including trust, dependence, mutual recognition, authority, and shared norms.
Legitimation	The social acceptance of the technology and its compliance with relevant institutions.
Influence on the direction of search	The incentives and/or pressures for organizations to enter the technological field, as well as guidance within the field.
Market formation	The factors driving market formation, such as articulation of demand from customers, institutional change, and changes in price/performance.

Empirically, the paper is based on 25 semi-structured interviews (Table 2), 6 short e-mail communications, and direct observations during 3 multi-stakeholder workshops.[7] Data were also obtained through a mapping of Swedish public RD & D funding,[8] patent search,[9] mapping of the number of bills and motions concerning marine energy from the Swedish government and parliament,[10] and media search.[11] In addition, the study builds on industry reports, official documents from public agencies, actors' websites, and academic literature.

3. The global context for marine energy technology

Marine energy technologies have a large physical resource potential estimated at about 90 000 TWh per year (Sandén et al., 2014).[12] It is clear, however, that only a minor part of the physical potential can realistically be exploited due to technical, economic, social, and ecological constraints. For example, marine energy power plants moored to the seafloor exclude large parts of the global potential due to insurmountable depths, sites far offshore will be more expensive to exploit due to infrastructure requirements, some areas may be reserved for other activities such as fishing, and local environmental impacts must be weighed against global benefits. Although the socioeconomic potential (i.e., the realistically expected level of deployment) is dynamic and dependent on how constraints are developed and perceived (IPCC, 2012),[13] it has been estimated at a few hundred (Sandén et al., 2014) or thousand (The Carbon Trust, 2012) TWh per year. While the global potential is not very impressive compared to solar and wind energy, it

Table 2
Distribution of interviews among actor categories and reference codes.

Stakeholder perspective	*Number of interviews*	*Ref. code*
Device developers	5	D1–D5
Suppliers and utilities	6	F1–F6
Industry associations	2	I1–I2
Universities and research institutes	5	R1–R5
Policy experts	2	E1–E2
Public actors	5	P1–P5

is quite substantial in some coastal regions (IPCC, 2012; Rourke et al., 2010). For example, marine energy is estimated to be able to meet 20% of the current UK electricity demand (The Carbon Trust, 2011).

The potential in Sweden is limited relative to other European countries. Available estimates for wave power range from 8 to 30 TWh annually (Bernhoff et al., 2006; Claesson et al., 1987; R2; WERG, 1979) but fail to account for important constraints such as the prevalence of lower energy content waves that some consider to significantly reduce cost-efficiency (F1; F4; R3). However, although the Swedish potential for commercial deployment is limited or non-existent, domestic waters are considered well-suited for test activities (Claesson et al., 1987; Ingmarsson, 2014; F1). The available tidal streams are considered negligible, although slower continuous currents may have some tidal power potential (Grahn, 2011; F1; D2).

Worldwide, hundreds of marine energy technology concepts are being developed (EMEC, 2014; Magagna and Uihlein, 2015). Technological diversity is high, although some convergence can be identified within tidal power (IPCC, 2012; Jeffrey et al., 2013; SI Ocean, 2014). Most technology concepts undergo conceptual development and small-scale sea trials, and only a handful have been tested and demonstrated at full scale (Magagna and Uihlein, 2015; OES, 2014a). There are accordingly very few power-producing installations; the total installed capacity only amounted to about 13 MW in 2014 (OES, 2014a), which is less than 1% of that for offshore wind the same year (IEA, 2016). However, with consented projects exceeding 200 MW, it can be expected to increase significantly in coming years (Fig. 1; OES, 2014a).

Despite the early development stage, many national governments promote the sector by setting national deployment targets, making detailed resource assessments, providing market incentives such as feed-in tariffs, establishing open test centers, and supporting RD & D (Table 3; de Jager et al., 2011; OES, 2014b). However, the support offered to marine energy constitutes a very small fraction of the resources dedicated to other renewables (Bloomberg New Energy Finance, 2014). The UK is widely considered the world leader in terms of RD & D activity with over two-thirds of both installed and consented capacity (Fig. 1), many involved actors, and a large number of scientific publications (Corsatea, 2014; OES, 2014a). This position has been attained through strong policy support responding to a large resource potential (Jeffrey et al., 2013; OES, 2014b; Winskel et al., 2014). Public RD & D funding in the UK amounted to roughly 220 MEUR between 2002 and 2011, and about 80% of this targeted testing, demonstration, and deployment activities (Jeffrey et al., 2014). In particular, the European Marine Energy Centre in Orkney is a focal point of global developments (EMEC, 2014), which, together with relatively high feed-in tariffs (DECC, 2013), mobilizes domestic actors, international device developers, and multinational firms. A similar development can be seen in Canada, around the Fundy Ocean Research Centre for Energy in Nova Scotia, as well as in other countries such as Ireland and Portugal (OES, 2014a).

At the supranational level, the EU has highlighted its commitment to marine energy in its recent Blue Energy communication, and provides extensive funding for RD & D through various funding mechanisms (EC, 2014). This has led to a several strategic initiatives and collaborative RD & D projects with actors from several European countries including Sweden (Ingmarsson, 2014). Moreover, Ocean Energy Systems, an initiative under the International Energy Agency, promotes the sector by coordinating the activities of national governments, facilitating multinational research and development (R & D) projects, and disseminating knowledge (OES, 2014a). Sweden is one of 23 member countries, represented by the Swedish Energy Agency (OES, 2014a).

Looking forward, the value chain structure for marine energy technology is uncertain: suppliers may diversify into device development and production, device developers may license or sell their technologies or supply turnkey power plants, and power utilities may own and operate power plants or focus on buying and distributing power. It is also difficult to foresee to what extent technology will be manufactured and assembled locally, close to the site of deployment, versus being exported from other regions. This is likely to depend on the characteristics of the particular technology concept (Huenteler et al., 2016), although what readily comes to mind is a development mirroring what can be observed in the emerging offshore wind sector, where turbine manufacturing facilities are set-up near harbors with globally sourced components and sub-systems (Jacobsson and Karltorp, 2013).

Furthermore, the relationship with other renewables shows indications of both complementarity and competition. There are potential knowledge spillovers and infrastructure complementarities, mainly from the offshore wind sector (Pérez-collazo et al., 2015; Jeffrey et al., 2013). Marine energy technology may help balance other variable renewables (Hammar et al., 2012; Kim et al., 2012). Also, there is a shared need for policy support, which opens opportunities for political coalitions. However, competition for financial investment and supportive government policies is likely if marine energy technologies can prove their reliability and performance and thus become an attractive alternative.

4. Structural components in the Swedish marine energy innovation system

Against the above review of the global context, the focus now turns to the structure of the Swedish marine energy innovation system.

4.1. Actors and technology

Actors in the TIS consist of device developers; suppliers of sub-systems, components, and services; electric utilities; research organizations; public actors; and NGOs. Ten Swedish device developers active in 2014 are identified in this study (Table 4). These are predominantly

[7] Interviewees were chosen to represent different stakeholder perspectives, based on an initial mapping of actors and a snowballing approach where additional key stakeholders were identified during the interviews. Moreover, the study was conducted in parallel with Swedish policy processes (e.g., the development of a funding program for research and development by the Swedish Energy Agency), which enabled the researchers to make direct observations during three multi-stakeholder workshops (referred to as "Meeting Notes"). The process of mapping actors was also supported with material from these parallel processes and databases originating from earlier industry activities (see e.g., Andersson, 2013).

[8] The mapping of public investments included funds from the following agencies: the Swedish Energy Agency, the Swedish Innovation Agency, the Swedish Agency for Economic and Regional Growth, the Swedish Research Council, and Region Västra Götaland. The mapping drew on information from actors' websites, searches in project databases using multiple key words (marine energy, wave energy, tidal energy etc.) and other documentation. Note that some minor beneficiaries may not appear due to methodological limitations of the mapping: only main project owners were included, so project partners in collaborative projects do not appear. In addition, general-purpose projects such as those including both offshore wind and marine energy and minor support to start-up companies were left out. However, it appears that these limitations had insignificant effects on the results, since interviewees confirm the mapping outcome.

[9] The patent data search was performed on 2014-04-03 on the European Patent Office's international database (http://worldwide.espacenet.com) and included Swedish applicants in the patent classes Y02E10/28 (tidal stream or damless hydropower) or Y02E10/38 (wave energy or tidal swell).

[10] The search for bills and motions was performed on 2014-04-22 using multiple key words (marine energy, wave energy, tidal energy, etc.) in the Swedish Parliament's archive (www.riksdagen.se).

[11] The media search was performed on 2014-05-08 using multiple key words (marine energy, wave energy, tidal energy, etc.) in the Retriever Business database (www.business.retriever.se).

[12] The few existing global resource estimates differ in their assumptions and results (IPCC, 2012; Sandén et al., 2014).

[13] For example, innovation may reduce cost and make additional sites attractive, economic development may increase the willingness-to-pay for marine energy, and shifting environmental concerns and changing power relations between different industries and social groups may alter political priorities.

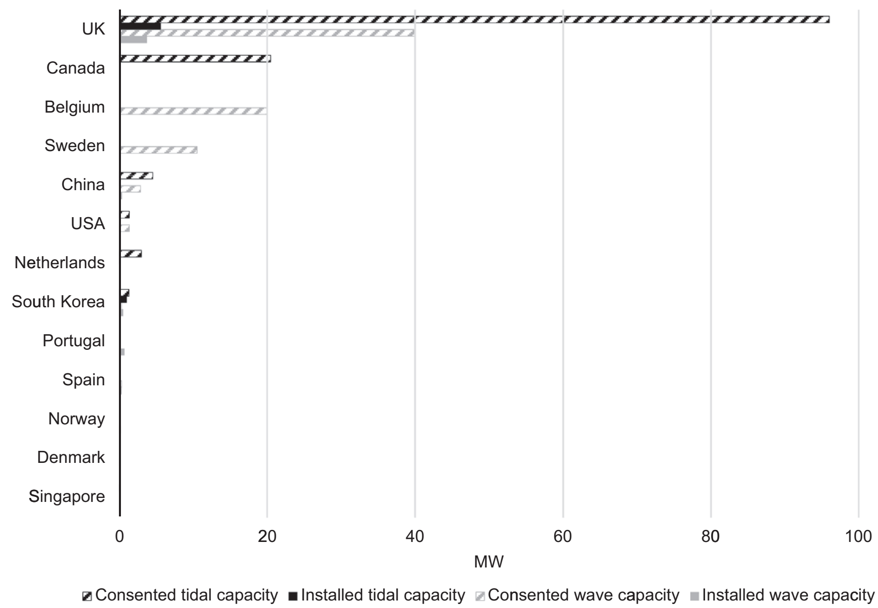


Fig. 1. Global installed and consented marine energy capacity in MW as reported to Ocean Energy Systems in 2014 (OES, 2014a).

Table 3
Policy support offered by different national governments (based on OES, 2014b).

	RD & D support	*Detailed resource assessment*	*National deployment targets*	*Open test centers*	*Feed-in tariff (or similar)*
United Kingdom	x	x	x	x	x
Canada	x	x	x	x	x
Germany	x	x	x	x	x
Ireland	x	x	x	x	
Spain	x	x	x	x	
Italy	x		x		x
China	x	x		x	
USA	x	x		x	
South Korea	x	x	x		
Denmark	x				x
Singapore	x			x	
Portugal	x		x		
Australia	x	x			
Belgium	x	x			
Japan	x	x			
New Zealand		x			
Mexico	x				
Norway	x				
Sweden	x				

Table 4
An overview of Swedish device developers active in 2014[a].

Name	*Technology*	*Employees*	*Phase*	*Location*
CorPower Ocean	Wave	5–10	Lab/tank tests	Stockholm
Current Power	Tidal	< 5	Full-scale river trials	Uppsala
Exim Strömturbiner	Tidal	< 5	Small-scale river trials	Stockholm
Minesto	Tidal	20–30	Small-scale sea trials	Gothenburg
Ocean Dynamic Power	Tidal	< 5	Full-scale river trials	Stockholm
Ocean Harvesting Technologies	Wave	< 5	Lab/tank tests	Karlskrona
Seabased	Wave	60–70	Full-scale sea trials	Uppsala/Lysekil
Vigor Wave Energy	Wave	5–10	Lab/tank tests	Gothenburg
Waves4Power	Wave	< 5	Full-scale sea trials	Gothenburg
WaveTube	Wave	< 5	Lab/tank tests	Gothenburg

[a] Current Power, Ocean Dynamic Power, and Exim Strömturbiner had mainly performed their tests in inland rivers, but their concepts can potentially be applied in both ocean and inland river environments (R2; Ocean Dynamic Power, 2014; Pettersson, 2014).

small start-up companies, and their concepts reflect the technological diversity and immaturity observed globally. Some are university spin-offs, and others are based on ideas from individual inventors or established industry actors (CorPower Ocean, 2012; Current Power, 2014; Minesto, 2013; Seabased, 2013). Seabased, an Uppsala University spin-off, had come the furthest in its development. In 2013, the company started building a demonstration plant on the western Swedish coast that is meant to become the world's largest wave power array with 420 devices and a 10 MW capacity (Seabased, 2015; D1).[14] Minesto was also relatively far in its development, with quarter-scale test activities in Northern Ireland (D2; Minesto, 2013).[15] The other eight device developers had limited activities with few employees and mainly focused on early-stage concept development, modeling, and tank testing.

Suppliers and utilities with relevant capabilities and knowledge, control of physical infrastructure, and access to investment capital are essential for accelerating marine energy technology development (F3; F4; D3). However, these established actors were passive both in Sweden and globally. In 2014, about 20 companies in the power electronics, manufacturing, and offshore sectors had supplier relationships with device developers, ranging from joint development of customized solutions to supply of standard components and informal knowledge exchanges (F3; D3; D4).[16] The multinational bearings

[14] Since the study, Seabased has initiated a collaboration with a utility in Ghana with the ambition to deploy a 14MW wave power array (Seabased, 2015).

[15] Since the study, Minesto has received European Union funding to deploy a 10MW array in Wales (Minesto, 2015).

[16] Only one company, the mooring supplier Seaflex Energy Systems, specializes in

company SKF had had several collaborations with Swedish device developers and also held a number of relevant patents (F3), while the multinational power electronics company ABB was more oriented toward supplying standard components (F1). With regard to utilities, the Finnish company Fortum had by far invested the most in Sweden through its engagement in Seabased's demonstration plant (Fortum, 2011). Other utilities such as Vattenfall, E.ON, and Göteborg Energi had only had minor collaborations with Swedish device developers (F6; D3; Vattenfall, 2011; Waves4Power, n.d.). Instead, large suppliers and utilities in Sweden focused on markets with more promising resource potentials and stronger public support systems (F2; Vattenfall, 2011). On these markets, they employed specialized staff (F2) and invested in device developers (F1). However, the main motivation was to strategically monitor development rather than generate short-term returns (F1; F2; F6; Vattenfall, 2011).

The most engaged research organizations in 2014 were Uppsala University, Chalmers University of Technology (Chalmers), and SP Technical Research Institute of Sweden (SP). Uppsala University's research was considered world leading (Nordgren et al., 2011) with about 50 researchers and 2 marine energy test sites (R2; Uppsala University, 2013a, 2013b). The university focused on applied and multi-disciplinary research related to two specific technology concepts for wave and tidal power (Uppsala University, 2011) and closely collaborated with the spin-off companies Seabased and Current Power (Billquist and Södahl, 2012; R2). Chalmers had conducted wave power research during the 1970s and 1980s, including sea trials in collaboration with industry actors (R3; Waves4Power, n.d.; WERG, 1979), and hosted the collaboration platform Ocean Energy Centre between 2011 and 2014 (Andersson, 2013; R4). In 2014, however, Chalmers' activities were limited to a few doctoral students working with marine energy.[17] SP was involved in a number of R & D initiatives and participated in the European industry association Ocean Energy Europe (R1; R5). In addition, Blekinge Institute of Technology and KTH Royal Institute of Technology had minor collaborations with individual device developers (Ingmarsson, 2014; D3). Minor activities were also found at the research institute SSPA, whose tank testing facility and related competence were used by several device developers (R5; D5).

Among public actors, mainly the Swedish Energy Agency and Swedish Innovation Agency funded RD & D activities (Ingmarsson, 2014; E1; P4; P5; Meeting Notes, 2014c; Swedish Government, 2014). The Swedish Agency for Marine and Water Management (SwAM) is the most prominent actor in the consenting process, though many other public actors on national, regional, and local levels participate. However, their activities were limited by the very small number of sea installations (P3; P4). SwAM also coordinated the development of offshore marine spatial plans expected to become important for marine energy deployment (SwAM, 2014a). In addition, government ministries play an indirect and potentially important role in instructing funding and regulating agencies, although their involvement had been limited (E1).

Region Västra Götaland, a regional administration in western Sweden, previously identified marine energy as a potential driver of regional economic development and provided R & D funding (P1; Wenblad et al., 2012). Moreover, several municipalities, mainly in western Sweden, supported device developers, facilitated sea installations, and developed coastal marine spatial plans (Ingmarsson, 2014; P2; Rantakokko, 2014).

Finally, there were no marine energy-specific NGOs or trade associations active in Sweden in 2014, although they existed in other countries and on a supranational level. However, certain lobby activities had been undertaken within R & D-oriented initiatives, such as proposals for a joint strategic innovation agenda for the industry (Andersson, 2013; Andersson et al., 2013).

4.2. Networks

The most prominent network identified in 2014, hereafter referred to as the Uppsala Network, revolved around Uppsala University and its spin-off companies. It was characterized by extensive person mobility, with key individuals holding employments and positions of trust at both organizations, as well as joint R & D projects (Billquist and Södahl, 2012; D1). There was a strong focus on technologies being commercialized by the spin-off companies, and the network was therefore perceived as closed by other actors (Billquist and Södahl, 2012; R3). Another network evolved from the Ocean Energy Centre, hereafter referred to as the OEC Network, and included device developers and research organizations outside the Uppsala Network. These actors had an informal collaboration that did not focus on a specific technology. Although the OEC Network had significantly less interaction and collaboration than the Uppsala Network, it had played an important role in initiating collaborative R & D projects and developing a joint strategic innovation agenda (Andersson, 2013; R4). Although the Ocean Energy Centre was made inactive in 2014, the network appeared to live on in other initiatives, often led by SP (Meeting Notes, 2014a, 2014b, 2014c).

The Uppsala Network and OEC Network initially had very limited mutual collaboration, and the contacts between Uppsala University and Chalmers had been weak, with few examples of joint research activities (Meeting Notes, 2014a, 2014b, 2014c). However, by 2014 their interaction had increased through various initiatives, most notably in the preparation process for a Swedish Energy Agency funding program (F6; D2; Meeting Notes, 2014c).

Furthermore, firm-specific networks were emerging around device developers, through relationships with specialized suppliers (D2; D3; D4), and in research collaborations (R3; D2), but interactions with large suppliers and utilities remained limited (F3; F6; R4). These networks were often international and focused on the UK, where firms also networked through industry associations in the renewable energy sector (D2; D3; D4).

Finally, networks between public agencies were weak and characterized by a lack of dialogue and coordination (F4; P4; Meeting Notes, 2014c).

4.3. Institutions

The development of marine energy is influenced and largely driven by policies that promote renewable energy technologies. One relevant policy was the Swedish electricity certificate system that included wave power but excluded tidal power (Swedish Government, 2003). However, the system only gave a very small effective price subsidy for wave power compared to other countries that employed technology-specific feed-in tariffs (Sections 3 and 5.7). Financial resources were instead mobilized through substantial public RD & D funding (Section 5.3). Despite this, Swedish energy policy experts did not perceive marine energy as politically prioritized (E1; E2), which is confirmed by the lack of politically endorsed goals, strategies, and planning frameworks (SwAM, 2014a).

There were no marine energy-specific laws and regulations in 2014, but all sea installations for testing and commercial purposes had to undergo a consenting process based on the Swedish Environmental Code and obtain permission from Land and Environmental Courts (The Swedish Energy Agency, 2012). The consenting process handles conflicting interests among stakeholders and between negative local environmental impacts and positive global climate benefits.

Regarding norms, beliefs, and expectations, it is clear that public

(*footnote continued*)
marine energy (F5).

[17] Chalmers also played a role in fostering the device developers Minesto and WaveTube through its business incubator Encubator and its School of Entrepreneurship (Encubator, 2012; D2).

attitudes to marine energy were very positive, and there was no organized opposing lobby (Hedberg, 2011; R2; F6; R3; D2). There had been tensions between the Uppsala Network and stakeholders with an interest in sea space allocation, such as the Swedish Armed Forces and fishing industry, but these were largely resolved (P2; D1). Furthermore, expectations on the Swedish market potential for wave power differed widely due to uncertainties regarding the available resource potential (Section 3). Some actors had a strong belief in the potential for deploying wave power technologies in Sweden, whereas others discarded the resource as insufficient and proposed a focus on export markets (F1; R2; F4; R3).

5. Analysis of functions and blocking factors

The structure of the Swedish marine energy innovation system is clearly weak. To identify factors that hinder further development, this section analyses strengths, weaknesses and interdependencies of functions. The seven identified blocking factors are labelled B1–B7.

5.1. Knowledge development and diffusion

Uppsala University's extensive, broad, and prominent research (Billquist and Södahl, 2012; Nordgren et al., 2011); activities at Chalmers (R3; WERG, 1979); and the advancement of several internationally recognized device developers indicate strength in knowledge development. A patent search identified 102 Swedish marine energy patents (Fig. 2) in 2014. While developments dated back to the 1970s, they were only intensified around the turn of the century. The increased activity was largely driven by Seabased, which holds about one-third of all patents granted between 2000 and 2014. Moreover, knowledge development was strengthened by interactions between Swedish and international actors (D2; D3; F2; F3; F5; R2; R3). For example, Swedish device developers and suppliers engaged in multinational R & D projects (D2; D5; F5), and both Uppsala University and Chalmers had collaborations with foreign universities in countries such as the UK and Denmark (R2; R3).

While knowledge development was relatively strong, knowledge spread poorly in the system. This limited positive externalities and constituted an important weakness in the function. Public investments in RD & D had heavily focused on Seabased's technology (Section 5.3) and led to non-generic knowledge development concentrated in the Uppsala Network. With the exception of graduate and Ph.D. mobility from Uppsala University, limited collaboration and person mobility between the Uppsala Network and other universities and device developers hindered knowledge dissemination to the rest of the system (R2; F4; Billquist and Södahl, 2012). Outside the Uppsala Network, there was also limited collaboration across different technology concepts,[19][20] and between research institutions and private actors (F1; R3; R4; D2; D4; Meeting Notes, 2014b, 2014c). In addition, the links between early research activities at Chalmers and contemporary knowledge development were perceived as weak (F1; R3; R4; D2; D4; Meeting Notes, 2014b, 2014c). Poor knowledge diffusion was mainly due to a lack of social capital (Section 5.5).

