Towards sustainable innovation

Analysing and dealing with systemic problems in innovation systems

Op weg naar duurzame innovatie
Het analyseren van en het omgaan met systemische problemen in innovatie systemen

(met een samenvatting in het Nederlands)

Proefschrift

ter verkrijging van de graad van doctor aan de Universiteit Utrecht
op gezag van de rector magnificus, prof.dr. G.J. van der Zwaan,
ingevolge het besluit van het college voor promoties
in het openbaar te verdedigen

op woensdag 15 oktober 2014 des middags te 2.30 uur

door

Anna Justyna Wieczorek

geboren op 15 april 1972 te Kutno, Polen

Promotor: Prof.dr. Marko Hekkert

This thesis was partly accomplished with financial support from the Dutch Knowledge Network on System Innovation (KSI)

Table of Contents

Chapter I

Introduction

1. Background

1.1. On the development of system thinking in innovation studies

Innovation is not a new phenomenon but has for long been very difficult for societies to understand and define (Fagerberg et al. 2005). Innovation was therefore seen as a 'manna from heaven', something intangible and given from above. Time, but particularly the scientific discoveries in the early 20th century and during World War II, led to belief in the so-called linear model of innovation. According to this model, the source of innovation is basic research. Results of this research feed into applied research and development, which in turn lead to manufacturing and sales on a market. In this process new knowledge is automatically transformed into new products or processes via a sequence of fixed, linear activities (Smith, 2000). The neoclassical perception of innovation that coevolved with this linear model further argues that uncertainty, inappropriability and indivisibility of scientific knowledge cause under-investment in R&D by private actors and a non-optimal allocation of resources for invention; this phenomenon is also known as a market failure. In these conditions governments hold major responsibility to fund basic research in the belief that it would eventually lead to wealth, health and national security. The model was widely adopted after 1945 and has been central to the creation of research units and science support structures from the end of the 19th century. The policy instruments used to address market failures were dominated by financial tools such as R&D subsidies or tax incentives (Smits an Kuhlman, 2004).

In the 1980's the field of innovation research presented empirical evidence that most innovations do not necessarily occur in the way described by the linear model. Kline and Rosenberg (1986) identified two main problems with the linear model. Firstly, it led to excessively high expectations of the impact and applicability of basic research results, while in most cases, the key driver of innovation is a need of users in the market or within a company. A commonly used example was the transistor, which was developed years before the underlying scientific principles were formulated. Secondly, the linear model ignored many feedbacks and loops that occur between the 'stages'. By this it underestimated the importance of incremental changes, particularly related to the production processes. Furthermore, very few innovations are radical or disruptive although research may be relatively more important in such cases (see Abernathy and Clark, 1985). Kline and Rosenberg (1986) proposed a more up-to-date model of technological innovation, the so-called chain-linked model. According to this model new knowledge is not always the driver of innovation. Innovation may also be driven by market needs. When a problem arises, actors first turn to the existing pool of scientific and technical knowledge to look for solutions. Only when this knowledge does not suffice is new research conducted to fill the gaps. While basic research is the main and most important contribution to the stock of existing knowledge, it has rather an indirect influence on innovation. Furthermore, to be able to exploit basic research, actors require certain types of skills and experience, the so-called 'absorptive capacity' (Cohen and Levinthal 1990). Its absence may be a more important bottleneck to the use of science in innovation than the quality of the research itself. The chain-linked model emphasized that although the process of innovations can be sequential, there are numerous complex feedback loops between all the stages.

The early 1990s brought further realization that innovation does not take place in isolation, but that it is a collective act determined by a range of social, organizational, economic and institutional factors. Furthermore, actors involved in the innovation processes have come to face problems other than the availability of finance for R&D which were beyond the reach of the traditional policy instruments. These problems began to manifest in the environment external to the firms and they created a serious barrier to innovation. Examples include: poorly articulated demand, too weak network hindering knowledge transfer, too strong network causing lock-in and dominance of incumbents, legislation favouring incumbent technologies (Jacobson and Johnson, 2002).