Furthermore, there was limited access to capabilities, resources,

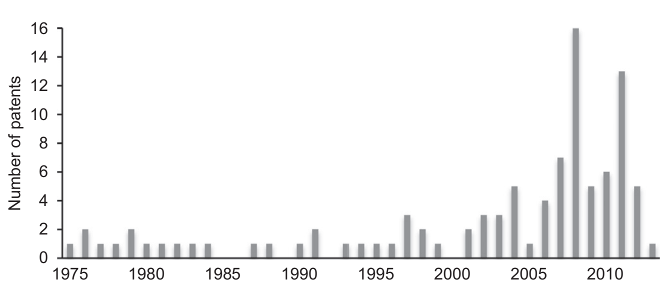


Fig. 2. Swedish marine energy patenting over time.[18]

and knowledge from industries in the energy, manufacturing, and offshore sectors in Sweden and internationally (F1; F3; F6; R2; R4; Ingmarsson, 2014); due to weaknesses in influence on the direction of search (Section 5.6).

5.2. Entrepreneurial experimentation

The extent of historical and on-going RD & D activities indicate strength in entrepreneurial experimentation. In the 1970s, Chalmers and industrial actors performed several wave power sea trials in western Sweden. Around 2005, the Uppsala Network initiated extensive domestic test and demonstration activities of Seabased's and Current Power's technologies, while Minesto performed sea trials in the UK a few years later. Several other device developers also expressed high ambitions for continued experimentation in Sweden and abroad (D2; D4; R5), and there was on-going experimentation with less mature technologies, ranging from conceptual modeling to lab and tank tests (Table 4).

However, an important weakness in entrepreneurial experimentation can be derived from the resource demanding nature of test and demonstration activities. This is mainly because it is considerably more expensive to perform test activities at sea than on land (DNV GL, n.d.; Jeffrey et al., 2013), but Swedish device developers also described limited access to appropriate and reasonably priced domestic test facilities (Ingmarsson, 2014), even though Swedish waters were considered well suited for these purposes (Claesson et al., 1987; Ingmarsson, 2014). This led some developers to experiment abroad,[21] thereby gaining access to both infrastructure and knowledge (EIT, 2013; D2). Some also found the consenting process time and resource demanding due to extensive documentation demands (Ingmarsson, 2014).[22]

In combination with weaknesses in resource mobilization (Section 5.3), limited collaboration among developers (Section 5.1), and passive established actors (Section 5.6), this resulted in persistent uncertainties and knowledge gaps (Hammar, 2014; R2; R5; Meeting Notes, 2014a, 2014c), which mirrored the fairly slow international development (OES, 2014a; Vantoch-Wood, 2012). The limited test and demonstration activities are therefore identified as a critical blocking factor (B1).

5.3. Resource mobilization

Resource mobilization comprises access to public and private financial capital, human capital, relevant infrastructure, and sea sites. The mobilization of Swedish public capital to RD & D until 2014 indicates certain strength. A national funding program had allocated over 1.5 MEUR[23] to wave power R & D between 1976 and 1986. Public

[19] Evidence from UK marine energy development suggests that lack of collaboration can slow the development of the entire technology area (Winskel, 2007). Conversely, increased collaboration can potentially lead to joint knowledge development and achieve the critical mass required to mobilize specialized suppliers, which in turn can create economies of scale that lead to customized and more cost-effective solutions.

[20] One recent initiative gathered three device developers to design a shared concept building on the core technologies and solutions of each. However, this initiative did not involve actors from the Uppsala Network (R5).

[21] The activities of Swedish device developers abroad are generally considered to increase the risk of these companies leaving Sweden and weakening domestic value chain development (F6). However, experimentation abroad can also provide important knowledge about future export markets.

[22] Device developers must demonstrate that the direct environmental impacts of their installations are either marginal or surpassed by their common good (LEC, 2014). Thus, results from extensive environmental studies, building on data that are difficult to obtain without having performed sea trials, were required in early stages, which implies an obvious risk of “catch-22” situations (Meeting Notes, 2014c). Moreover, SwAM was by some considered to lack both knowledge and internal coordination around marine energy (P4) and was not guided by any clear political direction (Section 5.6), which further complicated the consenting process. A national marine spatial planning initiative, ongoing in 2014, could potentially lead to a simplified process (D1; P2; D4; I2; P3).

Table 5
Swedish public funding to marine energy RD & D from January 2003 to April 2014.

Funding agency	Amount (MEUR)	Percentage
Swedish Energy Agency	24.7	89.4%
Swedish Research Council	1.5	5.6%
Region Västra Götaland	0.7	2.4%
Swedish Innovation Agency	0.6	2.3%
Swedish Agency for Economic and Regional Growth	0.1	0.3%
Total	27.6	100%

Table 6
Swedish public funding to marine energy from January 2003 to April 2014.

Beneficiary	Amount (MEUR)	Percentage
Seabased AB	17.6	63.8%
Uppsala University	7.3	26.4%
Chalmers University of Technology	1.1	4.0%
Corpower Ocean AB	0.8	2.9%
Minesto AB	0.6	2.2%
Others	0.2	0.7%
Total	27.6	100%

support then decreased in the 1990s but began rising again after 2005. An analysis of grants to marine energy RD & D projects revealed that 27.6 MEUR was allocated between 2003 and 2014, mainly by the Swedish Energy Agency (Table 5).[24] This is equivalent to roughly 10% of RD & D funding in the UK between 2002 and 2011 (Section 3), which is arguably quite substantial given the limited Swedish domestic resource. Actors within the Uppsala Network received over 90% of public funding during the period (Table 6). Seabased's demonstration plant alone accounted for more than 50%. This largely explains the spike in public funding in 2010 and 2011, which is when the majority of funds was allocated to Seabased (Fig. 3).

Although the magnitude of Swedish public funding had been quite substantial, several actors felt that its distribution had been uninformed and unfair and that its allocation had lacked coordination and transparency (Andersson, 2013; Billquist and Södahl, 2012; Ingmarsson, 2014; R2; F4; R3; D2; R5; E2; P5). A combination of these weaknesses had led to a partly unintentional focus by funding agencies on the Uppsala Network and in particular on Seabased's technology concept. By attracting funds at a relatively early stage, these actors managed to leverage additional funding by pointing to previous achievements. This resulted in a crowding-out effect on other technology concepts (Billquist and Södahl, 2012; Ingmarsson, 2014; R2; R3; D2; R5), which could also be observed in other countries such as the UK (Vantoch-Wood, 2012). Thus, the lack of knowledge and coordination among funding agencies constitutes a blocking factor (B2).

Swedish actors also benefitted from international public funding. For example, Minesto received a substantial grant from the Department of Energy and Climate Change in the UK (Minesto, 2014), and several participated in EU-funded R & D projects (D2; D5; F5). Apart from financially enabling RD & D activities, this gave Swedish device developers access to competence and capabilities from foreign actors, which strengthened knowledge development (Section 5.1).

Private capital mobilization had both strengths and weaknesses. Fortum's investment in Seabased's demonstration plant was extensive, and the other device developers had attracted smaller but significant funds from both domestic and foreign actors (Ingmarsson, 2014; D2; D3). Nevertheless, most actors considered access to private capital in Sweden to be very limited, and several expressed concerns about having to move abroad as a consequence (Fröberg, 2013; D1; D2; Johnsson, 2013; Magnusson et al., 2014). Large suppliers and utilities

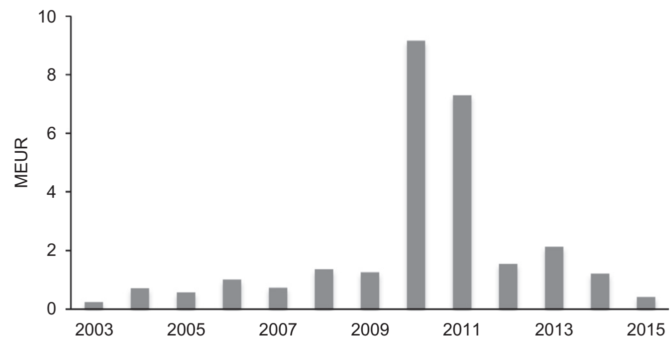


Fig. 3. Swedish public funding to marine energy over time.[25]

active in Sweden had invested in marine energy, but it was primarily abroad and to a decreasing extent over time (Section 5.6).

Regarding infrastructure, the existing power grid in Sweden in 2014 would have had to be extended to enable domestic deployment, to some extent on land (Ingmarsson, 2014; Magagna and Uihlein, 2015), but particularly offshore where there was a need to develop new transmission capacity (F4; Magagna and Uihlein, 2015). Moreover, there was suitable infrastructure for operations and maintenance, although large-scale diffusion may have required increased dock capacity and a larger number of service vessels (R2; I1). Finally, marine energy could potentially have benefitted from the developing offshore wind power infrastructure (D2; E2; Jeffrey et al., 2013), but some actors considered these opportunities to be exaggerated (D4).

The availability of human capital was considered in line with perceived needs, which also indicates strength. Uppsala University had extensive educational activities, and there were also relevant and transferable competence in other industries in the offshore, manufacturing, and energy sectors (F1; F3; R2; D1).

Finally, access to suitable Swedish sea sites was expected to become a challenge if large-scale deployment would become a reality, partly because of the limited domestic resources but also due to potential conflicts of interest (P2; Meeting Notes, 2014c). The latter had been rare[26] until 2014 since there were few installations, but considerate marine spatial planning would be needed to manage forthcoming competition for sea sites (SwAM, 2014a). The maritime strategy and offshore marine spatial plans, under development in 2014, were expected to deal with this issue, but the outcome of these processes remains unclear (Ingmarsson, 2014; E1; P4; Meeting Notes, 2014c).

5.4. Development of social capital

The high levels of trust and extensive collaboration within the Uppsala Network, and to some extent within the OEC Network, indicate certain strengths in the development of social capital. This is contrasted by several indications of important weaknesses.

(footnote continued)
[23] This figure is a nominal value that has not been adjusted for inflation.
[18] The analysis did not provide any specific explanation of the high number of patents in 2008 and 2011. For example, the connection to temporal variations in resource mobilization seems weak, since the spikes in public RD & D funding in 2010 and 2011 came too late to explain patenting variations. Instead, it is plausible that the variations are due to individual actor strategies, but analyzing these is beyond the scope of the study.
[24] The analysis only includes marine energy-specific funding. Funding to more general research activities in academic environments, which may have had some marine energy features, is not covered. To grasp the extent of marine energy research activities, it may therefore be useful to consider the number of researchers working with marine energy, which was about 50 at Uppsala University and 3–4 at Chalmers (Section 4.1). Moreover, all figures are nominal values.

[26] Earlier consenting processes led to conflicts of interest between renewable offshore energy, fishing, shipping, and environmental conservation, although these conflicts were largely resolved (R2; D1; I2; P3; P4).

First, trust and collaboration between the Uppsala Network and OEC Network was very weak.[27] This was partly due to diverse attitudes about collaboration based on different perceptions of the best technology development strategy. The Uppsala Network proposed a strong focus on the most developed technology concept and acted rather closed to other initiatives and actors, which in turn saw an urgent need to unite the industry to share risks and enable joint learning around common challenges (R2; D1; R4; D3; R5; Meeting Notes, 2014b). Second, collaboration between research institutions and commercial actors was perceived as weak with the exception of within the Uppsala Network. There was a lack of understanding regarding differences in roles, drivers, and needs; commercial actors called for more applied research that could benefit their immediate development efforts, while researchers requested stronger capabilities for research collaboration and knowledge transfer among commercial actors, as well as longer time frames (F1; R4; D2; Meeting Notes, 2014b, 2014c). Third, the passivity of established industrial actors, poor coordination among public actors, and distrust of many developers in funding agencies indicate insufficient social networks between developers and actors at the system boundary (Ingmarsson, 2014; F2; F6; P4; Meeting Notes, 2014b). The lack of knowledge and coordination among public actors also resulted in what many perceived to have been an unfair allocation process (see Section 5.3). The outcome of this process contributed to the lack of trust and collaboration among developers (Ingmarsson, 2014; R3; D2; R5).

In summary, the development of social capital was limited by a lack of broader collaboration among actors, which is identified as a blocking factor (B3).

5.5. Legitimation

Very positive public attitudes toward marine energy indicate strong legitimation. A generally positive outlook toward renewable energy drove these attitudes, together with perceived visual and noise benefits compared to wind power (Esteban and Leary, 2012; P2; R3; D2; Meeting Notes, 2014a). Moreover, public actors had developed a positive attitude based on research results showing limited environmental impacts of offshore installations (I2; P4). In addition, the resolution of conflicts between marine energy developers and competing interests led to increased acceptance (R2; D1). Nevertheless, some actors expressed concern that positive attitudes may change if a large-scale deployment takes place or if installations are placed in areas that bring new conflicts of interest (I2; F4). Also, experiences from the UK had shown that marine energy deployment can induce concerns about environmental impacts and the realization of benefits to the local community, despite positive general attitudes (Corsatea, 2014).

Furthermore, increased focus on sustainability, together with a strong commitment to the sector from the EU, led to renewed and intensified political interest. This is confirmed by the increasing number of bills and motions from the Swedish government and parliament mentioning marine energy since the turn of the century (Fig. 4). Individual parliament members had also expressed support in the media (Lundgren, 2011; Tiger, 2009), regional administrations included the sector in strategies and supported R & D activities (P1), and several municipalities showed political interest, for example by including marine energy installations in their spatial planning (P2; Meeting Notes, 2014c). These actors had high expectations that future deployment would create growth opportunities for local businesses (Henricson, 2012; Ingmarsson, 2014; P1; P2; Wangel, 2009).

Another indication of strong legitimation is that Swedish device developers had been gaining international recognition and media attention for their concepts, which had increased the legitimacy of marine energy in Sweden (Corneliusson, 2013; Ehn and Nordin, 2013; Johnsson, 2013; Sievers, 2010; Zerpe, 2008).

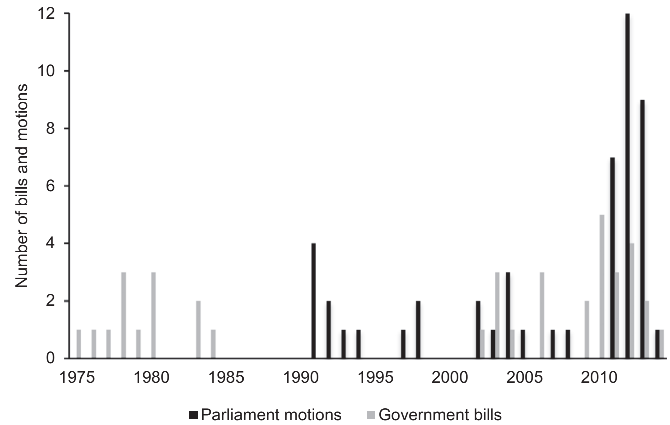


Fig. 4. Number of bills and motions from the Swedish government and parliament mentioning marine energy.

However, political lobbying for marine energy was poor. Some actors had experienced opposition from wind and nuclear power advocates and claimed that marine energy had been marginalized by wind power as a result of weak lobbying efforts (R2; R3; D4). The political interest described above had not led to prioritization of marine energy in terms of political actions, and some political actors held skeptical attitudes (E1; E2; Levin, 2012; Södermanlands Nyheter, 2012). This was partly due to the lack of collaboration among actors (B3) that made it difficult to gather the industry around joint lobbying initiatives, as well as uncertainties regarding the Swedish resource potential (Section 5.6).

Finally, both device developers and other stakeholders stated that attitudes toward marine energy had suffered from national and international technical failures, a lack of long-term test results, safety concerns around sea trials, and a lack of standards for technology evaluation that facilitated the emergence of irresponsible actors (Ingmarsson, 2014; R2; D4; I2; P3; Meeting Notes, 2014b). Hence, the limited test and demonstration activities (B1) affected both knowledge development and legitimation.

5.6. Influence on the direction of search

Interest and belief in the potential of marine energy among many Swedish actors, manifested by the fairly strong mobilization of RD & D funding, indicate strength in influence on the direction of search. This was largely driven by international developments such as the strong commitments showed by policymakers in the EU and the UK.

However, there were several indications of weaknesses in the function. Technical uncertainties concerning the insufficiently demonstrated reliability and affordability of marine energy devices (Section 5.2) discouraged actors from engaging and investing due to high financial risk and long pay-back times (Ingmarsson, 2014). Also, dominant designs[28] had not emerged, which potentially obstructed guidance within the system, increased investment decision complexity, complicated policies for promoting collaborative R & D projects, and constituted a barrier for system entry. Moreover, RD & D projects abroad had been too optimistic about technological maturity and

[25] Public funding is allocated to different years according to the funding agencies' approval decisions.

[27] However, on-going initiatives in 2014, such as the preparation of a funding program at the Swedish Energy Agency, seemed to bring these networks and other actors closer (Meeting Notes, 2014c).

[28] Several technology concepts adapted for different resource and site conditions might exist in parallel as the area matures. Technical diversity can also be a strength in innovation systems characterized by large uncertainties (Jacobsson et al., 2004). In this case, there are indications that the lack of dominant designs and collaboration had limited technological development.

expected results (Jeffrey et al., 2013), which led to a backlash where important suppliers and utilities, some of them Swedish, withdrew from the technology field (Meeting Notes, 2014a; Vantoch-Wood, 2012). This restricted the system's access to knowledge, capabilities, and financial capital, thus limiting the extent of test and demonstration activities. The passivity of established actors is therefore identified as a blocking factor (B4).

Furthermore, the relatively small and uncertain Swedish market potential made many actors dismiss domestic waters as unsuitable for anything except testing (Ingmarsson, 2014; F1; F4; F5; I1; E1). Even though others believed that commercial domestic deployments might be realistic to a small extent and in a longer time perspective (Andersson, 2013; Ingmarsson, 2014; R2; D3), this made actors passive or focus on other markets. Thus, the small and uncertain domestic market potential is identified as a blocking factor (B5).

Finally, there were no political visions, strategies, or roadmaps for marine energy (Andersson, 2013; R2; D4; Meeting Notes, 2014b). Accordingly, it is unclear whether the technology field was politically prioritized and, if so, whether the ambition was to deploy technology in Sweden or create an industry that can supply the global market. The absence of strategies or roadmaps contributed to poor coordination among public actors and was also reflected in the lack of clear instructions to public actors involved in the consenting process for sea installations (R2; P3; P4). Collectively, these features comprise a lack of political direction, which is identified as a blocking factor (B6).

5.7. Market formation

Marine energy was expensive in 2014 (Fig. 5), and there were very few power-producing installations both in Sweden and globally. It was estimated that it would take decades before the technologies could fully compete with other renewables (Esteban and Leary, 2012), which indicates major weaknesses in market formation. At the same time, markets with higher energy prices, various niche applications (e.g., desalination plants and fish farming) and integration with other offshore renewables were considered possible routes to faster commercialization (Hammar, 2014; Ingmarsson, 2014; Meeting Notes, 2014b, 2014c; F5; D4).

Although it is unclear whether the ambition was to deploy technology in Sweden or create an industry that can supply the global market (Section 5.6), domestic market development is considered important for enabling test and demonstration activities and fostering local industry (Lewis and Wiser, 2007). In 2014, the electricity certificate system was the only demand-side policy instrument in Sweden that aimed to stimulate domestic market formation. However, since wave power technology was less mature than other included renewables, the scheme was ineffective in driving market formation. The discrepancy between technology maturity and the design of the Swedish electricity certificate system becomes obvious when the estimated cost of energy for wave power in 2014 is compared to the Swedish electricity price including the certificate subsidy (Fig. 5). In comparison, many European countries had stronger support schemes (Section 3). For example, Fig. 5 illustrates that the UK strike price for wave power was about five times higher than the Swedish electricity price including the electricity certificate subsidy.

The appropriateness of market formation policies obviously depends on the political direction. Presuming that the technology field was of some political interest, which is reasonable given the substantial public RD & D funding (Section 5.3), there was, however, a need for test and demonstration activities that the Swedish demand-side policies failed to enable. Therefore, the lack of sufficient market incentives is identified as a blocking factor (B7).

5.8. Blocking factors

The analysis shows that the functions had several weaknesses that can be explained by seven blocking factors (Table 7). Identifying prioritized policy objectives is possible based on the observations that some of these are partly beyond the reach of policy intervention while others are interdependent (Sandén and Jacobsson, 2014).

The analysis indicates that the small and uncertain domestic market potential (B5) hindered the development of political direction (B6), particularly around the crucial issue of whether policy interventions should aim to deploy marine energy technologies in Sweden or create an industry that can supply the global market. Simultaneously, the absence of political direction (B6) likely added to uncertainty regarding domestic market potential (B5) since policy had not played an active role in shaping expectations. The uncertainties created by these related blocking factors (B5 and B6) had a number of dynamic impacts on the system.

First, they contributed to a lack of knowledge and coordination among public actors (B2), which led to unbalanced allocation of RD & D funding. This reduced trust in the system and limited collaboration among actors (B3).[30] In turn, this hindered the possibilities to pool resources and share risk when carrying out test and demonstration activities, which limited their extent (B1). Another consequence of the poor collaboration among actors (B3) was weak political lobbying for the technology field, which could potentially have resolved uncertain-

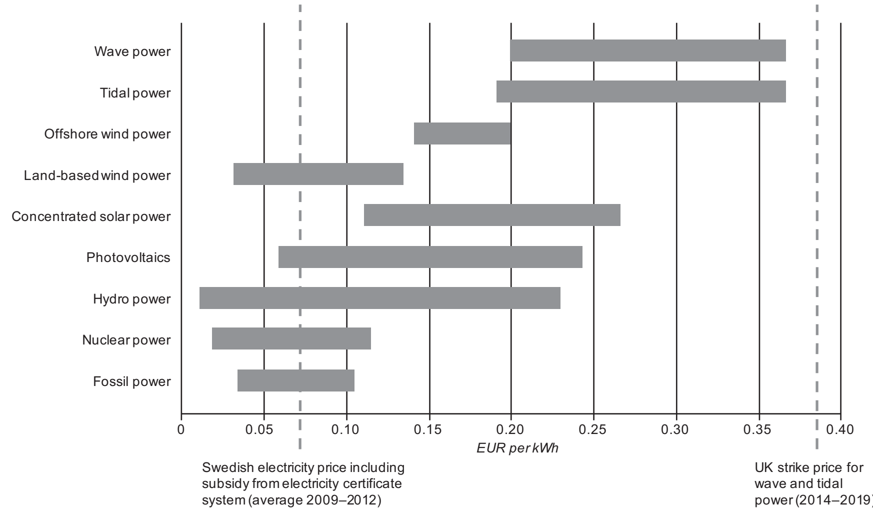


Fig. 5. Costs of electricity from different energy conversion technologies in 2014, as estimated by Bloomberg New Energy Finance (2014),[29] compared to the Swedish electricity price with the electricity certificate system subsidy (Swedish Energy Agency, 2014) and the UK strike price for electricity from marine energy sources (DECC, 2013).

Table 7
An overview of the identified blocking factors and their main impacts on the system.