In response to these developments a concept of an innovation system (IS) has been developed and has become a new model of innovation. The model has roots in various disciplinary traditions such as sociology (Granovetter, 1985), evolutionary economics (Nelson and Winter, 1982), institutional studies (North, 1990, Johnson 1992), economics of innovation (Mowery and Rosenberg, 1979; Kline and Rosenberg, 1986; Freeman, 1987; Freeman and Lundvall, 1988; Lundvall, 1992; Nelson 1993) and economics of knowledge (Dosi, 1996, Lundvall and Johnson, 1994; Cohen and Levinthal, 1990; Foray and Lundvall, 1996). Triggered by the deficiencies of the linear model and the neoclassical view of innovation, these disciplines coevolved and built on each other's findings about long-term technological change and the role of innovation (Smits, 2002).

Despite initial great variety of definitions of the innovation system, there emerged a broad consensus that the innovation system concept emphasises the importance of institutions, which jointly and individually contribute to the development and diffusion of new technologies, and which explain why actors behave the way they do in the system. By emphasising that innovation is an outcome of numerous complex interactions among the elements of a system where learning processes and knowledge-sharing among heterogeneous actors play a critical role, the innovation system approach shifted the focus of analysis away from individual actors (firms) to networks of organisation (Chaminade and Edquist, 2006). It also broadened the debate about sources of innovation beyond R&D (Soute et al., 2010) and directed policy attention to other problems than market failure, namely systemic problems[1] (Metcalfe,2005). Such problems hinder the operation and the development of the entire innovation system (OECD, 1997; Smith, 2000; Jacobsson and Johnson, 2000; Klein-Woolthuis et al., 2005; Chaminade and Edquist, 2006, 2007). To be effectively addressed the problems require policy instruments that would operate at the level of a system (Metcalfe, 1995) and not ones that support its individual elements. By this the system approach defied the non-context specific, one-size-fits-all neoclassical policy advice, the assumption of a (non-existent from the evolutionary, systemic perspective) welfare maximising equilibrium and a market failure rationale based on removing any

[1] E.g. institutional problems, network problems or capabilities problems.

divergences from the equilibrium through support to R&D. Still, because technological knowledge does create beneficial externalities, it creates sufficient argument to further encourage R&D beyond the levels provided by the incentives of the free market (Lipsey et al., 2005). In that sense the systemic rationale complements the neoclassical market failure.

1.2. Innovation systems and sustainability

1.2.1. The Technological Innovation System (TIS) perspective

Ever since the innovation system was conceptualised there have been a number of different types of innovation systems identified in the literature. Initially the National Innovation System (NIS) (Freeman, 1987; Lundvall, 1992; Nelson, 1993) received increased attention following the empirical comparative study by Nelson (1993). Other analyses that followed also focused on analyzing and comparing the structural configuration of the systems in the hope of clarifying the differences in innovation levels, identifying problems and informing innovation policy. It has, however, been difficult to learn only from the structure and also challenging to transfer elements from one system to another because the structures differ and the contexts in which they are embedded vary as well. What works well in one country may not be suitable for another. Innovation system scholars began therefore to search for other conceptualizations of innovation systems that would free the analyses from national borders. Sectoral (Breschi and Malerba, 1997), Technological (Carlsson and Stankiewicz, 1991; Carlsson and Jacobsson, 1997) and Regional (Cooke, 2001) innovation systems were coined and began to be used in a broader than national context. Still, however, being focused on comparing structural configurations of the systems they became rather static and did not create any insights into the dynamics of innovation processes. Another common feature of all types of analyses was that they all addressed the contribution of innovation to fostering economic growth. Innovations at that time were often referred to as creations of an economic significance (Edquist, 1997) and expected to fundamentally contribute to economic development and wealth creation (Smith, 2000; Polt and Rojo, 2002; OECD, 2000). The 'Lisbon Strategy' that included the EU's intention to become 'the most competitive and dynamic knowledge-based economy in the world' (EU, 2000) may serve as a good illustration of this tendency.

In the late 90's, however, increasingly more attention was paid to the impact that the growth in productivity poses on the global environment. Innovations and technological change were again expected to offer innovative solutions that would help achieve sustainability in the broad sense. Given the deficiency of product and process innovations to deal with the global environmental challenges, a new field of sustainability transitions developed that put significant emphasis on the long-term co-evolutionary change in the ways human needs are satisfied, also referred to as system innovation (Elzen and Wieczorek, 2005).

Much attention in this field focussed on social framing of technological change and the so-called multilevel perspective on technological transitions (MLP) (Geels, 2002). The MLP conceptualises the provision of human needs such as water, energy or mobility as enabled by socio-technical systems encompassing both technological as well as socio-economic aspects. Established systems, often termed socio-technical regimes, create the core of economic structure and provide stability and continuity

(Geels, 2005). The literature assumes radical change of these systems (system innovation) is needed for transitions towards sustainability. Such a sustainability transition comes about as the result of mutually reinforcing changes at the level of socio-technical regimes, landscapes that provide context for the regimes, and of experimentation with alternative technologies, services and policies occurring in niches (Geels and Schot, 2007). Given however that niches, regimes and landscapes are co-created by various actors acting across space and time, transitions of socio-technical systems are shaped by and come out of the interactions between spatially heterogeneous actors (Raven et al., 2012). As an analytical framework the MLP is widely used to clarify transformations of socio-technical systems at the level of societal functions (socio-technical transformations, socio-technical systems innovation) taking place in various geographical contexts.

In the context of sustainability transitions, the Technological Innovation System (TIS), given its focus on technologies and their socio-economic and institutional environment, was often presented as a useful way to understand how radical innovations with sustainability promise come about. A Technological Innovation System has been defined as ‘a dynamic network of agents interacting in a specific economic/industrial area under a particular institutional infrastructure and involved in the generation, diffusion, and utilization of technology’ (Carlson et al., 1991). In order to respond to the earlier mentioned limitations related with the static structural analyses, a growing number of studies began to focus on processes that influence the development, diffusion and utilization of mainly renewable technologies. These processes have been termed ‘functions’ of innovation systems (Bergek et al, 2008a; Hekkert et al, 2007) and they encompass: entrepreneurial activities F1, knowledge development F2, knowledge diffusion F3, guidance of the search F4, market formation F5, resources mobilization F6, legitimacy creation F7 (see Table 1).

Table 1. Key processes of innovation systems

Key process	Description
Entrepreneurial activities F1	In this process entrepreneurs translate knowledge into business opportunities, and eventually innovations, through market-oriented experiments.
Knowledge development F2	This process refers to learning activities, mostly on emerging technology, but also on markets, networks and users. The activities include learning-by-searching and learning-by-using. Both are at the heart of any innovation process.
Knowledge diffusion F3	This process encompasses all activities that relate to the diffusion of knowledge among actors through learning by interacting.
Guidance of the search F4	This function refers to those processes that lead to a clear goal for the development of new technology based on actors’ expectations, articulated user demand and societal discourse. This process enables selection, which guides the distribution of resources.
Market formation F5	This process involves activities contributing to the creation of demand for new technology. In early phases of developments these can be small niche markets but later on larger markets are required to facilitate cost reductions and incentives for entrepreneurs to move in.
Resource mobilization F6	This function is about allocation of financial, physical and human capital as necessary basic inputs for all processes in the innovation system. Unavailability of these resources hampers all other system activities.
Legitimacy creation F7	Innovation is by definition uncertain. This process refers to activities that counteract resistance in the incumbent system and provide a certain level of legitimacy for actors to commit investment and adopt the new technology.

Over time the TIS developed into a theoretical model that helps to describe, analyse and understand the diffusion of particular, mostly renewable, technologies and their contribution to sustainability transitions. The core of the current TIS studies comprise the analysis of the emergent structural configuration (actor-networks, technology, institutions) and major processes (functions) that support formation and development of radically new systems (Hekkert et al, 2007; Bergek et al, 2008a). The argument is that the success of innovations is, to a large extent, determined by how the innovation system is constructed (defined as structure of the innovation system) and how it functions.

Despite a number of common conceptual grounds, the TIS perspective differs from the MLP approach by focusing on the prospects and the dynamics of a particular technological innovation and not of the broader transformation process. It is also rather concerned with the internal innovation system dynamics as opposed to the broad analysis of transformation of socio-technical systems providing human needs. Furthermore, while in MLP systems aim at the provision of human needs, in TIS the objective of the system is innovation (Markard and Truffer, 2008). Some however, e.g. Lovio and Kivimaa (2012) argue that the empirical differences between the two approaches are smaller than the theory would suggest.