Blocking factor	*Main impacts*
B1. Limited test and demonstration activities	Persistent technical uncertainties, knowledge gaps, and skeptical attitudes among some actors
B2. Lack of knowledge and coordination among public actors	Unbalanced allocation of public funding, concentrated knowledge development, low levels of trust, and limited collaboration among actors
B3. Lack of collaboration among actors	Limited knowledge diffusion, few joint RD & D projects (which enable resource-pooling and risk sharing), and poor political lobbying
B4. Passivity of established actors	Lack of knowledge, capabilities, and financial capital
B5. Small and uncertain domestic market potential	Passive established actors, focus on foreign markets, and lack of political direction
B6. Lack of political direction	Lack of clear instructions to and coordination among public actors, passive established actors, and uncertainties regarding the domestic market potential
B7. Insufficient market incentives	Lack of market incentives for test and demonstration activities and passive established actors

ties by stimulating the development of political direction (B6). Second, the small and uncertain domestic market potential (B5) and lack of political direction (B6) made established actors with much-needed capabilities and resources passive and reluctant to enter the system (B4), which limited test and demonstration activities (B1). The end result was persistent technical uncertainties that perpetuated the passivity of established actors (B4). Finally, the unclear role of the domestic market contributed to the lack of sufficient market incentives (B7), further hindering test and demonstration activities (B1) beyond pilot-scale experiments and adding to the passivity of established actors (B4).

The described interdependencies among the blocking factors show that if policymakers wished to promote marine energy in Sweden in 2014, they primarily needed to address the lack of political direction (B6) and reduce uncertainties regarding domestic market potential (B5). If these central blocking factors had been addressed, it is likely that the performance of the innovation system would have been enhanced through increased collaboration and strengthened engagement of established actors. This could in turn have mobilized resources, stimulated RD & D activities, and led to technological advancement.

6. Discussion

The analysis clearly shows that an informed political direction could have played an important role in advancing the Swedish marine energy innovation system from its state in 2014. Three main alternatives can be identified: Swedish policymakers may conclude that marine energy merits no political attention, which implies that support policies should be consciously withdrawn; the ambition can be to achieve domestic deployment; or the focus can be on creating an export industry. Since public support to renewable energy technology is normally driven by a desire to stimulate domestic low-carbon power production, securing the energy supply, and creating industries, jobs, and exports (Swedish Government, 2012, 2009),[31] the political direction should ultimately correspond to the technology's potential contribution to these objectives. Although assessing the domestic market and global export potentials is clearly difficult, a necessary starting-point is to reduce uncertainties regarding the domestic resource endowment.

If the political direction were to focus on exports, a significant challenge would be ensuring that industrial development and job creation takes place in Sweden even though there is no domestic market. Experiences from solar power in Germany demonstrate that policy interventions designed to promote a technology field may unintentionally lead to industry growth and economic benefits that largely arise abroad (Binz et al., 2014; Pegels and Lütkenhorst, 2014). In these cases, public support may still make important contributions at a global level by reducing the cost of renewable energy technology, but this may not necessarily be in line with the policy rationale that originally motivated the investments. Introducing support systems that stimulate a domestic niche market for testing and demonstration might retain parts of the value chain in Sweden despite an export focus, which is emphasized by experiences from wind power (Lewis and Wiser, 2007). However, this may unintentionally promote technologies adapted for Swedish conditions but not necessarily suitable for export.

Unless the political direction implies withdrawn support policies, it has to be concretized in strategies and roadmaps that create balance, predictability, and transparency in support systems. This is likely to facilitate coordination among public actors in different policy areas such as research, innovation, energy, and environment, as well as guide them in balancing global climate benefits against local environmental impacts when allocating sea space. In addition, a clear political direction can potentially build trust and stimulate collaboration, as well as attract established actors with important capabilities and resources. This would likely reduce technical uncertainties by stimulating knowledge diffusion and enabling test and demonstration activities. However, the ultimate decisions to invest, engage, and collaborate lie with the industrial and academic actors.

Many of the findings in this study are in line with previous research on marine energy in other national contexts. For example, Hamawi and Negro (2012) highlighted the need for a clear vision and more collaboration in Portugal, while Vantoch-Wood (2012) emphasized the need for coherent and transparent innovation support in the UK. However, this paper paints a slightly different picture of the Swedish marine energy innovation system than Corsatea (2014), which described Sweden as having very high private and public investments relative to many other European countries. This is largely because that analysis drew heavily on data from 2011, which was an exceptional year in terms of Swedish resource mobilization (Section 5.3). Moreover, by focusing on quantitative data, Corsatea (2014) failed to highlight uncertainties regarding resource availability and political direction, weak networks and poor collaboration, and passivity of established actors.

Finally, the critical role of informed political direction has also been pointed out in the broader innovation literature, where scholars emphasize the importance of collective priorities and strategic policy approaches, and point to lack of directionality as a common failure in innovation processes (Mazzucato, 2016; Weber and Rohracher, 2012). However, the case of marine energy in Sweden further emphasizes its importance in early development stages, as well as its connection to domestic market potential. In addition, the case highlights an important area for further research, namely policy challenges associated with promoting a technology field where domestic market potential is highly limited—or at least disputed—but for which there is promising innovation activity and export potential. This also underlines calls for

[30] Although uninformed and uncoordinated policy actions have induced poor collaboration among actors, this is obviously not the only influencing factor.

[29] This report is supported by SI Ocean (n.d.), which estimated the cost of electricity at 0.30–0.59 EUR per kWh.

[31] An additional rationale is the potential contribution to global sustainable development by supporting technologies that can be deployed abroad, especially in developing countries.

methodological advancements to account for the geographical dimension of innovation, to which a number of recent studies have responded by exploring novel empirical approaches that focus on transnational TIS linkages and dynamics (Binz et al., 2014, 2012; Gosens et al., 2015; Quitzow, 2015; Vasseur et al., 2013).

7. Conclusions and policy implications

This study reveals that in 2014 both the Swedish marine energy innovation system and the global sector as a whole was characterized by immature and expensive technologies. Marine energy has a substantial global market potential, but it is domestically limited and at the time uncertain. Despite promising device developers and world-class research, established industrial actors and private investors remained passive. Public funding had been substantial, although its allocation was questionable; coordination among policy actors was poor; and no visions, strategies, or roadmaps were in place. Among certain actor groups, social networks were strong with highly concentrated knowledge development, but there was a lack of knowledge diffusion, collaboration, and trust in the system as a whole. Finally, market incentives were insufficient to stimulate testing and demonstration.

The analysis clearly highlights the critical role of informed political direction in the development of a new technology field. For marine energy, the focus can be either domestic deployment or creating an export industry, unless the technology field is deemed not to merit any political attention. Determining the appropriate direction requires assessments of domestic market and export potentials in relation to the policy rationales that motivate public support. Furthermore, in case the political direction involves policy intervention, it needs to be concretized in strategies and roadmaps that target the observed weaknesses and blocking factors.

These findings are largely in line with previous research on innovation in marine energy, as well as with the broader innovation literature. However, the analysis of Swedish marine energy further emphasizes the importance of political direction in early development stages, highlights its connection to the domestic market potential, and underlines the need for methodological advancements that account for the geographical dimension of innovation.

Acknowledgements

The study presented in this paper was funded by the Swedish Energy Agency (Grant no. 39885-1). Officials from this agency also participated in interviews and workshops that provided valuable input to the analysis and the authors are thankful for this contribution. An earlier version of the paper was presented at the 6th International Sustainability Transitions Conference in Brighton, UK, in August 2015. The authors are grateful for points raised at the conference, valuable comments from anonymous referees, and the engagement of the many interviewees who made this work possible.

References

Andersson, J., 2013. Blå energi – En strategisk innovationsagenda för marin energi. Chalmers University of Technology, Sweden, (Accessible at)⟨http://publications.lib.chalmers.se/records/fulltext/176376/local_176376.pdf⟩.

Andersson, J., Bolund, B., Carlson, O., Fängström, O.D., Jansson, A., Larsson, T., Lindelöf, U., Lord, R., Losman, B., Möller, P., Sidenmark, M., Waller, E., 2013. Fiska jobb och energi ur havet. NyTeknik, 29.

Bergek, A., 2012. Ambiguities and challenges in the functions approach to TIS analysis: a critical literature review. In: Proceedings of the International Conference on Sustainability Transitions. Copenhagen, Denmark.

Bergek, A., Jacobsson, S., Sandén, B.A., 2008b. "Legitimation" and "development of positive externalities": two key processes in the formation phase of technological innovation systems. Technol. Anal. Strateg. Manag. 20, 575–592. http://dx.doi.org/10.1080/09537320802292768.

Bergek, A., Jacobsson, S., Carlsson, B., Lindmark, S., Rickne, A., 2008a. Analyzing the functional dynamics of technological innovation systems: a scheme of analysis. Res. Policy 37, 407–429. http://dx.doi.org/10.1016/j.respol.2007.12.003.

Bergek, A., Hekkert, M., Jacobsson, S., Markard, J., Sandén, B., Truffer, B., 2015. Technological innovation systems in contexts: conceptualizing contextual structures and interaction dynamics. Environ. Innov. Soc. Transit. 16, 51–64. http://dx.doi.org/10.1016/j.eist.2015.07.003.

Bernhoff, H., Sjöstedt, E., Leijon, M., 2006. Wave energy resources in sheltered sea areas: a case study of the Baltic SeaRenew. Energy 31, 2164–2170. http://dx.doi.org/10.1016/j.renene.2005.10.016.

Billquist, K., Södahl, B., 2012. Utvärdering av CFE II 2011. Report to the Swedish Energy Agency.

Binz, C., Truffer, B., Coenen, L., 2014. Why space matters in technological innovation systems—Mapping global knowledge dynamics of membrane bioreactor technology. Res. Policy 43, 138–155. http://dx.doi.org/10.1016/j.respol.2013.07.002.

Binz, C., Truffer, B., Li, L., Shi, Y., Lu, Y., 2012. Conceptualizing leapfrogging with spatially coupled innovation systems: the case of onsite wastewater treatment in China. Technol. Forecast. Soc. Change 79, 155–171. http://dx.doi.org/10.1016/j.techfore.2011.08.016.

Bloomberg New Energy Finance, 2014. Global Trends in Renewable Energy Investment. Frankfurt, Germany. Accessible at: ⟨http://fs-unep-centre.org/system/files/globaltrendsreport2014.pdf⟩

Claesson, L., Forsberg, J., Rylander, A., Rindby, T., 1987. Energi från havets vågor. Energiforskningsnämnden, Stockholm, Sweden.

Corneliusson, M., 2013. Centerpartister besökte Seabased. Bohusläningen, 22 January, 11.

CorPower Ocean, 2012. CorPower Ocean. ⟨http://www.corpowerocean.com⟩ > (accessed 04.14).

Corsatea, T.D., 2014. Increasing synergies between institutions and technology developers: lessons from marine energy. Energy Policy 74, 1–16. http://dx.doi.org/10.1016/j.enpol.2014.07.006.

Current Power, 2014. Current Power. ⟨http://www.currentpower.eu⟩ > (accessed 04.14).

D1, 2014. Anonymous telephone interview with representative from Swedish device developer, 19 March.

D2, 2014. Anonymous personal interview with representative from Swedish device developer, 7 April.

D3, 2014. Anonymous personal interview with representative from Swedish device developer, 11 April.

D4, 2014. Anonymous telephone interview with representative from Swedish device developer, 13 March.

D5, 2014. Anonymous personal interview with representative from Swedish device developer, 10 October.

Dalton, G., Ó Gallachóir, B.P., 2010. Building a wave energy policy focusing on innovation, manufacturing and deployment. Renew. Sustain. Energy Rev. 14, 2339–2358. http://dx.doi.org/10.1016/j.rser.2010.04.007.

DECC, 2013. Investing in renewable technologies – CfD contract terms and strike prices. Report from the UK Department of Energy & Climate Change. Accessible at: ⟨https://www.gov.uk/government/uploads/system/uploads/attachment_data/file/263937/Final_Document_-_Investing_in_renewable_technologies_-_CfD_contract_terms_and_strike_prices_UPDATED_6_DEC.pdf⟩

DNV GL, n.d. Offshroe Wind 10 Years 10 Lessons Reflections on a decade of experience. Accessible at: ⟨http://www.gl-group.com/assets/technical/10years_10_lessons_GL_GH.pdf⟩

E1, 2014. Anonymous personal interview with Swedish policy expert, 8 April.

E2, 2014. Anonymous personal interview with Swedish policy expert, 1 April.

EC, 2014. Blue Energy: action needed to deliver on the potential of ocean energy in European seas and oceans by 2020 and beyond. Communication from the commission to the European Parliament, the Council, the European Economic and Social Committee and the Committee of the Regions. European Commission, Brussels, Belgium, (COM(2014)(8).

Ehn, T., Nordin, L., 2013. Framtidens energi finns i Bohuslän. Bohusläningen, 16 October, 23.

EIT, 2013. KIC InnoEnergy: CorPower Ocean – Getting Closer to the Sea. European Institute of Innovation & Technology. http://eit.europa.eu/newsroom/kic-innoenergy-corpower-ocean-–-getting-closer-sea > (accessed 04.14).

EMEC, 2014. European Marine Energy Centre. < ⟨www.emec.org.uk⟩(accessed 03.14).

Encubator, 2012. Encubator. ⟨http://www.encubator.com⟩(accessed 04.14).

Esteban, M., Leary, D., 2012. Current developments and future prospects of offshore wind and ocean energy. Appl. Energy 90, 128–136. http://dx.doi.org/10.1016/j.apenergy.2011.06.011.

F1, 2014. Anonymous telephone interview with representative from Swedish firm, 22 April.

F2, 2014. Anonymous telephone interview with representatives from Swedish firm, 28 April.

F3, 2014. Anonymous personal interview with representatives from Swedish firm, 7 March.

F4, 2014. Anonymous personal interview with representative from Swedish firm, 3 April.

F5, 2014. Anonymous telephone interview with representative from Swedish firm, 2 April.

F6, 2014. Anonymous telephone interview with representative from Swedish firm, 4 April.

Fortum, 2011. Fortum and Seabased AB to start construction of a wave power park in Sweden. ⟨http://www.fortum.com/en/mediaroom/Pages/fortum-and-seabased-ab-to-start-construction-of-a-wave-power-park-in-sweden.aspx⟩(accessed 04.14).

Foxon, T.J., Gross, R., Chase, A., Howes, J., Arnall, A., Anderson, D., 2005. UK innovation systems for new and renewable energy technologies: drivers, barriers and systems failures. Energy Policy 33, 2123–2137. http://dx.doi.org/10.1016/j.enpol.2004.04.011.

Fröberg, J., 2013. Sex heta miljöteknikbolag blev sex iskalla. Svenska Dagbladet, 5 July,

4.
Gosens, J., Lu, Y., Coenen, L., 2015. The role of transnational dimensions in emerging economy "technological innovation systems" for clean-tech. J. Clean. Prod. 86, 378–388. http://dx.doi.org/10.1016/j.jclepro.2014.08.029.
Grahn, D., 2011. Utredning av möjligheterna till marin förnybar energi i Öresund (M.Sc. Thesis). Department of Technology and Society, Lund Institute of Technology, Sweden.
Hamawi, S., Negro, S.O., 2012. Wave Energy in Portugal The paths towards a successful implementation. In: Proceedings of the International Conference on Ocean Energy. Dublin, Ireland.
Hammar, L., 2014. Power from the Brave New Ocean - Marine Renewable Energy and Ecological Risks (Ph.D. Thesis). Department of Energy and Environment, Chalmers University of Technology, Sweden.
Hammar, L., Ehnberg, J., Mavume, A., Cuamba, B.C., Molander, S., 2012. Renewable ocean energy in the Western Indian Ocean. Renew. Sustain. Energy Rev. 16, 4938–4950. http://dx.doi.org/10.1016/j.rser.2012.04.026.
Hedberg, P., 2011. Färre vill satsa mer på vindkraft. In: Holmberg, S., Weibull, L., Oscarsson, H. (Eds.), Lycksalighetens ö. SOM Institute, Gothenburg University, Sweden, (red).
Hekkert, M.P., Negro, S.O., 2009. Functions of innovation systems as a framework to understand sustainable technological change: empirical evidence for earlier claims. Technol. Forecast. Soc. Change 76, 584–594. http://dx.doi.org/10.1016/j.techfore.2008.04.013.
Hekkert, M.P., Suurs, R.A.A., Negro, S.O., Kuhlmann, S., Smits, R.E.H.M., 2007. Functions of innovation systems: a new approach for analysing technological change. Technol. Forecast. Soc. Change 74, 413–432. http://dx.doi.org/10.1016/j.techfore.2006.03.002.
Henricson, L., 2012. Alliansförslag skapar irritation. Göteborgs-Post. 30 (May), 11.
Hillman, K.M., Sandén, B.A., 2008. Exploring technology paths: the development of alternative transport fuels in Sweden 2007–2020. Technol. Forecast. Soc. Change 75, 1279–1302. http://dx.doi.org/10.1016/j.techfore.2008.01.003.
Huenteler, J., Schmidt, T.S., Ossenbrink, J., Hoffmann, V.H., 2016. Technology life-cycles in the energy sector - Technological characteristics and the role of deployment for innovation. Technol. Forecast. Soc. Change 104, 102–121. http://dx.doi.org/10.1016/j.techfore.2015.09.022.
I1, 2014. Anonymous personal interview with representative from Swedish industry association, 9 April.
I2, 2014. Anonymous personal interview with representative from Swedish industry association, 7 April.
IEA, 2016. About offshore wind. International Energy Agency. ⟨http://www.iea.org/topics/renewables/subtopics/wind/⟩ (accessed 09.16)
Ingmarsson, P., 2014. Förstudie om havsenergibranschens forsknings och utvecklingsbehov. Report to the Swedish Energy Agency. SP Technical Research Institute of Sweden and ÅF-Infrastructure AB, Sweden.
IPCC, 2012. Renewable Energy Sources and Climate Change Mitigation. Special report of the Intergovernmental Panel on Climate Change. Prepared by Working Group III [O. Edenhofer, R. Pichs-Madruga, Y. Sokona (eds.)]. IPCC, Geneva, Switzerland
IPCC, 2014. Climate Change 2014: Synthesis Report. Contribution of Working Groups I, II and III to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change [Core Writing Team, R.K. Pachauri and L.A. Meyer (Eds.)]. IPCC, Geneva, Switzerland
Jacobsson, S., Karltorp, K., 2013. Mechanisms blocking the dynamics of the European offshore wind energy innovation system – Challenges for policy intervention. Energy Policy 63, 1182–1195. http://dx.doi.org/10.1016/j.enpol.2013.08.077.
Jacobsson, S., Sandén, B., Bångens, L., 2004. Transforming the energy system—the evolution of the German technological system for solar cells. Technol. Anal. Strateg. Manag. 16, 3–30. http://dx.doi.org/10.1080/0953732032000199061.
de Jager, D., Klessmann, C., Stricker, E., Winkel, T., de Visser, E., Koper, M., 2011. Financing Renewable Energy in the European Energy Market. Report to the European Commission. (doi:http://dx.doi.org/10.1016/j.energy.2010.07.004)
Jeffrey, H., Jay, B., Winskel, M., 2013. Accelerating the development of marine energy: exploring the prospects, benefits and challenges. Technol. Forecast. Soc. Change 80, 1306–1316. http://dx.doi.org/10.1016/j.techfore.2012.03.004.
Jeffrey, H., Sedgwick, J., Gerrard, G., 2014. Public funding for ocean energy: a comparison of the UK and U.S. Technol. Forecast. Soc. Change 84, 155–170. http://dx.doi.org/10.1016/j.techfore.2013.08.006.
Johnsson, L., 2013. Aktier ska förverkliga Seabaseds nya fabrik. Bohusläningen 27, (June, 17).
Kerr, S., Watts, L., Colton, J., Conway, F., Hull, A., Johnson, K., Jude, S., Kannen, A., MacDougall, S., McLachlan, C., Potts, T., Vergunst, J., 2014. Establishing an agenda for social studies research in marine renewable energy. Energy Policy 67, 694–702. http://dx.doi.org/10.1016/j.enpol.2013.11.063.
Kim, C.-K., Toft, J.E., Papenfus, M., Verutes, G., Guerry, A.D., Ruckelshaus, M.H., Arkema, K.K., Guannel, G., Wood, S. a., Bernhardt, J.R., Tallis, H., Plummer, M.L., Halpern, B.S., Pinsky, M.L., Beck, M.W., Chan, F., Chan, K.M. a., Levin, P.S., Polasky, S., 2012. Catching the right wave: evaluating wave energy resources and potential compatibility with existing marine and coastal usesPLoS One 7, e47598. http://dx.doi.org/10.1371/journal.pone.0047598.
LEC, 2014. Ansökan om tillstånd för uppförande och drivande av vindkraftverk i Kattegatt. Mål nr M 2036-12. The Swedish Land and Environmental Court, Vänersborg, Sweden, (Court proceedings).
Levin, D., 2012. Politiker avvaktar satsningar. Dagens Nyh., 1 Oct., 9.
Lewis, J.I., Wiser, R.H., 2007. Fostering a renewable energy technology industry: an international comparison of wind industry policy support mechanisms. Energy Policy 35, 1844–1857. http://dx.doi.org/10.1016/j.enpol.2006.06.005.
Lindroth, S., Leijon, M., 2011. Offshore wave power measurements - a review. Renew. Sustain. Energy Rev. 15, 4274–4285. http://dx.doi.org/10.1016/j.rser.2011.07.123.
Løvdal, N., Neumann, F., 2011. Internationalization as a strategy to overcome industry barriers-An assessment of the marine energy industry. Energy Policy 39, 1093–1100. http://dx.doi.org/10.1016/j.enpol.2010.11.028.
Lundgren, A., 2011. Vågkraften har potential i Sverige. GT, 31 January, 19.
Magagna, D., Uihlein, A., 2015. 2014 JRC Ocean Energy Status Report. Technology, market and economic aspects of ocean energy in Europe. The European Commission's Joint Research Centre, Petten, The Netherlands. http://dx.doi.org/10.2790/866387.
Magnusson, M., Lindner, G., Edlund, M., 2014. Statliga fonder agerar som kortsiktiga riskkapitalister. Dagens Nyheter (web ed.), 28 March. ⟨http://www.dn.se/debatt/statliga-fonder-agerar-som-kortsiktiga-riskkapitalister/⟩ (accessed 04.14)
Markard, J., Truffer, B., 2008. Technological innovation systems and the multi-level perspective: towards an integrated framework. Res. Policy 37, 596–615. http://dx.doi.org/10.1016/j.respol.2008.01.004.
Mazzucato, M., 2016. From market fixing to market-creating: a new framework for innovation policy. Ind. Innov. 23, 140–156. http://dx.doi.org/10.1080/13662716.2016.1146124.
Meeting Notes, 2014a. Notes from marine energy workshop organized by SP Technical Research Institute of Sweden. Gothenburg, Sweden, 11 April.
Meeting Notes, 2014b. Notes from Ocean Energy Centre workshop organized by Chalmers University of Technology. Gothenburg, Sweden, 21 May.
Meeting Notes, 2014c. Notes form workshop on business, environment and renewable energy in Western Sweden organized by The Swedish Federation of Business Owners, Fouriertransform and Sotenäs Municipality. Smögen, Sweden, 26 June
Minesto, 2013. Minesto. ⟨http://www.minesto.com⟩ (accessed 03.14)
Minesto, 2014. Det brittiska energidepartementet tilldelar £500,000 för fortsatt utveckling av Deep Green. ⟨http://minesto.com/det-brittiska-energidepartementet-tilldelar-500000-for-fortsatt-utveckling-av-deep-green/⟩ (accessed 07.15).
Minesto, 2015. Welsh Government invests 13 million euros of EU funds in marine energy leader Minesto to start the commercial roll out of marine power plants in Wales. ⟨http://minesto.com/welsh-government-invests-13-million-euros-of-eu-funds-in-marine-energy-leader-minesto-to-start-the-commercial-roll-out-of-marine-power-plants-in-wales/⟩ (accessed 07.15).
Negro, S.O., Alkemade, F., Hekkert, M.P., 2012. Why does renewable energy diffuse so slowly? A review of innovation system problems. Renew. Sustain. Energy Rev. 16, 3836–3846. http://dx.doi.org/10.1016/j.rser.2012.03.043.
Nordgren, J., Andersson, P., Eriksson, L., Sundquist, B., 2011. Quality and Renewal 2011. An overall evaluation of research at Uppsala University 2010/2011. Uppsala University, Sweden, (Accessible at)⟨http://www.teknat.uu.se/digitalAssets/385/385022_3quality-renewal.pdf⟩.
Nyheter, S., 2012. Nej till vågkraft i Oxelösund. Södermanlands Nyheter, 12 October, 6.
Ocean Dynamic Power, 2014. We're here to change things. ⟨http://odp-group.com/about-odp/⟩ (accessed 05.14).
OES, 2014a. Annual Report: Implementing Agreement on Ocean Energy Systems. Accessible at: ⟨https://report2014.ocean-energy-systems.org⟩
OES, 2014b. ⟨,⟩. Ocean energy: review of supporting policies. Ocean Energy Systems. Accessible at: ⟨https://www.ocean-energy-systems.org/library/oes-technical-reports/market-policies-overview/document/policy-study-review-2014/⟩
P1, 2014. Anonymous personal interview with representative from Swedish public actor, 17 April.
P2, 2014. Anonymous personal interview with representative from Swedish public actor, 8 April.
P3, 2014. Anonymous personal interview with representative from Swedish public actor, 7 April.
P4, 2014. Anonymous personal interview with representative from Swedish public actor, 8 April.
P5, 2014. Anonymous personal interview and continuous communication with representatives from Swedish public actor, March-June.
Pegels, A., Lütkenhorst, W., 2014. Is Germany's energy transition a case of successful green industrial policy? Contrasting wind and solar PV. Energy Policy 74, 522–534. http://dx.doi.org/10.1016/j.enpol.2014.06.031.
Perez Vico, E., 2014. An in-depth study of direct and indirect impacts from the research of a physics professor. Sci. Public Policy 41, 701–719. http://dx.doi.org/10.1093/scipol/sct098.
Pérez-collazo, C., Greaves, D., Iglesias, G., 2015. A review of combined wave and offshore wind energy. Renew. Sustain. Energy Rev. 42, 141–153. http://dx.doi.org/10.1016/j.rser.2014.09.032.
Pettersson, I., 2014. Personal communication, 15 May.
Quitzow, R., 2015. Dynamics of a policy-driven market: the co-evolution of technological innovation systems for solar photovoltaics in China and Germany. Environ. Innov. Soc. Transit. 17, 126–148. http://dx.doi.org/10.1016/j.eist.2014.12.002.
R1. Anonymous personal interview with representative from Swedish research organization, 24 April.
R2, 2014. Anonymous personal interview with representative from Swedish research organization, 3 April.
R3, 2014. Anonymous personal interview with representatives from Swedish research organization, 1 April.
R4, 2014. Anonymous personal interview with representative from Swedish research organization, 1 April.
R5, 2014. Anonymous personal interview and continuous communication with representative from Swedish research organization, March-June.
Rantakokko, E., 2014. De ska enas om havets villkor. Bohusläningen, 29 January, 11.
Rourke, F.O., Boyle, F., Reynolds, A., 2010. Tidal energy update 2009. Appl. Energy 87, 398–409. http://dx.doi.org/10.1016/j.apenergy.2009.08.014.
Sandén, B., Jacobsson, S., 2014. Teknikpolitiska lärdomar. In: Hellsmark, H. (ed.),