1.2.2. Drawbacks and limitations of the TIS approach

Where TIS continues to fall short is a lack of clear conceptualisation of the system problems. Many studies have been released that list various classifications of problems that may occur in the innovation systems but the lists do not necessarily converge. In most cases the authors name specific types or aspects of problems such as lock-in problems (Chaminade and Edquist, 2010; Smith, 2000). Lock-in is not a problem but rather an outcome of too strong interaction, hence it can be classified as an interaction-related problem. Complementarity problems as defined by Chaminade and Edquist (2010) refer to a lack of connectivity and compatibility between competencies within the system. They can therefore also be regarded as a type of interaction problem. Similarly, in case of infrastructural problems: different types of infrastructure are highlighted by different sources: physical (Smith 2000; Klein-Woolthuis et al. 2005; Chaminade and Edquist 2010), knowledge/research (OECD 1997; Jacobsson and Johnson 2000; Chaminade and Edquist 2010) and financial/investment (Smith 2000; Chaminade and Edquist 2010). Furthermore, Jacobsson and Johnson (2000) highlight legislative failures while Smith (2000) points institutional failures and refers to the absence of a relevant regulatory framework to support the system. This literature does not address the definition of systemic problems either. For example, Chaminade and Edquist (2007) refer to a systemic problem as one that is not automatically solved by private actors. They also suggest that systemic problems can be identified by conducting empirical analyses that explicitly compare systems of innovation but no clear definition is proposed.

The second flaw of especially the empirical TIS-based analyses is that policy advice based on the ambiguous definition of problems is of a very general character at best. The various studies advise increasing user capability, developing standards, creating a market (see e.g. Bergek et al, 2008b; Negro et al, 2007) but they do not provide any clear explanation as to how exactly user capacity can be improved and how the problems could be addressed in a coherent way. Given a changed view of innovation as a systemic process, policy attention has shifted away from market failures towards systemic problems and new forms of instruments to address them. The new tools are called systemic instruments and they are supposed to operate at the (innovation) system level in contrast to existing, primarily financial, policy tools which focus on R&D production and either support individual elements of the system or stimulate bilateral relations (Smits and Kuhlmann, 2004; Metcalfe, 1995). Systemic instruments, however, so far have not been clearly conceptualised. The innovation literature has a number of examples of *national* policy mixes (e.g. OECD, 2012) or systemic instruments *avant la lettre* (Smits and Kuhlman, 2004; Mierlo et al, 2010). There is, however, no empirical evidence of systemic instruments that were proposed based on systematic TIS analyses, whether of national or broader, spatially informed, character.

Thirdly, although technology is not confined to national borders and originally TIS emerged from the criticism of a narrow national focus of the NIS analyses, the later empirical TIS studies limited their scope to using 'national' as a unit of analysis. These studies led to criticism of TIS for national delimitation of the studied systems and a lack of an explicit recognition of the spatial context in which innovations and transitions occur (see e.g. Jacobsson and Lauber; 2006; Negro et al., 2008; Hekkert et al., 2007; Negro et al, 2007; Bergek et al., 2008b; Hillman et al., 2008). The choice of 'national' has often been justified by the aim to inform domestic technology policy. The transnational aspects that influence specific technological fields are predominantly discussed under a broad term of 'exogenous forces' without a clear explanation of their impact on analysed TIS (Coenen and Truffer, 2012; Markard et al, 2012). The recent insights in sustainability transition literature also demonstrate considerable spatial variation of the structural configurations of the systems (Berkhout et al, 2011; Dewald and Truffer, 2011; Späth and Rohracher, 2011; Coenen et al, 2010, 2012; Truffer and Coenen, 2012; Binz et al, 2012; Raven et al, 2012). More attention to space and scale is therefore called for (Coenen et al, 2012). Without this spatial sensitivity, it is argued, the studies overlook the creation of local policies and resources in broader networks, markets and contexts. The national departure of the empirical TIS analyses also implies that they miss out on a number of valuable insights such as advantages, tensions or conflicts that arise in a wider context in which technologies are embedded and by this they provide a biased policy advice.

Fourthly, most of the TIS studies so far have described technological systems that have passed their formative stage and entered the growth phase. In these studies the innovation systems are characterized by a distinct structural configuration, rather well developed supply chains, defined products and emerging consumer markets (Negro et al., 2007, 2008, 2011). However, little is written about systemic problems and policy for less developed, nascent systems that have a low degree of structuration, a small number of actors and markets that have not had the chance to be created. Because of a lack of clear systems structure and system momentum, according to Bergek, et al., (2008b) and Raven (2005), such juvenile configurations may be particularly vulnerable to the impact of so-called *external forces* such as world crises or evolving climate change debate. Looking only inward and ignoring spatial contexts (as explained above) may therefore be damaging for potential policy recommendations in the case of such system.

Given this background, the problem that this thesis is addressing is the lack of clear conceptualisation and empirical underpinning of systemic problems and instruments in technological innovation systems in various stages of development, and of differing geographical delimitation.

2. Research questions and objective

The main research questions of this thesis include:

> *RQ1: Based on the recent insights from the innovation system studies how can systemic problems and systemic instruments be conceptualized and identified?*
>
> *RQ2: What are the systemic problems in a nascent and nationally delimited technological innovation system of aquatic biomass in the Netherlands and how can they be addressed?*
>
> *RQ3: What are the systemic problems and instruments in a more mature and nationally delimited technological innovation system of offshore wind in the Netherlands?*
>
> *RQ3: What is the impact of system environment on the identification of systemic problems and instruments in more mature technological innovation systems of offshore wind in the Netherlands?*

The overall objective of this thesis is to contribute to the improvement of innovation processes for sustainability through definition and identification of systemic problems and instruments in renewable energy Technological Innovation Systems.

3. Thesis outline

The research questions will be answered in specific chapters. In chapter 2 systemic problems and instruments are conceptualised and a systemic policy framework is proposed that links structural and functional analyses with the aim to identify problems hindering the system development and the systemic instruments that could address them in a coordinated way. The framework is a theoretical proposal for the type of analysis that can be carried out in TISs. In the chapters that follow, the framework is applied to the analysis of empirical cases. Since the TIS analysis as well as presentation of the results can be done in various ways, it is interesting to explore whether the proposed theoretical framework has any empirical limitations. The chapters 3-6, therefore, experiment with various stages of the system development, geographical delimitation of the system and various ways of analysis and presentation of results.

Chapter 3 presents the analysis of a nascent and nationally delimited, Dutch aquatic biomass TIS. It makes explicit use of a longitudinal analysis of events that historically shaped the system development from its emergence until 2012. Personal communications with experts support the major findings. The chapter focuses on identification of systemic problems and policy based on internal system dynamics. Using a typology of three types of context impacts: transnational linkages, impact of other TISs and landscape developments, it also reflects on their influence on the system formation.

Chapter 4 demonstrates the application of the framework to the analysis of a more mature and nationally delimited, Dutch offshore wind innovation system. Furthermore, the structural configuration and the dynamics of the innovation system is assessed for a specific moment in time: end of 2011 using a combination of events analysis as well as experts and key stakeholders interviews. Based on this assessment systemic problems are identified and national systemic policy proposed.

Since national analyses do not fully show all aspects of, e.g., competition between countries and how the national choices and decisions influence the strategies and policies of neighbouring, sister TISs, chapter 5 presents an assessment of four offshore wind innovation systems: Denmark, Germany, The Netherlands and UK that were leading offshore wind developments in Europe in 2011. While paying attention to the national policy challenges this chapter focuses on identifying common problems that hinder formation of a European offshore wind innovation system. The analysis presents a snapshot of a system in 2011.

Based on the insights from chapter 5, chapter 6 concentrates on highlighting the implications of a national TIS analysis focus compared with an international focus. It aims to highlight the interaction effects between the four national offshore wind innovation systems and discusses the impact on how an analyst would perceive the systemic problems when the interaction effects are not taken into account versus when they are accounted for. Thereby it is possible to analytically show what a broader geographical focus adds to a nationally focused TIS analysis.

The concluding chapter 7 summarises the major findings by providing conscience responses to the main research questions. It also reflects on the benefits and drawbacks of various ways of analysing TIS and makes suggestions for further research.