Teknologiska Innovationssystem Inom Energiområdet. Report to the Swedish Energy Agency, ER 2014:23.
Sandén, B., Hammar, L., Hedenus, F., 2014. Are renewable energy resources large enough to replace non-renewable energy? In: Sandén, B. (Ed.), Systems Perspectives on Renewable Power. Chalmers University of Technology, Sweden.
Sandén, B.A., Hillman, K.M., 2011. A framework for analysis of multi-mode interaction among technologies with examples from the history of alternative transport fuels in Sweden. Res. Policy 40, 403–414. http://dx.doi.org/10.1016/j.respol.2010.12.005.
Seabased, 2013. Seabased. ⟨http://www.seabased.com⟩ (accessed 03.14).
Seabased, 2015. Newsroom. ⟨http://www.seabased.com/en/newsroom⟩(accessed 07.15).
SI Ocean, n.d. Ocean Energy: State of the Art. Accessible at: ⟨http://si-ocean.eu/en/upload/docs/WP3/Technology/Status Report_FV.pdf⟩
SI Ocean, 2014. Wave and Tidal Energy Strategic Technology Agenda. Accessible at: ⟨http://www.oceanenergy-europe.eu/images/OEF/140215_SI_Ocean_-_Srategic_Technology_Agenda.pdf⟩
Sievers, J., 2010. Uppfinning från LiU hyllas. Norrköp. Tidn. 6 (December), 14.
Stern, N., 2006. The economics of climate change – the Stern review. Cambridge University Press, Cambridge, UK.
Suurs, R.A., Hekkert, M.P., 2009. Cumulative causation in the formation of a technological innovation system: the case of biofuels in the Netherlands. Technol. Forecast. Soc. Change 76, 1003–1020. http://dx.doi.org/10.1016/j.techfore.2009.03.002.
SwAM, 2014a. Marine spatial planning - Current status 2014. Report by the Swedish Agency for Water and Marine Management. Accessible at: ⟨https://www.havochvatten.se/download/18.44319c4a145d364b807436c/1402924457106/marine-spatial-planning-current-status-2014-english.pdf⟩
Swedish Energy Agency, 2014. Kontrollstation för elcertifikatsystemet 2015. Report by the Swedish Energy Agency. ER 2014:04. Accessible at: ⟨https://www.energimyndigheten.se/globalassets/nyheter/2014/kontrollstation-2015.pdf⟩
Swedish Government, 2003. Regeringens proposition 2003/04:42. Torv och elcertifikat. Bill from the Swedish Government, Stockholm, Sweden.
Swedish Government, 2009. Regeringens proposition 2008/09:163. En sammanhållen klimat- och energipolitik – Energi. Bill from the Swedish Government, Stockholm, Sweden.
Swedish Government, 2012. Regeringens proposition 2012/13:21. Forskning och innovation för ett långsiktigt hållbart energisystem. Bill from the Swedish Government, Stockholm, Sweden.
Swedish Government, 2014. Den maritima strategin växer fram. ⟨http://www.regeringen.se/sb/d/18185⟩(accessed 07.14).
The Carbon Trust, 2011. Accelerating marine energy. Accessible at: ⟨https://www.carbontrust.com/media/5675/ctc797.pdf⟩
The Carbon Trust, 2012. Marine Energy Briefing. Accessible at: ⟨https://www.carbontrust.com/resources/reports/technology/accelerating-marine-energy⟩
The Swedish Energy Agency, 2012. Utvecklingen av tillståndsprocesser för anläggningar som producerar förnybar el och för kraftnät. http://www.energimyndigheten.se/Global/Press/Pressmeddelanden/Redovisning_av_uppdrag_10_i_Regleringsbrevet_f?R_Energimyndigheten_20120831.pdf(accessed 05.14)
Tiger, A., 2009. Potentiellt utbyte inom vågkraft. Kristdemokraten, 4 September.
Uppsala University, 2011. CFE - Centrum för förnybar elomvandling. ⟨http://www.el.angstrom.uu.se/CFE/CFE_se.htm⟩(accessed 05.14).
Uppsala University, 2013a. Pågående forskningsprojekt. Marin Strömkraft. ⟨http://www.el.angstrom.uu.se/forskningsprojekt/MarinStromkraft.html⟩ (accessed 08.14).
Uppsala University, 2013b. Lysekilsprojektet – forskning och utveckling av vågkraft. ⟨http://www.el.angstrom.uu.se/forskningsprojekt/WavePower/Lysekilsprojektet.html⟩(accessed 08.14)
Vantoch-Wood, A., 2012. Developments within the UK Wave Energy Sector. Proceeding of BIEE In: Proceedings of the 9th Academic Conference, 19–20 September.
Vantoch-Wood, A., Connor, P.M., 2013. Using network analysis to understand public policy for wave energy. Energy Policy 62, 676–685. http://dx.doi.org/10.1016/j.enpol.2013.07.066.
Vasseur, V., Kamp, L.M., Negro, S.O., 2013. A comparative analysis of photovoltaic technological innovation systems including international dimensions: the cases of Japan and the Netherlands. J. Clean. Prod. 48, 200–210. http://dx.doi.org/10.1016/j.jclepro.2013.01.017.
Vattenfall, 2011. Ocean Energy Development Programme Annual Report 2011. Accessible at: ⟨http://corporate.vattenfall.com/Global/corporate/news_and_media/doc/Ocean_Energy_Annual_Report_2011_20781072.pdf⟩
VINNOVA, 2009. Var ligger horisonten? Stor potential men stora utmaningar för vågkraften. Report by the Swedish Innovation Agency, VA 2009:07. Stockholm, Sweden.
Wangel, U., 2009. Vågkraftsvisioner för Skurups kommun. Ystads Allehanda, 1 June, 16.
Waves4Power, n.d Den Historiska bakgrunden till W4P WAVES4POWER AB Åren 1974 till 2013. Report by Waves4Power AB.
Weber, K.M., Rohracher, H., 2012. Legitimizing research, technology and innovation policies for transformative change. Res. Policy 41, 1037–1047. http://dx.doi.org/10.1016/j.respol.2011.10.015.
Wenblad, A., Lindegarth, S., Hanning, A., 2012. Maritime Clusters in Västra Götaland. Gothenburg and Tjärnö, Sweden. University and Chalmers University of Technology, Region Västra Götaland, Sweden.
WERG, 1979. Vågenergi i Sverige. Report by the Wave Energy Research Group, commissioned by the Swedish committee for energy production research. Gothenburg, Sweden.
Winskel, M., 2007. Marine energy innovation in the UK energy system: financial capital, social capital and interactive learning. Int. J. Glob. Energy Issues 27, 472. http://dx.doi.org/10.1504/IJGEI.2007.014868.
Winskel, M., McLeod, A., Wallace, R., Williams, R., 2006. Energy policy and institutional context: marine energy innovation systems. Sci. Public Policy 33, 365–376. http://dx.doi.org/10.3152/147154306781778939.
Winskel, M., Radcliffe, J., Skea, J., Wang, X., 2014. Remaking the UK's energy technology innovation system: from the margins to the mainstream. Energy Policy 68, 591–602. http://dx.doi.org/10.1016/j.enpol.2014.01.009.
Zerpe, H.K., 2008. Länsföretag på ambassadörs lista för framtiden. Norrbott. Kur., 29 December, 36

Paper II

The spatial nature of innovation: Localized drivers and benefits of tidal kite technology development

Johnn Andersson*[a], Hans Hellsmark [a] and Björn A. Sandén[a]

[a] Chalmers University of Technology
Division of Environmental Systems Analysis
Department of Technology Management and Economics
Gothenburg, Sweden

*Corresponding author: johnn.andersson@chalmers.se, +46 (0) 70 3363747

Abstract

Policymakers promote the development and diffusion of new renewable energy technologies to mitigate climate change and other global sustainability challenges, but also to create environmental and socioeconomic benefits in their local context. However, public investments in technological innovation may lead to benefits that mainly arise in other, foreign, regions. Policy-oriented analysis of new technologies therefore requires a clear regional perspective and spatial sensitivity. This paper analyzes the development and diffusion of tidal kite technology from a Swedish policy perspective. It employs the technological innovation systems (TIS) approach and focuses on how the resources provided by domestic and foreign regions influence how a new TIS develops in the geographical dimension. The paper illustrates how knowledge and competence are particularly decisive in early development stages, by creating a path dependency that favors local build-up of TIS structures. In addition, the analysis shows that the location of markets becomes increasingly decisive for the spatial development trajectory as an emerging TIS advances towards full-scale demonstration and commercialization.

Keywords: technological innovation systems; innovation policy; marine energy; tidal power; tidal kite technology

Abbreviations: technological innovation systems (TIS); research and development (R&D); research, development and demonstration (RD&D)

Highlights:

- Policymakers promote new renewable energy technologies to mitigate climate change, reduce pollution, strengthen energy security and drive economic development
- Public investments may lead to unintended effects, since several of the sought benefits are localized and may appear in foreign regions
- Appropriate policies need to be based on an understanding of what determines the spatial development trajectory of a new TIS
- The presence of knowledge and competence is particularly decisive, by creating a path dependency that favors local build-up of TIS structures
- The location of markets becomes increasingly important as TISs advance towards full-scale demonstration and commercialization

1 Introduction

Avoiding catastrophic climate change and mitigating other global environmental problems requires a rapid transition to a low-carbon energy system (Hood and Briner, 2014; IPCC, 2014). Actions undertaken are not only associated with costs, but may also result in localized benefits, for example reduced pollution, strengthened energy security, new jobs and increased tax revenue (GCEC, 2015; IPCC, 2012). To create such benefits, national and regional governments actively promote the development and diffusion of renewable energy technologies through various policy measures (Frankfurt School-UNEP Centre/BNEF, 2016; IEA, 2015; Kern and Rogge, 2016; Quitzow et al., 2014).

In the sustainability transitions literature, which encompasses several interrelated and overlapping concepts, models and frameworks (Coenen and Díaz López, 2010; Markard et al., 2012), the technological innovation systems (TIS) framework is often described as an appropriate approach for analyzing emerging technologies and informing policy interventions (Binz et al., 2014; Jacobsson and Bergek, 2011; Markard et al., 2015; Truffer, 2015). In the TIS approach, technology development and diffusion is conceptualized as the gradual build-up of sociotechnical system structures, comprised of artifacts, actors and institutions (Bergek et al., 2008a; Hekkert et al., 2007; Sandén and Hillman, 2011). This process is understood by analyzing functions that describe how key conditions for growth are created, for example through mobilization of financial capital, knowledge development and market formation (Bergek et al., 2008a; Hekkert et al., 2007).

However, the TIS framework has been criticized for neglecting the geographical dimension of innovation (Binz et al., 2014; Coenen et al., 2012; Markard et al., 2012; Raven et al., 2012; Truffer and Coenen, 2012). Although a TIS in principle transcends national and regional boundaries, empirical studies have mainly focused on nations and paid insufficient attention to the international linkages and dynamics in the innovation process (ibid). Nonetheless, recent contributions to the literature have convincingly shown that geographical aspects can be fruitfully integrated into the TIS framework, by analyzing the roles and interaction between sub-systems on multiple scales (Binz et al., 2014, 2012; Gosens et al., 2015; Quitzow, 2015). While these contributions offer important insights, they do not adopt an explicit policy perspective and therefore fail to highlight the spatial nature of benefits from investing in novel technologies. For example, energy security will be strengthened in regions where renewable energy technology is deployed, whereas the main part of new jobs is likely to arise where technology is developed and produced (IRENA, 2014). However, regions that drive technology development by providing resources are not necessarily the ones that in the end reap localized benefits (Binz et al., 2017). From a policy perspective, this implies a risk for what we here refer to as 'benefits leakage'; namely that public investments in research, development and demonstration (RD&D), as well as support to technology deployment, mainly leads to localized benefits in other, foreign, regions.

Informing policy intervention thus requires an analysis that has a clear regional perspective and is sensitive to the spatial nature of drivers and benefits of technological innovation.

In this paper, we will develop knowledge concerning benefits leakage by focusing on tidal kite technology, which is developed to produce electricity from tidal streams and ocean currents. It is one of few technologies that might be able to exploit low-velocity currents, and it arguably has several other benefits compared to competing technology concepts (Minesto, 2016a). Tidal kite technology was invented in 2004 and has since then been developed mainly by Swedish actors. To date, small-scale prototypes have been tested in tank, sea and ocean environments, and the ambition is to deploy the first full-scale demonstration plant in 2017. A distinguishing feature of tidal kite technology is its dependence on suitable tidal streams or ocean currents that simply do not exist in Sweden. This rules out domestic deployment both for testing and commercial purposes (Andersson, 2013), which is why key actors from an early stage acted on an international level to access funding, supportive policy schemes, and suitable locations for testing and demonstration (Andersson et al., 2015). It is accordingly an extreme case (Flyvbjerg, 2016) with a high risk for benefits leakage, and therefore very interesting to study in order to learn more about linkages and dynamics across geographies in early development stages.

The purpose of this paper is therefore to analyze the emergence of tidal kite technology from a Swedish policy perspective, using the TIS approach, in order to answer the following research question: *How do the resources provided by domestic and foreign regions influence how a new TIS develops in the geographical dimension?*

The paper thus contributes to the literature by increasing the understanding of transnational innovation dynamics and the connection between the drivers and benefits of technological innovation as well as by proposing a new way of integrating a regional perspective and geographical sensitivity into policy-oriented TIS studies. In addition, it provides case-specific empirical findings and offers a discussion of policy implications from different geographical perspectives.

After this brief introduction, we proceed in Section 2 by developing a framework for analyzing the emergence of new technologies from a regional policy perspective. Section 3 describes the research case and methodology. In Section 4, the focus turns to analyzing the emergence of tidal kite technology. Thereafter, in Section 5, we answer our research question, discuss policy implications, and suggest avenues for future research. Finally, our conclusions are presented in Section 6.

2 Analytical framework

The development and diffusion of renewable energy technology can bring several environmental and socioeconomic benefits (GCEC, 2015; IPCC, 2012; Hood and Briner, 2014; IPCC, 2014). Some are global, in the sense that they benefit the whole planet, while others are localized since they arise in a specific region. Moreover, benefits can result directly from energy transitions (i.e. use of technology) or from the related industrialization (i.e. development, production, installation and maintenance of technology) (Table 1).

Table 1. A typology and examples of potential benefits from the development and diffusion of new renewable energy technology.

	Related to industrialization	**Related to energy transitions**
Global impact	Strengthened global knowledge-base and economic development	Mitigation of climate change and related global environmental problems
Local impact	New jobs, tax income, knowledge spill-overs to other industries	Improved energy security, compliance with international agreements and mitigation of local pollution

To develop these benefits, policymakers promote novel renewable energy technologies by, for example, funding RD&D, supporting market deployment, facilitating network formation, and adapting the education system (Sandén and Azar, 2005). Designing such technology specific policy interventions involves identifying problems in the innovation process (Borras and Edquist, 2013).

The TIS framework is considered a useful approach to analyzing the development and diffusion of novel technologies, in order to identify these problems and provide policy recommendations (Binz et al., 2014; Jacobsson and Bergek, 2011; Markard et al., 2015; Truffer, 2015). Building on the notion of technological systems proposed by Carlsson and Stankiewicz (1991), and later contributions by among others Jacobsson and Johnson (2000), Hekkert et al. (2007) and Bergek et al. (2008a, 2008b), we define a TIS as the sociotechnical system that enables the development, diffusion and utilization of a new technology (which can be more or less broadly defined).

A TIS consists of three main types of structural components: *artifacts* which are physical objects that may have a real value (i.e. a shovel) or convey meaning (i.e. a text); *actors,* such as individuals, firms, universities, public agencies, and non-governmental organizations (NGOs); and *institutions* that consist of regulative, normative and cognitive rules, embodied in formal laws, regulations and standards as well as in informal norms, values and beliefs (Bergek et al., 2008a; Sandén and Hillman, 2011).[1] A central proposition in the TIS literature is that few structural components are in place when a new technology emerges (Bergek et al., 2008b). Analyses of TISs therefore tend to be geared towards understanding how structure develops over time through the entry, accumulation and alignment of artifacts, actors and institutions (Bergek et al., 2008a, 2008b; Hekkert et al., 2007; Hekkert and Negro, 2009). To better capture the multifaceted and dynamic nature of this process of structural build-up, the TIS framework outlines a set of sub-processes, referred to as functions (Bergek et al., 2008a; Hekkert et al., 2007). Analyzing the performance and interdependence of functions enables identifying system weaknesses and deriving policy recommendations (Bergek et al., 2008a).

TIS functions can be defined, grouped and interpreted in many different ways (Bergek et al., 2008a; Markard and Truffer, 2008). In this paper, we adopt the view that functions describe how new sociotechnical structures are built-up through the development of key resources that emerge from existing structures (Bergek et al., 2008b; Binz et al., 2015). Thus, actors in a TIS can either create resources by building on system internal structures (i.e. knowledge development through R&D) or mobilize them from contextual structures (i.e. knowledge spillovers from related sectors). Furthermore, resources can exist at different levels: some are controlled by an individual actor (i.e. financial capital), while others emerge from the interplay of several actors and accordingly exist at the system level (i.e. markets) (Musiolik et al., 2012). As with benefits, resources can also be global or localized. For example, knowledge published in scientific journals is available globally to all actors, whereas some competence is more restricted to specific regions (i.e. individuals tend to be difficult to move both spatially and culturally) and its access controlled at the individual and organizational level. In this paper, we use a typology of six different resources, which are derived from the lists of functions commonly used in the TIS literature (Bergek et al., 2008a; Hekkert et al., 2007).[2]

---

[1] The social and technical components that make up a sociotechnical system have been categorized and described in different ways (c.f. Bergek et al., 2008a; Geels, 2002; Hughes, 1987; Sandén and Hillman, 2011). We would argue, however, that the different conceptualizations attempt to capture the same underlying phenomenon; namely that the world seemingly consists of physical objects that are either inert (i.e. artifacts) or have some kind of individual or collective agency (i.e. actors). These physical objects interact systemically under the influence of socially constructed rules (i.e. institutions), which exist as beliefs and values embedded in actors, and are also subject to the fundamental characteristics of nature (such as the force of gravity).

[2] The main deviations from the functions list presented by Bergek et al. (2008a) is that: 'entrepreneurial experimentation' has been merged with 'knowledge development and diffusion'; the function 'resource mobilization' has been divided into the three subcategories (corresponding to the resources competence, enabling technology and financial capital);'influence on the direction of search' has been omitted and is instead viewed as

Table 2. The typology of resources used in this paper, drawing on (Bergek et al., 2008a; Hekkert et al., 2007) but modified to the purpose of this paper.

Resource	Description
Knowledge	Scientific, technological, market and design knowledge embedded in artifacts or explicitly coded in scripts (texts, pictures etc.).
Competence	Scientific, technological, market and design knowledge embedded in actors.
Enabling technology	Generic infrastructure, products and services that are necessary for the development, diffusion and use of the technology.
Financial capital	Investments and other funds in the form of equity investments, R&D grants etc.
Legitimacy	The social acceptance and desirability of the technology as well as its compliance with relevant institutions.
Markets	New and existing markets for the technology.