References

Abernathy, W.J. Clark, K.B., 1985. Innovation: Mapping the Winds of Creative Destruction. Research Policy 14: 3-22

Bergek, A., Jacobsson, S., Carlsson, B.; Lindmark, S. Rickne, A., 2008a. Analyzing the functional dynamics of technological innovation systems: A scheme of analysis. *Research Policy*, 37:407-429

Bergek, A., Jacobsson, S., Sandén, B.A., 2008b. 'Legitimation' and 'development of external economies': two key processes in the formation phase of technological innovation systems, Technology Analysis and Strategic Management, 20:575-592

Berkhout, F., Wieczorek, A.J., Raven, R., 2011. Avoiding environmental convergence: a possible role for sustainability experiments in latecomer countries? International Journal of Institutions and Economies, 3(2):367-385

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, Technological Forecasting and Social Change, 79:155–71

Carlsson, B., Jacobsson, S., 1997. Diversity creation and Technological Systems: A technology policy perspective in Edquist, C. (ed.), 1997. Systems of innovation: Technologies, institutions and organizations, London, Pinter

Carlsson, B., Stankiewicz, R., 1991. On the Nature, Function, and Composition of Technological systems, Journal of Evolutionary Economics 1:93-118

Chaminade, C. and Edquist, C., 2010. Rationales for public policy intervention in the innovation process: A systems of innovation approach. In: Smits, R., Kuhlmann, S. Shapira, P. (eds), The Theory And

Practice of Innovation Policy, International Research Handbook. 95–114. Cheltenham: Edward Elgar
Chaminade, C. Edquist, C., 2006. From theory to practice. The use of the systems of innovation approach in innovation policy, in: Hage, J., De Meeus, M., (eds) Innovation, Learning and Institutions. OUP
Chaminade, C., Edquist, C., 2007. Rationales for public policy intervention in the innovation process: A systems of innovation approach, in Innovation Policy-Theory and practice. An international Handbook, Edward Elgar
Coenen, L, Truffer, B, 2012. Places and spaces of sustainability transitions: geographical contributions to an emerging research and policy field'. European Planning Studies, 20(3):367–74
Coenen, L., Benneworth, P., Truffer B., 2012. Towards a spatial perspective on sustainability transitions. Research Policy, 41:968–79
Coenen, L., Raven, R., Verbong, G., 2010. Local niche experimentation in energy transitions: A theoretical & empirical exploration of proximity advantages and disadvantages. Technology in Society, 32:295-302
Cohen, W.M., Levinthal, D.A., 1990. Absorptive capacity: A new perspective on learning and innovation, Administrative Science Quarterly, 35:128-152
Cooke, P., 2001. Regional Innovation Systems, Clusters and the Knowledge Economy. Industrial and Corporate Change, 10(4): 945-74
Dewald, U., Truffer, B., 2011. Market Formation in Technological Innovation Systems—Diffusion of Photovoltaic Applications in Germany. Industry and Innovation, (18)3:285–300
Dosi, G. 1996. The contribution of economic theory to the understanding of the knowledge-based economy, in Foray, D., and Lundvall, B-Å., (eds), Employment and growth in the knowledge-based economy, OECD, Paris
Edquist, C. (ed.), 1997. Systems of innovation: Technologies, institutions and organizations, London, Pinter
Elzen, B., Wieczorek, A.J., 2005. Introduction: Transitions towards sustainability through system innovation. Technological Forecasting and Social Change Journal, 72(6):651-662
EU, 2000. Lisbon European Council: Presidency Conclusions.
Fagerberg, J., Mowery, D.C. Nelson, R., 2005. (eds) The Oxford Handbook of Innovation, OUP
Foray, D., Lundvall, B-Å., (1996), The knowledge-based economy: from the economics of knowledge to the learning economy, in Foray, D., and Lundvall, B-Å., (eds), Employment and growth in the knowledge-based economy, Paris OECD.
Freeman, C., 1987. Technology policy and economic performance: lessons from Japan, London, Pinter
Freeman, C., Lundvall, B-A., 1988. Small countries facing the technological revolution, London and New York: Printer
Geels, F. W., 2002. Technological transitions as evolutionary reconfiguration processes: a multi-level perspective and a case study. Research Policy 31:257-1273
Geels, F.W., 2005. Processes and patterns in transitions and system innovations: Refining the co-evolutionary multi-level perspective. Technological Forecasting and Social Change, 72(6):681-696.
Geels, F.W., *Schot, J.,* 2007. Typology of Sociotechnical Transition Pathways, Research Policy Research Policy, 36 (3), 399-417
Granovetter, M., 1985. Economic Action and Social Structure. American Journal of Sociology, 91:481-510. Republished in Granovetter, M., Swedberg, R., The sociology of economic life, Oxford: Westview Press