As a new renewable energy technology is developed, diffused and used in society, TIS structures are built-up along its value chain. It is from these structures that benefits arise and their spatial composition thus determine which region that takes advantage of localized benefits (Table 1). In a globalized knowledge economy, where innovation processes are increasingly international and traditional industry life cycles are exhibiting increased spatial complexity, foreseeing the spatial composition of an emerging value chain is not straight-forward (Binz et al., 2017; Bunnell and Coe, 2001; Ernst, 2002; Quitzow, 2015). For example, market subsidies in one country may unintentionally lead to industrialization elsewhere, as has recently been observed with solar energy technology in Germany (Hoppmann et al., 2014; Pegels and Lütkenhorst, 2014; Quitzow, 2015). The risk for this type of benefits leakage calls for an analysis that is sensitive to the spatial nature of drivers and benefits of innovation.

However, scholars have argued that the TIS framework has a poor conceptualization of space and pays too little attention to geographical dimensions of transitions and innovation (Binz et al., 2014; Coenen et al., 2012; Markard et al., 2012; Raven et al., 2012; Truffer and Coenen, 2012), even though TISs fundamentally, and in contrast to national and regional innovation systems approaches, transcend territorial boundaries (Bergek et al., 2008a; Carlsson et al., 2002; Carlsson and Stankiewicz, 1991). Moreover, they criticize the dominance of empirical studies that analyze nationally delineated TIS, most often in developed countries, while treating global developments as contextual and possibly neglecting important transnational interaction and dynamics.

A growing literature, commonly referred to as "geography of TIS", has recently emerged in response to this criticism (Hansen and Coenen, 2015; Truffer et al., 2015). It proposes different ways of making the

---

resulting from the 'mobilization of legitimacy'; and 'development of external economies' has been omitted since it is captured by the dynamic interplay between the remaining functions.

geographical dimensions of innovation more explicit in the analysis, and has begun exploring empirical approaches that focus on transnational linkages and dynamics (see for example Binz et al. (2016, 2012), Gosens et al. (2015), Quitzow (2015) and Vasseur et al. (2013)). A common method is to distinguish between spatially delineated sub-systems within a global TIS, and analyze how they build-upon, complement and potentially compete with each other.

While furthering the understanding of the geographical dimensions of innovation, this literature largely lacks a regional policy perspective. Having a clear "problem-owner" is arguably important, since the desired spatial development path of an emerging TIS will differ for policymakers representing different regions. When defining the system under analysis, we therefore distinguish between 'domestic' and 'foreign' structures in the global TIS and its context (Figure 1).[3] This makes the spatiality of structural build-up explicit and enables analyzing how resources provided by domestic and foreign regions drive innovation and influence the spatial composition of structural build-up in the global TIS (i.e. the relation between the domestic and foreign TIS), which is what determines the distribution of benefits.

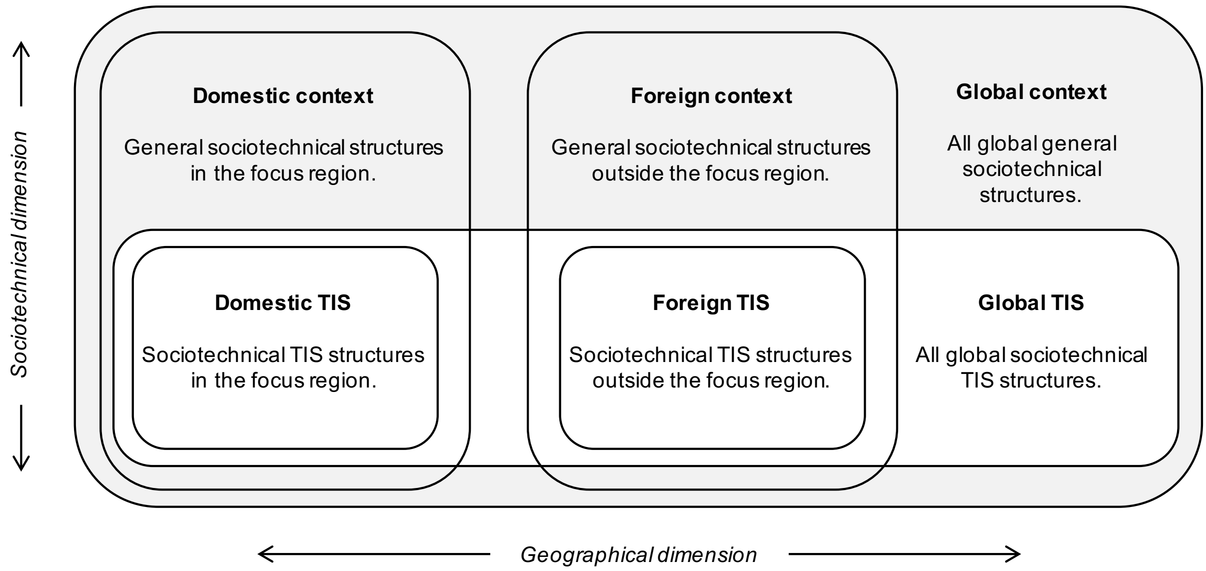


Figure 1. System delineation in the geographical and sociotechnical dimensions.

3 Research design

Based on the presented analytical framework, we will answer our research question using a case study approach which is described below.

[3] The region in focus may be defined on different levels and 'domestic' can accordingly refer to, for example, a municipality, county, country or collection of countries, depending on the perspective of the analyst.

3.1 Research case

Tidal kite technology is one of many concepts developed to harness marine energy.[4] It consists of an underwater kite, moored to the seafloor or a floating structure, that produces electricity by moving in a figure-eight shape perpendicular to a current in the ocean (EMEC, 2016). The kite movement accelerates the water passing through the turbine up to ten times the actual current velocity (Minesto, 2016a). This makes it one of few technologies that might be able to exploit low-velocity tidal and ocean currents (Sandén et al., 2014a). In addition, it enables a power plant that is smaller and lighter compared to most competing technologies, which can potentially lead to lower costs (Minesto, 2016a).

The technology concept was invented in 2004. Since then, small-scale prototypes have been tested in tank, sea and ocean environments, and the ambition is to deploy the first full-scale demonstration plant in 2017. A number of suppliers, universities, research institutes, investors and policymakers are involved in the development of the technology, though the technology developer Minesto is the central actor with patent rights covering the basic concept and several sub-systems. Minesto's activities are centered around their headquarters and research and development (R&D) department in Gothenburg, Sweden, and increasingly around the company's test site in Portaferry, Northern Ireland, and planned full-scale demonstration site in Holyhead, Wales.

A distinguishing feature of tidal kite technology is its dependence on suitable tidal streams or ocean currents. This is a highly localized[5] natural resource that is lacking in Sweden, which rules out domestic deployment both for testing and commercial purposes (Andersson, 2013; Interview 1, 2016; Interview 12, 2016; Interview 14, 2014). Tidal kite technology is accordingly an extreme case (Flyvbjerg, 2016) of a situation where domestic build-up of TIS structures has to draw on resources from foreign regions (i.e. markets). This makes it appropriate for generating knowledge related to our research question, since

---

[4] Marine energy refers to power production from waves, tidal streams and ocean currents in the ocean, and several technology concepts are under development in Sweden. Tidal kite technology is, however, the only Swedish concept for tidal streams and ocean currents that has attracted significant resources and been demonstrated beyond simple small-scale prototypes (Andersson et al., 2017; Interview 10, 2016; Interview 9, 2016).

[5] The resource is localized in several respects. Firstly, deploying the technology requires access to a part of the ocean, which for countries usually implies having a coastline. Secondly, this part of the ocean must have suitable currents with velocities ranging from 1.0-2.5 m/s. And thirdly, the sites where these currents exist should be accessible, in the sense that it is physically, economically, socially and ecologically feasible to deploy tidal kite power plants. This localized nature of the resource is shared with other marine energy technologies, and to some extent with renewables in general. However, for solar, wind and bioenergy technologies, most regions have at least a limited resource that can be exploited. This is not the case for tidal kite technology, where many regions completely lack access to suitable waves, tidal streams and ocean currents.

it may reveal the basic underlying mechanisms that determine the spatial development trajectories of emerging TIS. These are particularly interesting from a Swedish policy perspective, since there is an overhanging risk of benefits leakage if large public investments are made in RD&D and technology deployment. The analysis will therefore be made from this regional perspective, but its findings are likely to be of general interest.

3.2 Methodology

The first step in our methodology is to formalize the research case by delineating system boundaries. The TIS in focus is defined as artifacts, actors and institutions along the value chain for electricity from a tidal kite power plant (Figure 2). It should be pointed out, however, that the value chain is not yet developed, a part from structures relating to RD&D, and that alternative structures are possible. The boundary between the TIS and its context is determined by the degree of specificity; artifacts, actors and institutions that are to some extent specific to tidal kite technology are considered a part of the TIS, whereas more generic structures belong to its context.[6] Also, we choose to analyze the case from a Swedish perspective. This implies that the 'domestic TIS' and 'domestic context' refer to Swedish structures, while the 'foreign TIS' and 'foreign context' refer to structures abroad.

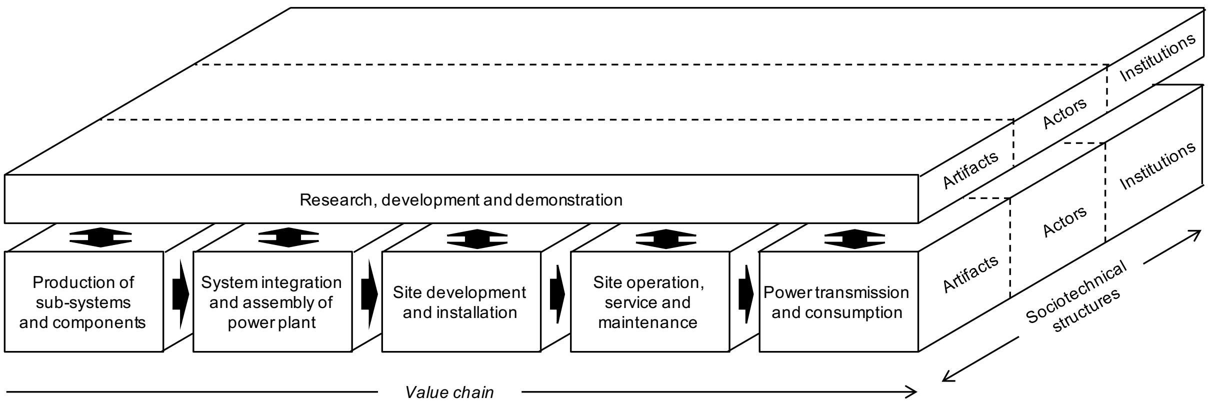


Figure 2. Sociotechnical system structures along the value chain for electricity from a tidal kite power plant.

Given this system delineation, we set out to analyze the emergence of tidal kite technology from its inception in 2004 until 2016, by adopting an event history approach (Negro et al., 2007; Poole et al., 2000; Reichardt et al., 2016). First, a timeline of events (for example the entry of a new actor, announcement of a public RD&D grant etc.) was constructed based on desktop research, including media archives, industry reports, company materials, patent databases, information from public agencies

[6] This approach admittedly implies a somewhat vague system boundary, since there is a continuous scale between the specific and the general. But for the purposes of this study, where the primary focus is on the geographical distinction between the domestic and the foreign, the principle creates sufficient clarity.

and previous research.[7] The findings from the desktop research were also complemented and verified by 15 semi-structured interviews with key informants (Table 3). Second, the events were used to map structural build-up over time, which made it possible to formulate a narrative of four episodes. For each episode, factors of domestic and foreign origin that influenced the mobilization of key resources were identified, which also revealed intra- and transnational innovation dynamics. The relative contribution by domestic and foreign regions was also qualitatively assessed for each resource, in order to highlight patterns and illustrate temporal and spatial differences. Finally, we applied these insights to our research question by examining the observed connection between regional structural build-up and resource provision, as well as by analyzing expected future developments.

Table 3. Performed interviews with key informants.

No.	Interviewee(s)	Dur.	Type	Date
1	Entrepreneurs (two participants) at Swedish marine energy site developer	1.5 h	Face-to-face	Nov 2016
2	Inventor/PhD Candidate at Linköping University, Sweden	1 h	Telephone	Nov 2016
3	Professor at Chalmers University of Technology, Sweden	1 h	Face-to-face	Nov 2016
4	Civil Servant at The Swedish Energy Agency, Sweden	1 h	Telephone	Nov 2016
5	Senior Manager at Mitsui Science Studies Institute, Japan	1 h	Telephone	Jun 2016
6	Senior Manager at Midroc New Technology, Sweden	1 h	Telephone	May 2016
7	Project Manager at Minesto, Sweden	2.5 h	Face-to-face	May 2016
8	CEO of German industry supplier	1 h	Telephone	May 2016
9	Entrepreneur at Swedish technology developer, Sweden	1.5 h	Telephone	Mar 2016
10	Project Manager at RISE Research Institutes of Sweden	2 h	Face-to-face	Mar 2016
11	Board Member of Minesto, Sweden	1 h	Face-to-face	Mar 2016
12	CEO of Minesto, Sweden	2.5 h	Face-to-face	Jan 2016
13	Civil Servant at The Ministry of Enterprise and Innovation, Swedish Government	1 h	Face-to-face	Apr 2014
14	Senior Executive at Minesto, Sweden	1 h	Face-to-face	Apr 2014
15	Senior Project Managers (three participants) at Swedish industry supplier	1.5 h	Face-to-face	Apr 2014

[7] Media reporting and Minesto Annual Reports were accessed through the database Retriever Business (www.retriever-info.com). A patent search was performed in the European Patent Office (www.epo.org).

4 The emergence of the tidal kite technology

This section describes and analyzes the tidal kite innovation system from its inception in 2004 to the beginning of 2016. The narrative is divided into four episodes that are examined separately.

4.1 Episode 1: The birth of a radical innovation (2004-2007)

The story of tidal kite technology starts when an engineer at SAAB, a Swedish multinational firm in the defense and aeronautics sector, realizes that the principles of a flying kite can be applied to harnessing energy from currents in the ocean (Interview 2, 2016). In 2004, the idea was presented to a venture creation department within SAAB, who decided to initiate an innovation project (Minesto, 2016b). This enabled further development of the concept, part of which took place in collaboration with master students at Linköping University in Sweden (Interview 7, 2016). It also led to the first patent application that was registered at the European Patent Office in 2006. Around this time, the innovation was brought to Chalmers School of Entrepreneurship (CSE), an incubator within Chalmers University of Technology (Chalmers) in Gothenburg, Sweden. During one year, three master students developed a business plan with guidance from experienced venture creation professionals. Moreover, they engaged in R&D activities together with a master student at Linköping University. This included the development of a basic prototype that was tested in sea conditions, which is considered an important milestone (Interview 6, 2016; Interview 7, 2016). Towards the end of the incubation period at CSE, the key stakeholders, including SAAB, Chalmers, the inventor and one of the students, formed a start-up company to commercialize the innovation. Minesto is born, which marks the end of the first episode.

During the episode, structural build-up is confined to Sweden and very limited (Figure 3), which is not surprising given the very early development phase. There are few actors involved, although the networks among them are strong with extensive interaction. Knowledge is limited and artifacts are yet to materialize beyond the basic prototype, although a patent application has been registered. Formal institutions in terms of technology-specific laws, regulations and standards have not emerged, but there are high expectations and positive attitudes towards the technology among the involved actors (Dimming, 2006).[8]

[8] Concurrent newspaper interviews with the involved actors reveal expectations that in hindsight can be considered naive, such as plans for prototype testing in ocean conditions in 2008 (Dimming, 2006).

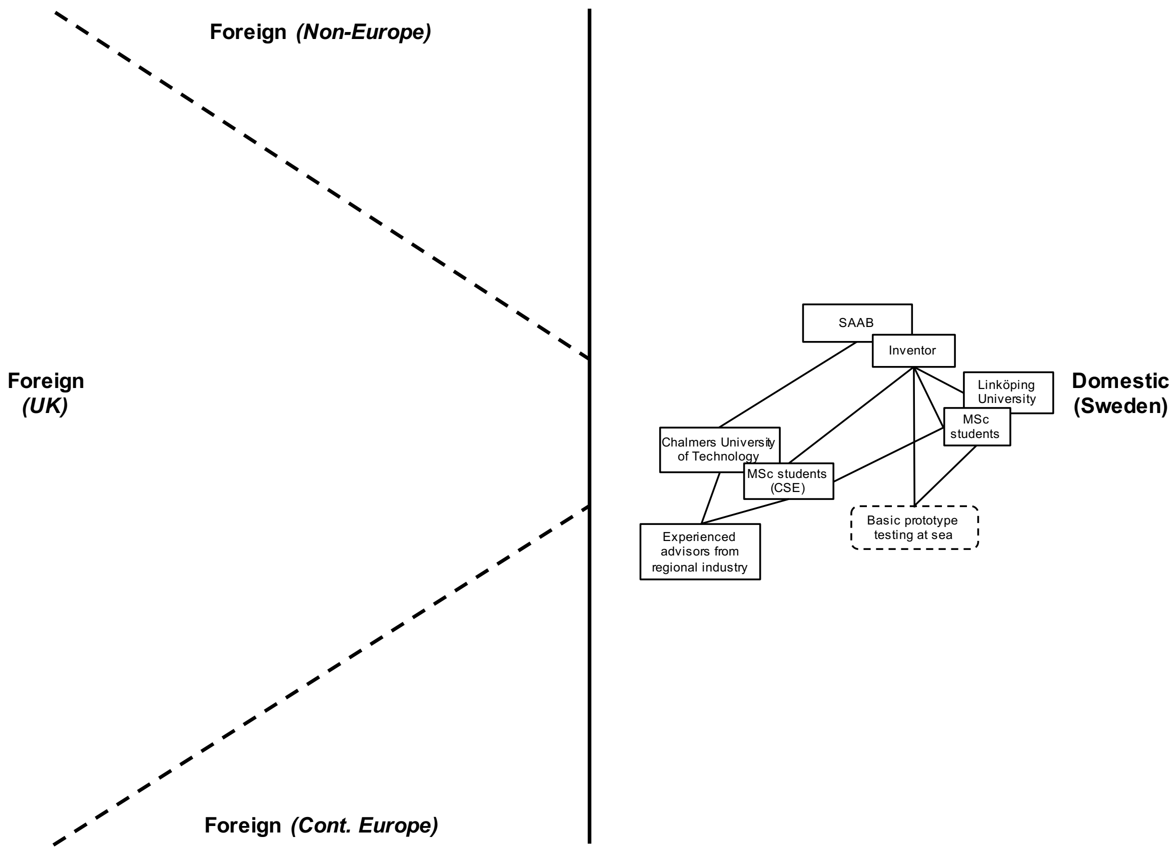


Figure 3. Illustration of key TIS actors in the end of the period 2001-2007.

The development is almost exclusively enabled by knowledge, competence and legitimacy mobilized domestically (Table 4). It was knowledge development, in the form of the conceptual invention in 2004, that initiated the system's development (Interview 2, 2016). This then led to mobilization of competence within SAAB as a project was formed within SAAB Ventures (Interview 6, 2016), which in turn enabled further knowledge development. Moreover, Chalmers and Linköping University were engaged through existing linkages with SAAB, bringing additional competence to the system (Interview 2, 2016). As a result, knowledge development was accelerated and expanded to include early test activities, business development and network-building (Interview 2, 2016), which created legitimacy. Additional legitimacy was also brought by the involvement of renown Swedish actors such as SAAB, Chalmers and Linköping University as well as by generally positive attitudes to renewable energy technology (Holmberg, 2006) and positive developments in the global marine energy sector (OES, 2006). Finally, there is very limited mobilization of financial capital and enabling technology, and market formation is hardly relevant at this early stage.

Table 4. Summary of factors of domestic and foreign origin that influenced the mobilization of key resources during the period 2001-2007, including a qualitative assessment of their relative importance for the build-up of TIS structures.

	Factors of domestic origin		Factors of foreign origin	
Knowledge	++	• Original invention and early concept development, which leads to patent application • Prototype tests at sea • Business development and network-building	0	
Competence	++	• Key individuals from SAAB, Chalmers and Linköping University	0	
Enabling technology	+	• Simple assets enabling early sea tests	0	
Legitimacy	++	• Positive attitudes to renewable energy technology • Involvement of renown actors • Successful early sea tests	+	• Positive attitudes to renewable energy technology • Positive developments in the global marine energy sector
Financial capital	+	• Minor funding from involved actors	0	
Markets	0		0	
++ major; + minor; 0 no observation				

4.2 Episode 2: Incorporation and prototyping (2007-2011)

In the beginning of the second episode, Minesto is a newly established start-up company led by a graduate from CSE. Soon after its creation, Minesto is awarded 2nd prize in Venture Cup, a renown Swedish innovation contest (Venture Cup, 2007). They also get the first patent published, which protects the basic technology concept and paves the way for Minesto's role as the key actor in the innovation system. Furthermore, Minesto is accepted as a participant in the UK Carbon Trust's Marine Energy Accelerator, a research and development program funded by the UK government. This gave access to experts and consultants that in particular highlighted that the technology concept may double the tidal power potential in the UK (Interview 2, 2016). Around the same time, Midroc New Technology, a venture capital firm based in Sweden, invests in Minesto and becomes its main owner (Interview 6, 2016; Karlberg, 2007). This made it possible to hire three more staff and commission a design study from a Swedish consultant that had been involved as an advisor in the early idea development (Interview 2, 2016). Based on the proposed design, Minesto started working on a scale 1:10 prototype in collaboration with a Swedish research institute, with some support from the Swedish Innovation Agency (VINNOVA) (Interview 7, 2016). The prototype was tested in a towing tank at SSPA, a Swedish hydrodynamics research institute, and at MARIN, a similar organization in the Netherlands with deeper tank facilities. A key milestone was reached in 2009 when electricity was produced during tank testing (NyTeknik, 2009). Encouraged by the successful test results, Minesto set-out to build an additional scale 1:10 prototype, intended for further tank testing and later ocean testing (Interview 7, 2016). But mobilizing financial capital for this next step was challenging, even though the existing owners made additional investments. The financial crisis had just struck the world economy and investors were hesitant to engage in high-risk ventures with long time-horizons. But eventually, BGA Invest, a family-owned venture capital firm in Sweden, invested in Minesto and became the second main owner, and was also joined by a number of smaller private investors (NyTeknik, 2010). This meant that the ocean tests could get underway, and Portaferry, Northern Ireland, was chosen as the designated location. In the end of the episode, TIME Magazine ranked Minesto's technology as one of the top 50 best inventions in 2010, which gave wide-spread media coverage and paved the way for the future development (Harrell, 2011; Interview 6, 2016).