Hekkert, M., Suurs, R., Negro, S., Smits, R., Kuhlmann, S., 2007. Functions of Innovation Systems: A new approach for analyzing technological change, Technol. Forecasting and Social Change, 74(4):413-43

Hillman, K., Suurs, R., Hekkert, M., Sanden, B., 2008. Cumulative causation in biofuels development: a critical comparison of the Netherlands and Sweden, Technological Analysis and Strategic Management, 20:592–612

Jacobsson, S., Johnson, A., 2000. The diffusion of renewable energy technology: an analytical framework and key issues for research, Energy Policy, 28(9):625-640

Jacobsson, S., Lauber, V., 2006. The politics and policy of energy system transformation – explaining the German diffusion of renewable energy technology, Energy Policy, 34:256–76

Johnson, B. 1992. Institutional learning, in Lundvall, B-Å. (ed.) (1992), National Systems of Innovation: Towards a Theory of Innovation and Interactive Learning, Pinter, London

Klein-Woolthuis, R., Lankhuizen, M., Gilsing, V., 2005. A system failure framework for innovation policy design, Technovation 25: 609-619

Kline, S.J. Rosenberg, N., 1986. An Overview of Innovation. In Landau, R. & Rosenberg, N., (eds), The Positive Sum Strategy, Harnessing Technology for Economic Growth*.* Washington: National Academy Press. 275-305

Lipsey, R., Carlaw K.I., Bekar, C.T., 2005. Economic Transformations. General Purpose Technologies and Long Term Economic Growth. OUP

Lovio, R., Kivimaa, P., 2012. Comparing alternative path creation frameworks in the context of emerging biofuel fields in the Netherlands, Sweden and Finland. Eur. Plan. Stud. 20(5):773–790

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

Lundvall, B-Å., Johnson, B., (1994), The learning economy, Journal of Industry Studies, 1(2), 23-42

Markard, J., Truffer, B., 2008 The development of processes and the multi-level perspective: towards an integrated framework. Research Policy 37:596-615

Metcalfe, J., 1995. The economic foundations of technology policy: equilibrium and evolutionary perspectives, in P. Stoneman (Ed.), Handbook of Economics and Innovation and Technology Change

Metcalfe, J., 2005. Systems failure and the case for innovation policy. in P. Llerena, P., and *Matt, M.,* (eds) *Innovation Policy* in a Knowledge-Based Economy: Theory and Practice, Springer

Mierlo van B., C. Leeuwis, Smits, R., 2010. Learning towards system innovation: Evaluating a systemic instrument. Technological Forecasting and Social Change, 77(2):318-334

Mowery, D., Rosenberg, N., 1979. The Influence of Market Demand Upon Innovation: A Critical Review of Some Recent Empirical Studies, Research Policy, reprinted in N. Rosenberg, Inside the Black Box: Technology and Economics

Negro, S.O., Alkemade, F., Hekkert, M.P., 2012. Why does renewable energy diffuse so slowly? A review of innovation system problems. Renewable Sustainable Energy Review, 16:3836-46

Negro, S.O., Hekkert, M.P., Smits, R., 2007. Explaining the failure of the Dutch innovation system for biomass digestion – a functional analysis. Energy Policy, 35:925–38

Negro, S.O., Suurs, R., Hekkert, M.P., 2008. The bumpy road of biomass gasification in the Netherlands: explaining the rise and fall of an emerging innovation system. Technological Forecasting and Social Change, 75:57–77

Negro, S.O., Vasseur, V., Sark, V., Hekkert, M.P., 2011. Solar eclipse – the rise and 'dusk' of the Dutch PV innovation system. International Journal of Technology, Policy and Management

Nelson, R., (ed), 1993. National Systems of Innovation: A Comparative Analysis, Oxford, OUP

Nelson, R., Winter, S., 1982. An Evolutionary Theory of Economic Change, Cambridge-MA, Harvard University Press

North, D. C., 1990. Institutions, Institutional Change and Economic Performance, CUP

OECD, 1997. Policy evaluation in innovation and technology. Towards best practices. Paris

OECD, 2000. A new economy? A changing role of innovation and information technology in growth, Paris

OECD, 2012. Statistical annex to the 2012 OECD STI Outlook Country Profiles, in OECD Science, Technology and Industry Outlook 2012, OECD Publishing