During the episode, the structure is gradually strengthened and begins to expand beyond Sweden (Figure 4). Knowledge development has led to a 1:10 scale prototype with a functional control system, and electricity has been produced for the first time. Minesto is the key actor, whose R&D activities in Gothenburg expands during the period. Its main owners, Midroc New Technology and BGA Invest, also take on prominent roles by providing financial resources and competence (Interview 6, 2016). In addition, Swedish consultants, research institutes and universities, for example Etteplan, IMEGO, SSPA and Chalmers, support knowledge development and provide important testing infrastructure. However, domestic public funding agencies have limited engagement and few suppliers are involved beyond the supply of standard components to prototypes. Abroad, structural build-up can be identified mainly in the UK. Here, Minesto establishes a subsidiary and the Carbon Trust enters as a supportive government actor. Outside the UK, the research institute MARIN in the Netherlands engages by collaborating around test activities. Finally, technology-specific formal institutions have still not emerged, although policy schemes in the UK offer marine energy extended support. Also, the high expectations and positive attitudes towards the technology persist (Dimming, 2009).

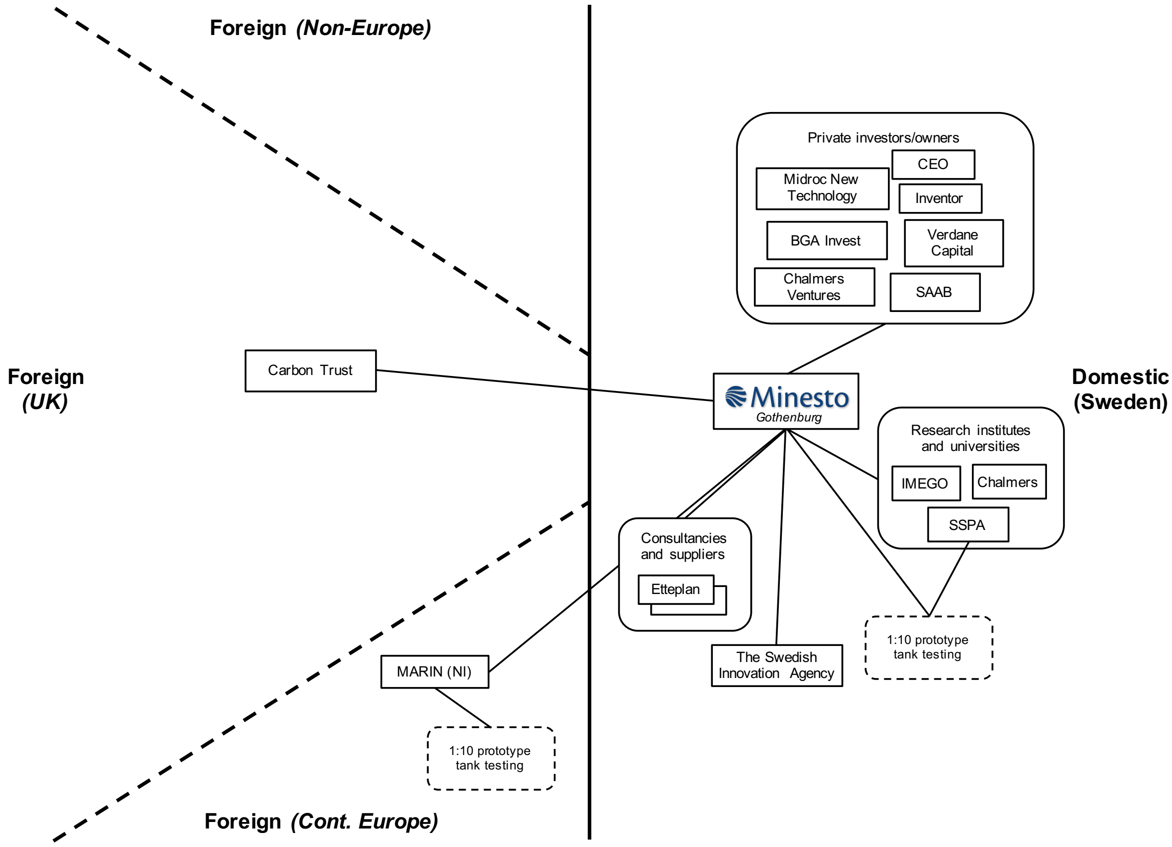


Figure 4. Illustration of key TIS actors in the end of the period 2007-2011.

The development is mainly driven by domestic structures, although other regions, mainly the UK, are beginning to have an influence (Table 5). At the core of developments lie knowledge, competence and legitimacy. Initially, the support from the Carbon Trust brought access to experts and consultants, who provided key knowledge and in-kind development resources. Moreover, it brought important legitimacy (Interview 12, 2016), since a key actor, on one of the major foreseen markets, explicitly acknowledged the potential of the technology concept. In addition, generally supportive marine energy policy schemes in the UK provided incentives for technology development. These developments were crucial for attracting Swedish venture capital from a strong owner that also supported the newly started Minesto with competence and a strong network. Thus, Minesto could mobilize competence and enabling technology, by hiring staff and initiate collaborations with consultants and research institutes, and carry-out R&D activities including prototype testing in both Sweden and the Netherlands. Successful test results together with Swedish and international awards further strengthened legitimacy, which paved the way for the mobilization of additional Swedish venture capital toward the end of the episode. In addition, the positive developments in the broader marine energy sector has started to materialize in Sweden as well, in the form of major public RD&D funding (The Swedish Energy Agency, 2010), which brings interest, high expectations and additional legitimacy.

Table 5. Summary of factors of domestic and foreign origin that influenced the mobilization of key resources during the period 2007-2011, including a qualitative assessment of their relative importance for the build-up of TIS structures.

	Factors of domestic origin		Factors of foreign origin	
Knowledge	++	• Minesto in-house R&D activities • Tank testing of scale 1:10 prototype	+	• Tank testing of scale 1:10 prototype
Competence	++	• Business expertise and network provided by strong owners • Collaborations with consultancies and research institutes • Minesto staff recruited locally	+	• Access to experts and consultants through the Carbon Trust
Enabling technology	+	• Tank testing facilities provided by SSPA	+	• Tank testing facilities provided by MARIN
Legitimacy	+	• Positive attitudes to renewable energy technology • Positive developments in the Swedish marine energy sector • Positive media coverage • Innovation awards • Successful test results	++	• Positive attitudes to renewable energy technology • Positive developments in the global marine energy sector • Supportive marine energy policy schemes in the UK • Innovation awards • Support from the Carbon Trust • Successful test results
Financial capital	+	• Mobilization of Swedish venture capital • Some public R&D funding	0	
Markets	0		0	
++ major; + minor; 0 no observation				

4.3 Episode 3: Into the ocean (2011-2014)

When the third episode starts, Minesto has started preparing for establishing an R&D center in Northern Ireland, in order to perform prototype tests in real ocean conditions. Collaborations are initiated with Queens University in Belfast, Strathclyde University in Glasgow, certification organizations, consultancies and suppliers. Also, Minesto mobilizes competence from the Global Maritime Alliance, which brings together local companies and universities in Northern Ireland to take advantage of opportunities in the emerging marine energy markets. Initially, the test activities are focused on the scale 1:10 prototype that had previously been tested in tank facilities (Interview 7, 2016). It is, however, soon replaced by a quarter scale prototype, which in 2013 produced electricity from ocean currents for the first time (Karlsson-Ottosson, 2013). Another result from the related R&D activities is additional patents that cover a number of critical sub-systems and also expands the protection to markets worldwide (Minesto, 2015a). The test activities in Northern Ireland and the development of the quarter scale prototype were made possible by financial resources from Minesto's Swedish owners and by public funding from the Swedish Energy Agency (The Swedish Energy Agency, 2014) and the Carbon Trust (NyTeknik, 2011). Moreover, the Crown Estate, which owns the seafloor around the UK, played a key role by granting the lease of the site in competition with other tidal energy technology developers (The Crown Estate, 2011). Although the developments in Northern Ireland mobilized some local and UK actors to the system, Minesto's rapidly growing R&D department remained in Sweden (Figure 5), where there were also collaborations with suppliers of components and sub-systems to the prototype power plant (Interview 15, 2014; Marstrom Composite, 2015). Through the Swedish collaboration platform Ocean Energy Centre, Minesto also worked with actors such as Chalmers, the research institutes SP and SSPA, and other technology developers in the marine energy sector (Andersson et al., 2017). This involved knowledge sharing, collaborative R&D projects as well as political lobbying activities (Andersson et al., 2013). In addition, tidal kite technology gained a lot of attention and recognition, both through praise in Swedish business media and international awards (e.g. Minesto, 2013, 2011; Pentland, 2013; Sjödén, 2013).

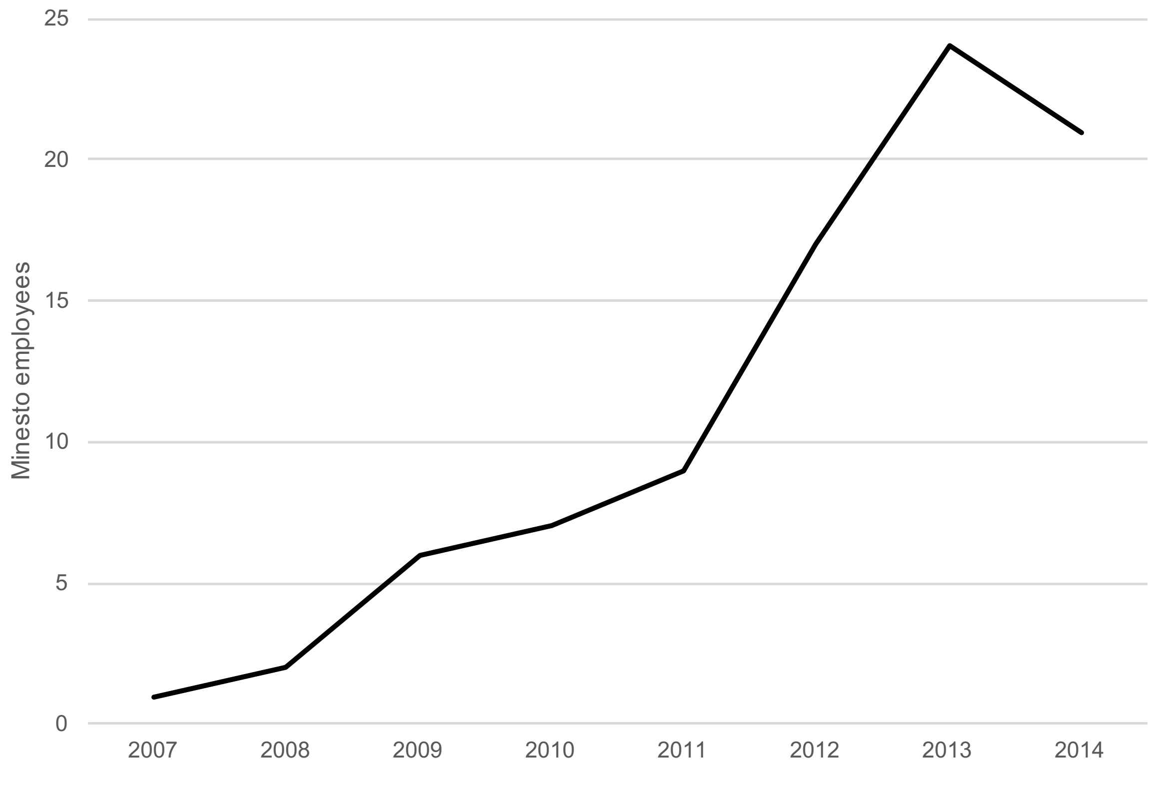


Figure 5. Average number of employees per year at Minesto from 2007 until 2014 (based on Minesto Annual Reports).

The episode involves significant structural build-up in both Sweden and the UK (Figure 6). The technology has advanced to a stage where both 1:10 and quarter scale prototypes have been successfully demonstrated in ocean conditions, where electricity has also been produced for the first time. A test platform has been established in Northern Ireland, complemented by simulators developed specifically for the technology. Minesto strengthens its role as the key actor by increasing their intellectual property rights. These are also demonstrated as strong when a court in the US dismisses a patent application from Honeywell concerning a similar technology concept. Thus, the key underlying knowledge is controlled by Minesto or embedded as competence in its R&D engineers (Interview 3, 2016; Interview 7, 2016), although some knowledge spillover to UK actors has probably occurred. A rapid increase of the number of involved actors can be seen, driven to a large extent by the test activities in Northern Ireland which attract local and UK actors. Moreover, the Carbon Trust expands its role to providing R&D funding and the Crown Estate enters as an important regulating body. In Sweden, the number of actors increase as well, but to a lesser extent than in the UK. The Swedish Energy Agency enters as an R&D funder and Minesto's network of suppliers is developed to include some closer relationships that go beyond the supply of standard components. Moreover, the networks among the actors in the Swedish marine energy sector are strengthened through the activities of the Ocean Energy Centre. Finally, technology specific institutions are still lacking, except for the high expectations that can be observed among the involved actors and in media, although the strong marine energy support schemes in the UK remain.

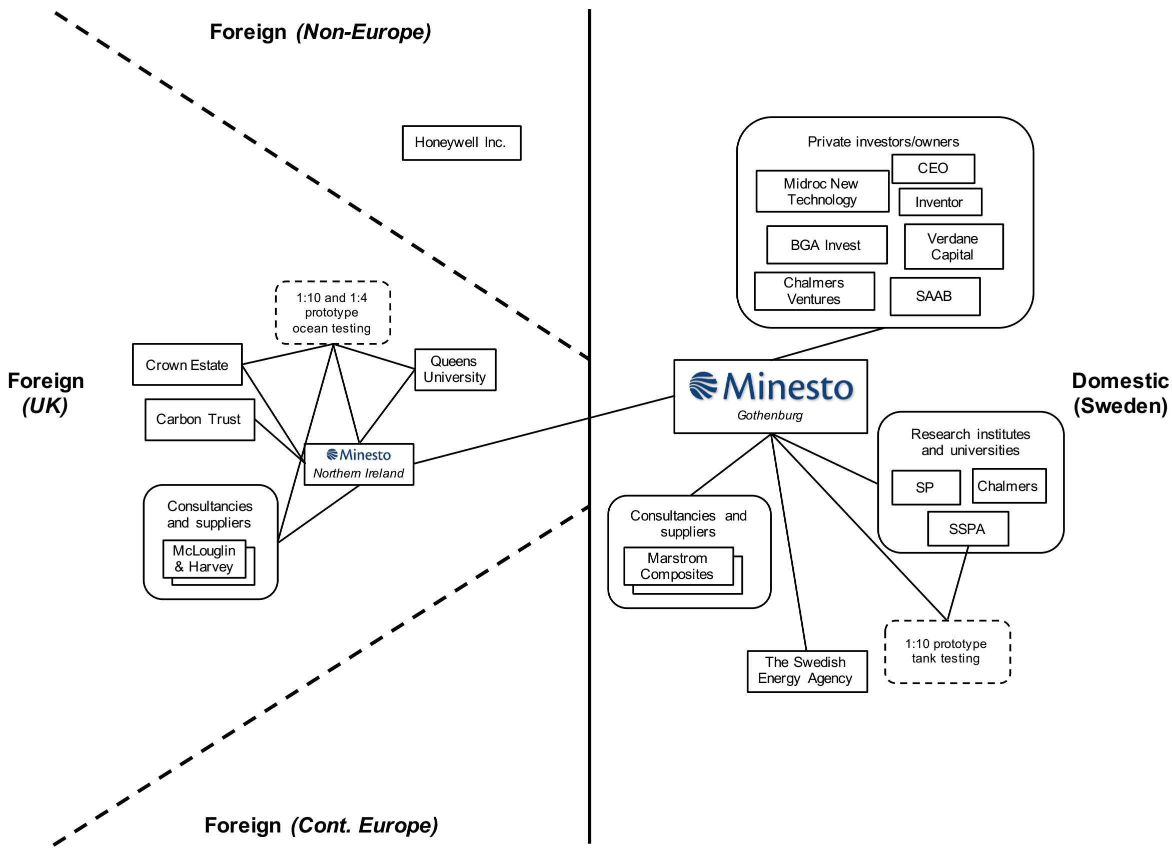


Figure 6. Illustration of key TIS actors in the end of the period 2011-2014.

The structural build-up is increasingly driven by foreign structures, and knowledge, financial capital and enabling technology play a prominent role (Table 6). Initially, the mobilization of Swedish venture capital makes it possible to start establishing a test site and initiate further R&D activities, which also enabled additional mobilization of financial capital from the Carbon Trust and the Swedish Energy Agency. As a result, universities, consultants and suppliers from both Sweden and the UK entered the system, bringing knowledge, competence and capabilities. Minesto could also increase their staff significantly, recruiting mainly from Western Sweden. In addition, networks in the marine energy sector in Sweden were strengthened, which stimulated knowledge development and strengthened legitimacy through lobbying activities. Finally, there are indications of isolated knowledge development in the US, but this does not seem to drive any structural build-up (i.e. the patent application was dismissed).

Table 6. Summary of factors of domestic and foreign origin that influenced the mobilization of key resources during the period 2011-2014, including a qualitative assessment of their relative importance for the build-up of TIS structures.

	Factors of domestic origin		**Factors of foreign origin**	
Knowledge	++	• Minesto in-house R&D activities leads to additional patents • Collaborative R&D projects	++	• Collaborative R&D projects • Ocean testing of 1:10 and quarter scale prototype leads to additional patents
Competence	++	• Business expertise and network provided by strong owners • Collaborations with universities, suppliers and consultancies • Minesto staff recruited locally	+	• Collaborations with universities, suppliers and consultancies
Enabling technology	+	• Some mobilization of standard components for prototypes	++	• Establishment of ocean testing facilities in Northern Ireland • Some mobilization of standard components for prototypes
Legitimacy	+	• Positive attitudes to renewable energy technology • Political networks developing in the Swedish marine energy sector • Positive media coverage	++	• Positive attitudes to renewable energy technology • Positive developments in the global marine energy sector • Supportive marine energy policy schemes in the UK • Industry awards • Successful results from ocean testing
Financial capital	++	• Mobilization of Swedish venture capital • R&D funding from the Swedish Energy Agency	+	• R&D funding from the Carbon Trust
Markets	0		0	
++ major; + minor; 0 no observation				

4.4 Episode 4: Towards full-scale demonstration (2014-2016)

The fourth episode constitutes an intense period of preparation activities for a planned demonstration project in Holyhead, Wales, although test activities in Northern Ireland are still ongoing (Interview 7, 2016). The Holyhead project involves developing, manufacturing and deploying a full-scale tidal kite power plant by 2017 as a first step, and thereafter gradually expand the installation to an array of 20 power plants and an installed capacity of 10 MW (Minesto, 2015a). However, developing the demonstration site and scaling-up the technology requires significantly more resources than previous development phases, which implies an order-of-magnitude increase in the mobilization of financial capital during the episode (Figure 7). Investments enabling the first step of the Holyhead project, which was fully funded in the end of 2015, came from three main sources. Firstly, the Welsh government invested 13 MEUR of European regional development funds in the demonstration project (Minesto, 2015b), which essentially made them the first customer for tidal kite technology. Secondly, Minesto made an IPO at a Swedish stock exchange, raising around 16 MEUR from 2500 new shareholders (Minesto, 2015c). And thirdly, Minesto received a 3.5 MEUR investment from the public-private investment consortium KIC InnoEnergy (KIC InnoEnergy, 2015). These resources made it possible for Minesto to go ahead with the demonstration project and expand their network of collaborators. Bangor University in Wales was engaged as a partner in site development, together with other local consultants and suppliers (Interview 12, 2016). The UK firm McLaughlin & Harvey and the Royal Institute of Technology in Sweden were pointed out as key partners in delivering the project (KTH, 2016; McLaughlin & Harvey, 2015). And technology partnerships were formed with the German firm Schottel Hydro (power take-off system) (Interview 8, 2016) and the UK firm Subsea Riser Products (bottom joint) (Minesto, 2016c). However, the value chain for the project has only begun to emerge and more key actors are expected to enter the system before the power plant is deployed (Interview 11, 2016; Interview 12, 2016). Actors and resources were also increasingly mobilized through collaborative R&D projects. The most substantial one was the PowerKite project that received 5.1 MEUR in funding from the EU Horizon 2020 program, and gathered a broad consortium with actors from several European countries (Interview 3, 2016; Minesto, 2015d). In addition, knowledge was developed in collaborative R&D projects with a broader scope, involving other marine energy technology developers, suppliers and research institutes, both in Sweden and the UK, with funding from actors such as the Swedish Energy Agency, VINNOVA and the EU Eurostars program. Furthermore, and in parallel to the developments in Sweden and the UK, the system starts to expand to other regions through Minesto's market development activities. Discussions are initiated with actors on potential markets in the USA, Chile, South Korea, Japan and Taiwan (Interview 11, 2016; Interview 12, 2016; Interview 5, 2016), and a formal collaboration project aiming to explore the market for tidal kite technology is set up with Florida Atlantic University (Minesto, 2014).

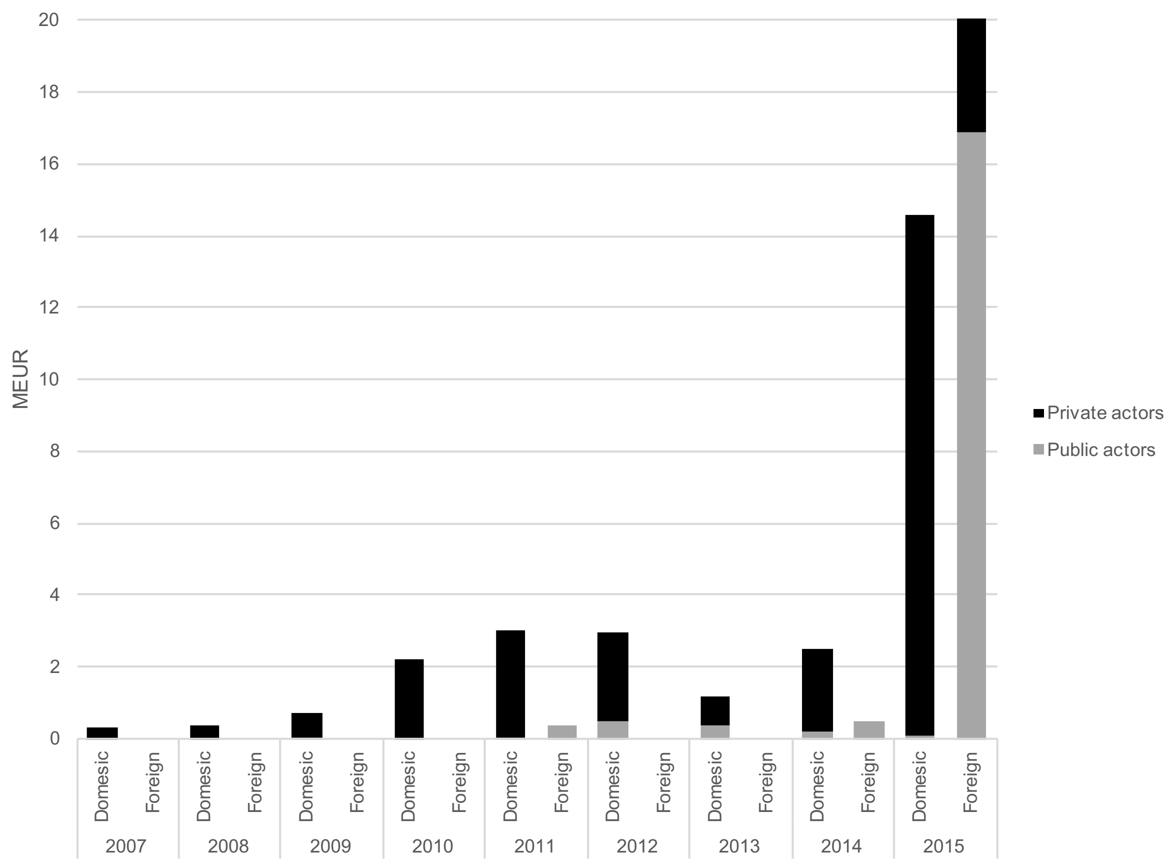


Figure 7. Mobilization of financial capital in MEUR from 2007 until 2015, divided by source type (domestic or foreign structures and public or private actors), and including Minesto equity investments and technology-specific RD&D projects (based on Minesto Annual Reports, media reporting and information from relevant public funding agencies).

The episode involves intense structural build-up in Sweden and abroad (Figure 8). The technology has kept advancing and moved towards full-scale demonstration, although the results of this development are yet to materialize. Knowledge is still to a large extent embedded in Minesto's engineers or codified in a way that is controlled by the firm, although knowledge diffusion is likely to be stimulated by technology partnerships. The number of involved actors keep increasing, but this time driven by the full-scale demonstration project and mainly outside of Sweden. Bangor University in Wales and Royal Institute of Technology in Sweden engage in the developments, technology partnerships are formed with suppliers such as Subsea Riser Products and Schottel Hydro, and a wide range of consultants and suppliers support R&D activities and site development. The Welsh government enters the system as the first customer and public funding is provided by EU, UK and Swedish agencies. Private capital is mobilized from KIC InnoEnergy and a large number of new Minesto shareholders in Sweden, although the main owners are still Midroc New Technology and BGA Invest. Moreover, the Crown Estate continues to play an important role by granting the site lease in Wales (The Crown Estate, 2014). Finally, technology specific formal institutions are still lacking, while informal institutions can be identified in the form of high expectations among the involved actors and in media. The market support policies for marine energy in the UK can, however, be expected to have played a key role in the decision to locate the first full-scale demonstration project in Wales. Moreover, the Blue Energy Communication from the EU, highlighting the potential of marine energy, is likely to have raised expectations and strengthened legitimacy.

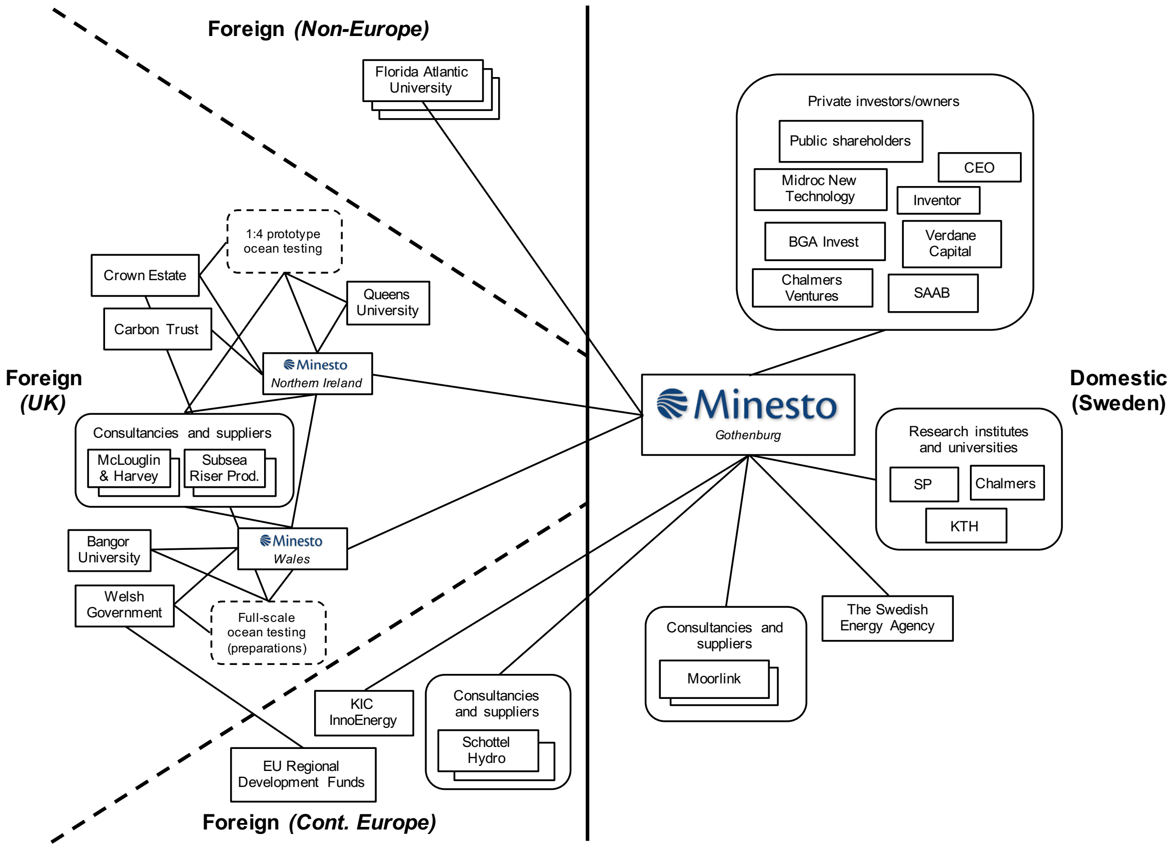


Figure 8. Illustration of key TIS actors in the end of the period 2014-2016.

The developments are driven by both domestic and foreign structures, and financial capital and legitimacy are at the core of developments (Table 7). Initially, Minesto's plans create a compelling vision that is given legitimacy by previous technological advancements, and fueled by policy developments in the EU. The result is strengthened incentives, even though slow technological development in the global marine energy sector and uncertainties regarding the future policy support in the UK likely acted as barriers. In the end, the Welsh government entered the system as Minesto's first customer, which is the first indication of market formation. This meant a vast increase in the mobilization of financial capital compared to previous episodes, but also implied certain demands regarding local sourcing of products and services for the demonstration project. The investment by the Welsh government in turn enabled mobilization of financial capital through an IPO in Sweden, since it strengthened the offering to potential investors. But in a similar vein the private capital raised was necessary for matching the funds provided by the Welsh government, which is required when dealing with European regional development funds. The extensive mobilization of financial capital in relation to prior phases (Figure 7) in turn mobilized competence and enabling technology, and strengthened knowledge development through both in-house and collaborative R&D activities. However, the developments fueled by the key investments have only just begun and it is an open question what the final structure around the demonstration project in Wales and beyond will look like.

Table 7. Summary of factors of domestic and foreign origin that influenced the mobilization of key resources during the period 2014-2016, including a qualitative assessment of their relative importance for the build-up of TIS structures.

	Factors of domestic origin		Factors of foreign origin	
Knowledge	++	• Minesto in-house R&D activities • Major collaborative R&D projects • Collaborations with consultants, suppliers and universities	++	• Major collaborative R&D projects • Collaborations with UK universities, consultants and suppliers • Technology partners developing sub-systems • Continued ocean tests in Northern Ireland
Competence	++	• Business expertise and network provided by strong owners • Collaborations with universities, suppliers and consultancies • Minesto staff recruited locally	++	• Collaborations with universities, suppliers and consultancies • Formation of technology partnerships
Enabling technology	+	• Some mobilization of standard components	++	• Access to ocean testing facilities in Northern Ireland • Mobilization of standard components
Legitimacy	+	• Positive attitudes to renewable energy technology • Extensive positive media coverage • Compelling vision by Minesto, supported by technological advancements	++	• Positive attitudes to renewable energy technology • Supportive marine energy policy schemes in the UK (although uncertainties exist about their future) • Policy development in the EU (Blue Energy Communication) • Innovation awards • Support from key actors
Financial capital	++	• Swedish IPO raises major private investments • R&D funding from the Swedish Energy Agency	++	• Funding for demonstration project by Welsh government • R&D funding from the Carbon Trust, DECC and various EU offices • Private investment from KIC InnoEnergy
Markets	0		+	• Welsh government enters as first customer
++ major; + minor; 0 no observation				

5 Discussion

This paper has so far analyzed the emergence of tidal kite technology. In this section, we present our results, discuss their policy implications, and suggest avenues for future research.

5.1 How do the resources provided by domestic and foreign regions influence how a new TIS develops in the geographical dimension?

The case concerns a TIS that started its development in Sweden, where early conceptual development and verification as well as business development was carried-out by Minesto in collaboration with universities, research institutes and industry. The system then gradually branched out to the UK. Initially through the establishment of an ocean test site in Northern Ireland, but more recently in the form of preparations for a full-scale demonstration project in Wales. Currently, the system also shows signs of spreading to regions beyond Europe through Minesto's market development activities. Although this has implied that a number of international and UK actors have entered the system, including both research organizations and industry, Western Sweden has remained the main location of Minesto's growing R&D and management activities. Accordingly, this is still where the system has its center of gravity in terms of TIS structure.

The development is the result of a number of interlinked factors, which we have described by looking at how and from where key resources were mobilized throughout the TIS's emergence. In particular, we have focused on how domestic and foreign regions have influenced the build-up of system structure (Figure 9).

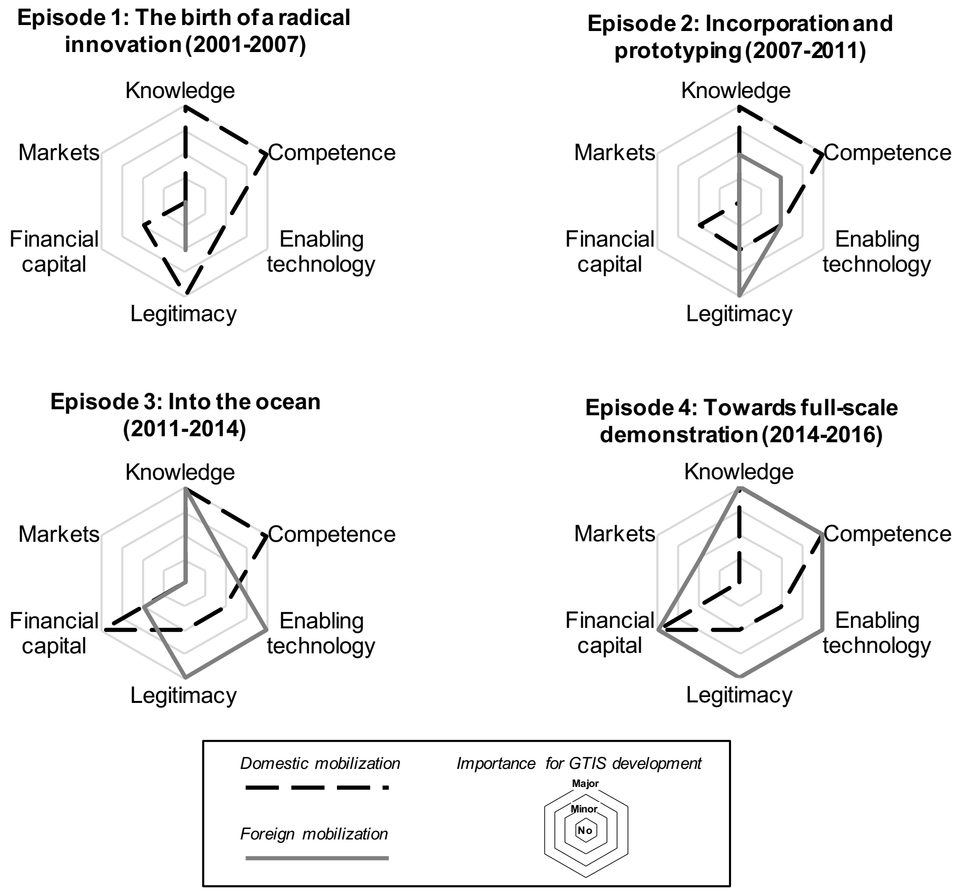


Figure 9. Qualitative assessment of the importance of domestic and foreign provision of key resources for the build-up of TIS structures.

It is clear that the system initially depended almost exclusively on domestic resources, such as knowledge, competence and legitimacy. In the second episode, foreign regions started playing a role, mainly by providing legitimacy, although domestic sociotechnical structures still dominated as the sources of knowledge, competence and financial capital. In the third episode, foreign regions increased their importance by giving access to crucial enabling technology, in the form ocean testing infrastructure, while knowledge, competence and financial capital were mainly mobilized domestically. Finally, in the fourth episode, foreign regions arguably started playing an equally important role as the domestic, by providing financial capital, an early niche market as well as other key resources. However, domestic structures remained important sources of financial capital, knowledge and competence.

Looking more closely at the mobilization of financial capital, where available data enables a quantitative overview (Figure 7), it is evident that the system's development has depended almost completely on funds from domestic private actors. However, the picture changes completely in 2015, when the mobilization of financial capital surges by almost an order of magnitude, foreign actors contribute more than domestic actors, and public actors match private funding.

We can thus conclude that domestic and foreign regions have played different roles throughout the emergence of tidal kite technology. They have contributed with different resources to varying degrees, and also been subject to different amounts of structural build-up. Our analysis suggests that the development of TIS structures in one region corresponds to the resources provided by its sociotechnical structures; Sweden has played a major role and this is also where the system currently has its center of gravity. However, when examining the observed dynamics more closely, it is clear that the mobilization of resources from one region does not necessarily mean that TIS structures, building on these resources, will be developed in the same place. For example, legitimacy derived from support by the UK Carbon Trust, as well as from earlier knowledge development and testing in the region around Linköping in central Sweden, mainly led to structural build-up in the Gothenburg area in western Sweden. Also, although Northern Ireland provided access to enabling technology, knowledge and competence in connection to ocean testing activities, which have arguably been key for the development of the system as a whole, this region has only seen limited structural build-up.

It arguably appears as if something has made the development of TIS structures gravitate towards Sweden, even though foreign regions have provided certain key resources. This suggests that knowledge and competence, which have to a large extent been mobilized domestically, are particularly decisive for the spatial development of TIS structure. An additional explanation is that early developments in Sweden, such as the basic invention and the incubation period at Chalmers, shaped the spatial development trajectory by creating early networks that provided access to crucial knowledge and competence, which created a path dependency that hindered the development of TIS structures abroad. Finally, it should be noted that there is a time lag between the mobilization of resources and structural build-up. Therefore, we do not yet see the full results of the influence of foreign regions, especially in the latest episode.

As tidal kite technology advances, and more parts of the value chain are developed, it is reasonable to assume that other factors will play an increasingly important role for the spatial development trajectory. Firstly, the location of sites for further demonstration, up-scaling and commercialization will naturally determine where system structures around site development and installation, site operation, service and maintenance, and power transmission and consumption are built-up. An indication of this expected development can be observed in the last two episodes, which involved testing activities in Northern Ireland and related development of system structure. In this case, however, the limited extent of the activities led to weak development of local structures and also made it possible to build on Swedish structures (i.e. Minesto staff from Gothenburg could travel to Northern Ireland occasionally to oversee activities (Interview 3, 2016; Interview 7, 2016)). Secondly, as the focus of innovation activity shifts from concept development to more incremental improvements in components and sub-systems, R&D activities tend to become more dependent on user-producer interactions (Huenteler et al., 2016). This might make geographical proximity between different parts of the value chain more important and thus create additional incentives for structural build-up close to deployment sites. Finally, it is likely that different regions will to some extent compete for structural build-up in parts of the value chain that are less bound to deployment sites, for example R&D, production of sub-systems and components, and system integration.

5.2 Policy implications

The results from our analysis have important policy implications from a Swedish perspective, since they suggest an increased tendency for structural build-up abroad. The reason is that Sweden lacks a domestic resource endowment, which makes it impossible to form a domestic market. This leaves the development of system structures around final assembly, site development and installation, site operation and maintenance, and power transmission and consumption largely beyond reach. Moreover, it reduces the incentives for domestic policymakers to invest in RD&D in relation to their foreign counterparts, since the latter can build on arguments relating to both energy transitions and industrialization. This may lead to a situation where Sweden simply loses out in the competition for less site-specific structural build-up, due to more attractive conditions for actors to establish operations elsewhere. There is accordingly a risk that the system's domestic development stagnates, or even that it leaves the country altogether. This is clearly undesirable from a Swedish point of view, since potential localized benefits are lost in case the system succeeds.

A key question is therefore what role Swedish policymakers should adopt in the future development of tidal kite technology; can domestic structural build-up be promoted, how and at what cost, and do potential benefits motivate this kind of policy intervention? Up until now targeted public support to tidal kite technology has mainly come from the Swedish Energy Agency, which has provided quite significant R&D funding. This agency has recently also established a specific program for funding R&D in marine energy technologies, and are working on developing a strategy for the area (Interview 4, 2016). Still, Swedish policymakers are considered to have been quite passive regarding marine energy (Andersson et al., 2017; Interview 13, 2014), and our analysis confirms this view for tidal kite technology. Instead, they have mainly had an indirect influence on the development, by shaping the contextual structures that govern the access to knowledge, competence and private financial capital (i.e. through overarching education and taxation policy). It is questionable, however, whether this passive stance will allow for continued domestic structural build-up, given that the location of markets, which are lacking in Sweden, is expected to become increasingly important. Essentially, Swedish policymakers will probably have to strengthen the incentives for domestic structural build-up if they want to realize the potential localized benefits this would bring.

An analysis of appropriate policies for promoting tidal kite technology, while strengthening the incentives for domestic structural build-up, is beyond the scope of this study. Still, we will sketch a few broad options. The first one is to continue building on what seems to have been key for the system's domestic development so far, namely the access to knowledge, competence and financial capital. Further improving the contextual structures that provide these resources would strengthen the incentives for structural build-up in Sweden, but it is clearly an imprecise policy option (i.e. lowering the corporate tax benefits all firms) that often has its effect over long time horizons (i.e. investments in the education system pays-off after many years). A more direct way of building on the strength of contextual structures is to implement policies that facilitate and promote linkages with research organizations and industry, for example by funding collaborative R&D projects. This policy option is likely to lead to faster and more precise results, in terms of strengthening the incentives for structural build-up in Sweden, and also facilitate knowledge spill-over from the system to its context. Finally, a third policy option would be to provide some of the financial capital needed to advance the technology. This could be done in many ways, including direct support to Minesto, investments in future production facilities, and public procurement of the first commercial installations. However, this type of support has to be designed to create incentives for structural build-up in Sweden, or coupled with mechanisms that retains financial rewards, in order to avoid benefits leakage. Also, it must comply with EU legislation that often limits the extent to which national governments can subsidize individual companies and technology fields.

Although the analysis has been made from a Swedish policy perspective, our findings have policy implications for foreign regions as well, in particular the UK and other regions where technology deployment may happen in the future. Here, local benefits relating to energy transitions are important motivations for public investments, but policymakers are also looking to create new jobs and stimulate economic development (Section 2). However, it is not certain that support to technology deployment in these regions will lead to domestic structural build-up in parts of the value chain that are less bound to deployment sites, for example R&D, production of sub-systems and components, and system integration. This mirrors the situation in Sweden and policymakers accordingly face a similar challenge. However, it is arguably easier to couple support to technology deployment with incentives or even outright demands for domestic structural build-up, than it is for support to technology development. The former has also been observed in the last episode where public funding was coupled with demands for local sourcing in Wales.

Finally, and from a global perspective, the competition between regions for structural build-up may also be negative for the overall development of tidal kite technology. The risk for benefits leakage perceived by policymakers could lead to a reduced willingness to make public investments, and interventions might focus too much on supporting deployment rather than early-stage R&D, since the immediate benefits of the former are easier to retain domestically. Moreover, the dependence on a highly localized natural resource, which makes the spatial distribution of markets highly uneven, emphasizes the importance of linkages that enable national sub-system in the global TIS to fill different functions (i.e. technology development, production and deployment). This highlights the role of supra-national actors such as the EU, who could potentially implement policies based on a more overarching perspective, and the general importance of international policy coordination.

5.3 Contributions and future research

This paper contributes to the understanding of transnational linkages and dynamics in the innovation process by analyzing the emergence of tidal kite technology. In particular, we have highlighted that knowledge and competence are key for the spatial development trajectory of an emerging TIS. In early stages of development, the presence of these resources seemingly creates a path dependency that favors local build-up of TIS structures. This resonates well with the conventional view that knowledge development and learning is facilitated by spatial proximity and mainly takes place in local clusters (Boschma, 2004). At the same time, however, our findings support more recent claims that knowledge networks are increasingly existing on global and local levels simultaneously (Bathelt et al., 2004). After all, the development of tidal kite technology has benefitted from knowledge mobilized from foreign regions, although learning has certainly been concentrated to Western Sweden. Furthermore, we argue that the location of markets becomes increasingly decisive for the spatial development trajectory as an emerging TIS matures and the focus turns to demonstration, up-scaling and commercialization. This is in line with findings by Huenteler et al. (2016), who demonstrate the importance of technology deployment and user-producer relationships for innovation in complex products and systems. Lastly, we emphasize that the challenge for regional policymakers is to stimulate global TIS growth while creating incentives for domestic structural build-up, while there is a need for international policy coordination that can counteract potential negative effects of regional competition. Thus, our findings support arguments put forth in the context of wind power and photovoltaics (see Binz et al. (2017) and Quitzow (2015)).

The paper also makes a theoretical contribution in proposing a new analytical framework for analyzing the emergence of new technologies from a regional policy perspective. The framework conceptualizes the build-up of TIS structures as a result of the mobilization of six key resources, which is in line with the approach adopted by Binz et al. (2015). Moreover, it distinguishes between domestic and foreign structures in the TIS and its context. Several recent contributions view global TISs as collections of spatially delineated sub-systems in a similar way (Binz et al., 2016, 2014; Quitzow, 2015), but few choose an explicit regional policy perspective and construct system boundaries accordingly. In this paper, we have shown that this enables an analysis that highlights the spatial nature of both drivers and benefits of innovation.

However, our analysis is historical and does not attempt to provide detailed recommendations about appropriate policies for promoting tidal kite technology. Taking this step would require a goal that can guide the analysis. Although Bergek et al. (2008a) are somewhat vague about the nature of these analytical goals in their seminal contribution, it seems to have become common practice among analysts to, explicitly or implicitly, adopt goals that only relate to system growth, without considering the different ways in which this growth can be achieved geographically. If the analysis only focuses on informing policymaking that aims to create global benefits, this might be adequate since these benefits in principle arise no matter how the emerging value chain is organized geographically. But if the analysis rather strives to inform regional policymaking that also aims to create domestic benefits, it is essential to employ analytical goals that reflect this reality. One possible approach is to formulate specific goals for different parts of the value chain, which has been suggested by Sandén et al. (2014b), and to identify appropriate policies through backcasting (Holmberg and Robert, 2000). This would be in line with the analytical framework introduced by Bergek et al. (2008a), but make the goal dimension sensitive to the spatial nature of innovation. Moreover, it could be fruitful to adopt a scenario-based approach where different goals are analyzed in parallel, since this would enable assessing the appropriateness of different policies in relation to the benefits they may bring. Further developing the analytical framework demonstrated in this paper along these lines is an area that clearly calls for further research.

Finally, we acknowledge that this study has a number of important limitations that have to be considered when building on its results. In particular, our analysis concerns a narrowly defined technology that has emerged in a region that completely lacks market opportunities. This is a somewhat unusual situation, which calls for caution when making generalizations based on our findings. However, the extreme nature of the case has at the same time enabled us to capture detailed dynamics in the innovation process and to problematize around the issue of benefits leakage. In addition, our analysis has suffered from a lack of quantitative data. This is due to the narrow definition and early development stage of the focal technology, which leaves adapted databases and statistics beyond reach.

6 Conclusions

The purpose of this paper is to analyze the emergence of tidal kite technology from a Swedish policy perspective. We employ the TIS approach and examine how the resources provided by domestic and foreign regions influence how a new TIS develops in the geographical dimension. Our results reveal that knowledge and competence are particularly decisive for the spatial development trajectory of an emerging TIS. In early stages of development, the presence of these resources creates a path dependency that favors local build-up of TIS structures. This explains the why the development of tidal kite technology has mainly taken place in Sweden, even though other critical resources have been mobilized from foreign regions. Furthermore, our analysis highlights that the location of markets becomes increasingly decisive for the spatial development trajectory as an emerging TIS advances towards full-scale demonstration and commercialization, at least for complex products and systems. This has critical policy implications, in particular for regions that for different reasons lack this resource. If public support to new technologies is motivated by both global and local benefits, which is most often the case, policymakers have to not only promote global TIS growth, but also create incentives for parts of this growth to take place domestically. Developing the TIS approach to enable the design of policies that balance these objectives opens up an interesting avenue for future research, which may build on the analytical framework used in this paper.

Acknowledgements

The research presented in this paper was funded by the Swedish Energy Agency (Grant no. 39885-1). We would like to thank Eugenia Perez Vico for performing three of the expert interviews and for providing valuable input. An earlier version of the paper was presented at the 7th International Sustainability Transitions Conference in Wuppertal, Germany, in September 2016. We are grateful for points raised at the conference, valuable comments from anonymous referees, and the engagement of the many interviewees who made this work possible. The usual disclaimer applies.

References

Andersson, J., 2013. Blå energi – En strategisk innovationsagenda för marin energi. Gothenburg, Sweden.

Andersson, J., Bolund, B., Carlson, O., Fängström, O.D., Jansson, A., Larsson, T., Lindelöf, U., Lord, R., Losman, B., Möller, P., Sidenmark, M., Waller, E., 2013. Fiska jobb och energi ur havet. NyTeknik 29.

Andersson, J., Perez, E., Hammar, L., 2015. The importance of informed political direction: An analysis of the Swedish marine energy innovation system, in: Proceedings of the International Sustainability Transitions Conference 2016.

Andersson, J., Perez Vico, E., Hammar, L., Sandén, B.A., 2017. The critical role of informed political direction for advancing technology: The case of Swedish marine energy. Energy Policy 101, 52–64. doi:10.1016/j.enpol.2016.11.032

Bathelt, H., Malmberg, A., Maskell, P., 2004. Clusters and knowledge: local buzz, global pipelines and the process of knowledge creation. Prog. Hum. Geogr. 28, 31–56. doi:10.1191/0309132504ph469oa

Bergek, A., Jacobsson, S., Carlsson, B., Lindmark, S., Rickne, A., 2008a. Analyzing the functional dynamics of technological innovation systems: A scheme of analysis. Res. Policy 37, 407–429. doi:10.1016/j.respol.2007.12.003

Bergek, A., Jacobsson, S., Sandén, B.A., 2008b. "Legitimation" and "development of positive externalities": two key processes in the formation phase of technological innovation systems.

Technol. Anal. Strateg. Manag. 20, 575–592. doi:10.1080/09537320802292768

Binz, C., Coenen, L., Truffer, B., 2016. Global Innovation Systems – a conceptual framework for technological innovation in transnational contexts, Paper accepted to the DRUID conference 2016.

Binz, C., Tang, T., Huenteler, J., 2017. Spatial lifecycles of cleantech industries – The global development history of solar photovoltaics. Energy Policy 101. doi:10.1016/j.enpol.2016.10.034

Binz, C., Truffer, B., Coenen, L., 2015. Path Creation as a Process of Resource Alignment and Anchoring: Industry Formation for On-Site Water Recycling in Beijing. Econ. Geogr. 0, 1–29. doi:10.1080/00130095.2015.1103177

Binz, C., Truffer, B., Coenen, L., 2014. Why space matters in technological innovation systems—Mapping global knowledge dynamics of membrane bioreactor technology. Res. Policy 43, 138–155. doi:10.1016/j.respol.2013.07.002

Binz, C., Truffer, B., Li, L., Shi, Y., Lu, Y., 2012. Conceptualizing leapfrogging with spatially coupled innovation systems: The case of onsite wastewater treatment in China. Technol. Forecast. Soc. Change 79, 155–171. doi:10.1016/j.techfore.2011.08.016

Borras, S., Edquist, C., 2013. The choice of innovation policy instruments. Technol. Forecast. Soc. Change 80, 1513–1522. doi:10.1016/j.techfore.2013.03.002

Boschma, R., 2004. Competitiveness of Regions from an Evolutionary Perspective. Reg. Stud. 38, 1001–1014. doi:10.1080/0034340042000292601

Bunnell, T.G., Coe, N.M., 2001. Spaces and scales of innovation. Prog. Hum. Geogr. 25, 569–589. doi:10.1191/030913201682688940

Carlsson, B., Jacobsson, S., Holmén, M., Rickne, A., 2002. Innovation systems: analytical and methodological issues. Res. Policy 31, 233–245. doi:10.1016/S0048-7333(01)00138-X

Carlsson, B., Stankiewicz, R., 1991. On the nature, function and composition of technological systems. J. Evol. Econ. 1, 93–118.

Coenen, L., Benneworth, P., Truffer, B., 2012. Toward a spatial perspective on sustainability transitions. Res. Policy 41, 968–979. doi:10.1016/j.respol.2012.02.014

Coenen, L., Díaz López, F.J., 2010. Comparing systems approaches to innovation and technological change for sustainable and competitive economies: an explorative study into conceptual commonalities, differences and complementarities. J. Clean. Prod. 18, 1149–1160. doi:10.1016/j.jclepro.2010.04.003

Dimming, L., 2009. Hallå Anders Jansson. Göteborgs-Posten.

Dimming, L., 2006. Göteborgsföretag tar kraften ur havsvågor. Göteborgs-Posten.

EMEC, 2016. European Marine Energy Centre – Tidal devices [WWW Document]. URL http://www.emec.org.uk/marine-energy/tidal-devices/

Ernst, D., 2002. Global production networks and the changing geography of innovation systems. Implications for developing countries. Econ. Innov. New Technol. 11, 497–523. doi:10.1080/10438590214341

Flyvbjerg, B., 2016. Five Misunderstandings About Case-Study Research. Qual. Inq. 12, 219–245. doi:10.1177/1077800405284363

Frankfurt School-UNEP Centre/BNEF, 2016. Global Trends in Renewable Energy Investment 2016.

GCEC, 2015. Seizing the Global Opportunity: Partnerships for Better Growth - The 2015 New Climate Economy Report. The New Climate Economy, Global Commission on the Economy and Climate. doi:978 0 9906845 0 3

Geels, F.W., 2002. Technological transitions as evolutionary reconfiguration processes: a multi-level perspective and a case-study. Res. Policy 31, 1257–1274. doi:10.1016/S0048-7333(02)00062-8

Gosens, J., Lu, Y., Coenen, L., 2015. The role of transnational dimensions in emerging economy "Technological Innovation Systems" for clean-tech. J. Clean. Prod. 86, 378–388. doi:10.1016/j.jclepro.2014.08.029

Hansen, T., Coenen, L., 2015. The geography of sustainability transitions: Review, synthesis and reflections on an emergent research field. Environ. Innov. Soc. Transitions 17, 92–109. doi:10.1016/j.eist.2014.11.001

Harrell, E., 2011. Deep Green Underwater Kite [WWW Document]. Times Mag. URL http://content.time.com/time/specials/packages/article/0,28804,2029497_2030623,00.html (accessed 1.17.17).

Hekkert, M.P., Negro, S.O., 2009. Functions of innovation systems as a framework to understand sustainable technological change: Empirical evidence for earlier claims. Technol. Forecast. Soc. Change 76, 584–594. doi:10.1016/j.techfore.2008.04.013

Hekkert, M.P., Suurs, R.A.A., Negro, S.O., Kuhlmann, S., Smits, R.E.H.M., 2007. Functions of innovation systems: A new approach for analysing technological change. Technol. Forecast. Soc. Change 74, 413–432. doi:10.1016/j.techfore.2006.03.002

Holmberg, J., Robert, K.-H., 2000. Backcasting — a framework for strategic planning. Int. J. Sustain. Dev. World Ecol. 7, 291–308. doi:10.1080/13504500009470049

Holmberg, S., 2006. Swedish and European Opinions on Energy Production. Gothenburg, Sweden.

Hood, C., Briner, G., 2014. Energy Sector Tranformation: Issues and Options for the UNFCCC Negotiations. Paris Cedex, France.

Hoppmann, J., Huenteler, J., Girod, B., 2014. Compulsive policy-making - The evolution of the German feed-in tariff system for solar photovoltaic power. Res. Policy 43, 1422–1441. doi:10.1016/j.respol.2014.01.014

Huenteler, J., Schmidt, T.S., Ossenbrink, J., Hoffmann, V.H., 2016. Technology life-cycles in the energy sector - Technological characteristics and the role of deployment for innovation. Technol. Forecast. Soc. Change 104, 102–121. doi:10.1016/j.techfore.2015.09.022

Hughes, T.P., 1987. The Evolution of Large Technological Systems.

IEA, 2015. World Energy Outlook 2015. Paris Cedex, France.

Interview 1, 2016. Face-to-face interview in Gothenburg, Sweden, with two entrepreneurs at a Swedish marine energy site developer. Performed by Johnn Andersson in November 2016.

Interview 10, 2016. Face-to-face interview in Gothenburg, Sweden, with a Project Manager at RISE Research Institutes of Sweden. Performed by Johnn Andersson in Mar 2016.

Interview 11, 2016. Face-to-face interview in Gothenburg, Sweden, with a Board Member at Minesto. Performed by Johnn Andersson in Mar 2016.

Interview 12, 2016. Face-to-face interview in Gothenburg, Sweden, with the CEO of Minesto. Performed by Johnn Andersson and Björn Sandén in Jan 2016.

Interview 13, 2014. Face-to-face interview in Stockholm, Sweden, with a Civil Servant at The ministry of Enterprise and Innovation, Swedish Government. Performed by Eugenia Perez Vico in Apr 2014.

Interview 14, 2014. Face-to-face interview in Gothenburg, Sweden, with a Senior Executive at Minesto. Performed by Johnn Andersson in Apr 2014.

Interview 15, 2014. Face-to-face interview in Gothenburg, Sweden, with three Project Managers at Swedish industry supplier. Performed by Eugenia Perez Vico in Apr 2014.

Interview 2, 2016. Telephone interview with an Inventor/PhD Candidate at Linköping University, Sweden. Performed by Johnn Andersson in November 2016.

Interview 3, 2016. Face-to-face interview in Gothenburg, Sweden, with a Professor at Chalmers University of Technology, Sweden. Performed by Johnn Andersson in November 2016.

Interview 4, 2016. Telephone interview with a Civil Servant at The Swedish Energy Agency, Sweden. Performed by Johnn Andersson in November 2016.

Interview 5, 2016. Telephone interview with a Senior Manager at Mitsui Science Studies Institute, Japan. Performed by Johnn Andersson in June 2016.

Interview 6, 2016. Telephone interview with a Senior Manager at Midroc New Technology, Sweden.

Performed by Johnn Andersson in May 2016.

Interview 7, 2016. Face-to-face interview in Gothenburg, Sweden, with a Project Manager at Minesto. Performed by Johnn Andersson in May 2016.

Interview 8, 2016. Telephone interview with the CEO of a German industry supplier. Performed by Johnn Andersson in May 2016.

Interview 9, 2016. Telephone interview with an Entrepreneur at Swedish technology developer. Performed by Johnn Andersson in Mar 2016.

IPCC, 2014. Climate Change 2014: Synthesis Report. Contribution of Working Groups I, II and III to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change [Core Writing Team, R.K. Pachauri and L.A. Meyer (eds.)]. IPCC, Geneva, Switzerland, 151 pp.

IPCC, 2012. IPCC Special Report on Renewable Energy Sources and Climate Change Mitigation.

IRENA, 2014. The Socio-economic Benefits of Solar and Wind Energy.

Jacobsson, S., Bergek, A., 2011. Innovation system analyses and sustainability transitions: Contributions and suggestions for research. Environ. Innov. Soc. Transitions 1, 41–57. doi:10.1016/j.eist.2011.04.006

Jacobsson, S., Johnson, A., 2000. The diffusion of renewable energy technology: an analytical framework and key issues for research. Energy Policy 28, 625–640. doi:10.1016/S0301-4215(00)00041-0

Joas, F., Pahle, M., Flachsland, C., Joas, A., 2016. Which goals are driving the Energiewende? Making sense of the German Energy Transformation. Energy Policy 95, 42–51. doi:10.1016/j.enpol.2016.04.003

Karlberg, L.A., 2007. Al-Amoudi satsar på svensk tidvattenkraft. NyTeknik.

Karlsson-Ottosson, U., 2013. Svenskar ordnar el från lugna vatten. NyTeknik.

Kern, F., Rogge, K.S., 2016. The pace of governed energy transitions: Agency, international dynamics and the global Paris agreement accelerating decarbonisation processes? Energy Res. Soc. Sci. 22, 13–17. doi:10.1016/j.erss.2016.08.016

KIC InnoEnergy, 2015. Minesto attracts a multi million euro investment from KIC InnoEnergy [WWW Document]. Press Release. URL http://www.innoenergy.com/minesto-attracts-a-multi-million-euro-investment-from-kic-innoenergy/ (accessed 9.28.15).

KTH, 2016. Underwater kites could be next wave in clean energy [WWW Document]. Press Release. URL https://www.kth.se/en/forskning/artiklar/undervattensdrake-ska-ge-havskraft-vind-i-seglen-1.618330 (accessed 1.18.17).

Markard, J., Hekkert, M., Jacobsson, S., 2015. The technological innovation systems framework: Response to six criticisms. Environ. Innov. Soc. Transitions 16, 76–86. doi:10.1016/j.eist.2015.07.006

Markard, J., Raven, R., Truffer, B., 2012. Sustainability transitions: An emerging field of research and its prospects. Res. Policy 41, 955–967. doi:10.1016/j.respol.2012.02.013

Markard, J., Truffer, B., 2008. Technological innovation systems and the multi-level perspective: Towards an integrated framework. Res. Policy 37, 596–615. doi:10.1016/j.respol.2008.01.004

Marstrom Composite, 2015. Minesto AB New energy solution [WWW Document]. URL http://www.marstrom.com/en/industry-and-automotive (accessed 1.18.17).

McLaughlin & Harvey, 2015. McL&H partner in Minesto Deep Green project [WWW Document]. Press Release. URL https://www.mclh.co.uk/media-centre/news/mclh-partner-in-minesto-deep-green-project/ (accessed 1.18.17).

Minesto, 2016a. Minesto – Deep Green [WWW Document]. URL http://minesto.com/deep-green/

Minesto, 2016b. Deep Green [WWW Document]. URL http://minesto.com/deep-green/ (accessed 1.17.17).

Minesto, 2016c. Minesto orders bottom joint system for Deep Green [WWW Document]. Press Release. URL http://minesto.com/minesto-orders-bottom-joint-system-for-deep-green/ (accessed 1.18.17).

Minesto, 2015a. Inbjudan till teckning av Units i Minesto AB (publ) inför listning på First North vid Nasdaq Stockholm. Prospect for Minesto's IPO on the Nasdaq stock exchange in Stockholm.

Minesto, 2015b. Welsh Government invests 13 million euros of EU funds in marine energy leader Minesto to start the commercial roll out of marine power plants in Wales [WWW Document]. URL http://minesto.com/welsh-government-invests-13-million-euros-of-eu-funds-in-marine-energy-leader-minesto-to-start-the-commercial-roll-out-of-marine-power-plants-in-wales/ (accessed 7.1.15).

Minesto, 2015c. Minesto tillförs 145 MSEK och får ca 2500 nya aktieägare [WWW Document]. Press Release. URL http://investor.minesto.com/nyheter/minesto-tillfors-145-msek-och-far-ca-2500-nya-aktieagare-41921?page=4 (accessed 1.18.17).

Minesto, 2015d. Another EUR 5.1 million to Minesto's Deep Green technology [WWW Document]. Press Release. URL http://minesto.com/another-eur-5-1-million-to-minestos-deep-green-technology/ (accessed 1.18.17).

Minesto, 2014. Memorandum of Understanding signed between Minesto and Florida Atlantic University to examine feasibility of ocean current power [WWW Document]. Press Release. URL http://minesto.com/memorandum-of-understanding-signed-between-minesto-and-florida-atlantic-university-to-examine-feasibility-of-ocean-current-power/ (accessed 1.18.17).

Minesto, 2013. Minesto wins international "industry pioneer" tidal energy award [WWW Document]. Press Release.

Minesto, 2011. Minesto receives Rushlight Marine and Hydro award [WWW Document]. Press Realease.

Musiolik, J., Markard, J., Hekkert, M., 2012. Networks and network resources in technological innovation systems: Towards a conceptual framework for system building. Technol. Forecast. Soc. Change 79, 1032–1048. doi:10.1016/j.techfore.2012.01.003

Negro, S.O., Hekkert, M.P., Smits, R.E., 2007. Explaining the failure of the Dutch innovation system for biomass digestion-A functional analysis. Energy Policy 35, 925–938. doi:10.1016/j.enpol.2006.01.027

NyTeknik, 2011. Fyra nya miljoner till undervattensdraken. NyTeknik.

NyTeknik, 2010. 20 miljoner till svenska undervattensdraken. NyTeknik.

NyTeknik, 2009. Titta den rör på sig. NyTeknik.

OES, 2006. OES Annual Report 2006. Paris Cedex, France.

Pegels, A., Lütkenhorst, W., 2014. Is Germany′s energy transition a case of successful green industrial policy? Contrasting wind and solar PV. Energy Policy 74, 522–534. doi:10.1016/j.enpol.2014.06.031

Pentland, W., 2013. Deep Green Power Plant Taps Low-Velocity Tidal Energy With Underwater Kites. Forbes.

Poole, M.S., Van de Ven, A.H., Dooley, K., Holmes, M.E., 2000. Organizational Change and Innovation Processes. Oxford University Press, New York, USA.

Quitzow, R., 2015. Dynamics of a policy-driven market: The co-evolution of technological innovation systems for solar photovoltaics in China and Germany. Environ. Innov. Soc. Transitions 17, 126–148. doi:10.1016/j.eist.2014.12.002

Quitzow, R., Walz, R., Köhler, J., Rennings, K., 2014. The concept of "lead markets" revisited: Contribution to environmental innovation theory. Environ. Innov. Soc. Transitions 10, 4–19. doi:10.1016/j.eist.2013.11.002

Raven, R., Schot, J., Berkhout, F., 2012. Space and scale in socio-Technical transitions. Environ. Innov. Soc. Transitions 4, 63–78. doi:10.1016/j.eist.2012.08.001

Reichardt, K., Negro, S.O., Rogge, K.S., Hekkert, M.P., 2016. Analyzing interdependencies between policy mixes and technological innovation systems: The case of offshore wind in Germany.

Technol. Forecast. Soc. Change 106, 11–21. doi:10.1016/j.techfore.2016.01.029

Sandén, B.A., Azar, C., 2005. Near-term technology policies for long-term climate targets - Economy wide versus technology specific approaches. Energy Policy 33, 1557–1576. doi:10.1016/j.enpol.2004.01.012

Sandén, B.A., Hillman, K.M., 2011. A framework for analysis of multi-mode interaction among technologies with examples from the history of alternative transport fuels in Sweden. Res. Policy 40, 403–414. doi:10.1016/j.respol.2010.12.005

Sandén, B., Hammar, L., Hedenus, F., 2014a. Are renewable energy resources large enough to replace non-renewable energy?, in: Sandén, B. (Ed.), Systems Perspectives on Renewable Power. Chalmers University of Technology. Chalmers University of Technology, Gothenburg, Sweden.

Sandén, B., Kamb, A., Kushnir, D., Gustafsson, A., Karlsson, S., 2014b. Solceller, in: Hellsmark, H. et al. (Ed.), Teknologiska Innovationssystem Inom Energiområdet. The Swedish Energy Agency.

Sjödén, K., 2013. Finner kraft i en undervattensdrake - Minesto hoppas bidra till framtidens elförsörjning. Göteborgs-Posten.

The Crown Estate, 2014. Crown Estate unlocks further UK wave and tidal current opportunities [WWW Document]. Press Release. URL https://www.thecrownestate.co.uk/news-and-media/news/2014/further-uk-wave-and-tidal-opportunities-unlocked/ (accessed 1.18.17).

The Crown Estate, 2011. Over 30 wave and tidal sites now released around UK [WWW Document]. Press Release. URL https://www.thecrownestate.co.uk/news-and-media/news/2011/over-30-wave-and-tidal-sites-now-released-around-uk/ (accessed 1.18.17).

The Swedish Energy Agency, 2014. Ny teknik kan ge ökad elproduktion ur tidvattenströmmar. Press Release.

The Swedish Energy Agency, 2010. Seabased Receives SEK 139 Million for Wave Power Project [WWW Document]. Press Release. URL http://www.energimyndigheten.se/en/news/2010/seabased-receives-sek-139-million-for-wave-power-project/ (accessed 1.17.17).

Truffer, B., 2015. Challenges for Technological Innovation Systems research: Introduction to a debate. Environ. Innov. Soc. Transitions 16, 65–66. doi:10.1016/j.eist.2015.06.007

Truffer, B., Coenen, L., 2012. Environmental Innovation and Sustainability Transitions in Regional Studies. Reg. Stud. 46, 1–21. doi:10.1080/00343404.2012.646164

Truffer, B., Murphy, J.T., Raven, R., 2015. The geography of sustainability transitions contours of an emerging theme. Environ. Innov. Soc. Transitions 17, 63–72. doi:10.1016/j.eist.2015.07.004

Vasseur, V., Kamp, L.M., Negro, S.O., 2013. A comparative analysis of Photovoltaic Technological

Innovation Systems including international dimensions: The cases of Japan and the Netherlands. J. Clean. Prod. 48, 200–210. doi:10.1016/j.jclepro.2013.01.017

Venture Cup, 2007. Storslam för Göteborg i Venture Cup's Sverigefinal [WWW Document]. Press Release. URL http://www.mynewsdesk.com/se/venturecup/pressreleases/storslam-foer-goeteborg-i-venture-cup-s-sverigefinal-151786 (accessed 1.18.17).

CHALMERS UNIVERSITY OF TECHNOLOGY
SE-412 96 Gothenburg, Sweden
Telephone: +46 (0)31 772 10 00
www.chalmers.se