Polt, W., Rojo, J., 2002. Policy instruments. Introduction, in Polt, W., Rojo, J., K. Zinocker, G. Fahrenkrog, & A. Tubke (Eds.), (2002), RTD Evaluation Toolbox - Assessing the socio-economic impact of RTD-policies (IPTS Technical Report Series, EUR 20382) (pp. 171-176). Brussels/Luxembourg: Institute for Prospective Technological Studies

Raven, R., 2005. Strategic niche management for biomass. Eindhoven: Technische Universiteit Eindhoven

Raven, R., Schot, J., Berkhout, F., 2012. Space and scale in socio-technical transitions. Environmental Innovation and Societal Transitions, 10(4):63-78

Smith, K., 2000. Innovation as a Systemic Phenomenon: Rethinking the Role of Policy, Enterprise and Innovation Management Studies, Routlege, 1(1):73-10

Smits, R., 2002. Innovation studies in the 21st century. Questions from a users perspective, in: Technological Forecasting and Social Change, 69(9), 861-883

Smits, R., S. Kuhlmann, 2004. The rise of systemic instruments in innovation policy. The International Journal of Foresight and Innovation Policy, 1(1/2):4-32

Späth, P., Rohracher, H., 2012. Local Demonstrations for Global Transitions—Dynamics across Governance Levels Fostering Socio-Technical Regime Change Towards Sustainability. European Planning Studies, 20(3):461-79

Truffer, B., Coenen, L., 2012. Environmental Innovation and Sustainability Transitions in Regional Studies, Regional Studies, 46(1):1-21

Chapter II

Systemic instruments for systemic innovation problems: a framework for policy makers and innovation scholars[2]

Abstract

Systemic policy instruments receive increasing attention among innovation scholars as means to stimulate sustainability oriented technological innovation. The instruments are called systemic in expectation to improve the functioning of entire (innovation) systems. A first step in designing systemic instruments is an analysis of the systemic problems that hinder the development of a specific technological trajectory. This paper argues that two approaches to study innovation systems - structural and functional analyses - can be combined in a systemic policy framework that helps to (i) identify the systemic problems and (ii) suggest the systemic instruments that would address these problems.

Keywords: innovation policy, systemic instruments, systemic problems, technological innovation system, functions of innovation system

1. Introduction

Current pathways of economic development are not sustainable. Most developed and developing economies are heavily dependent on fossil fuels, leading to enormous negative environmental effects. These economies are characterized by a huge throughput of materials, chemicals and products that lead to depletion of resources, loss of biodiversity and pollution of the environment. According to Rockström (2009) the world is no longer functioning in a safe operating space. Policy makers are trying to change the direction of technological change by innovation policies that address society's grand challenges (Innovation Union, 2011)

Systemic instruments receive increasing attention among innovation scholars and policy makers as novel means that can bring about these processes of change and stimulate sustainability oriented technological innovation (Smits and Kuhlmann; 2004, Raven et al, 2010; Voss et al, 2009; van Mierlo et al, 2010). According to Smits and Kuhlmann (2004) systemic instruments are tools that focus on the innovation system level instead of focusing on specific parts of innovation systems and support processes that play a crucial role in the management of innovation processes. The basic idea behind systemic instruments is that they aim to address problems that arise at the innovation system level and which negatively influence the speed and direction of innovation processes. These problems are often referred to as systemic weaknesses or systemic failures. They hinder the operation and development of innovation system as a whole and the presence of these system failures are often considered a new policy rationale replacing the neoclassical market failure (Edquist, 1997). Examples include: too weak or

[2] This chapter has been published as: Wieczorek, A.J., Hekkert, M.P., 2012. Systemic instruments for systemic innovation problems: A framework for policy makers and innovation scholars. Science and Public Policy, 39: 74–87

too strong innovation networks, poorly articulated demand for innovation or institutional capacity problems (Smith, 2000; Jacobsson and Johnson, 2000; Klein-Woolthuis et al, 2005). While the literature is rich in various categorisations of systemic problems, not much is being said about how to systematically identify them and with what type of tools they can best be addressed. Even more surprisingly, the literature on systemic instruments is poorly linked to the literature on systemic problems. The key article on systemic instruments by Smits and Kuhlmann (2004) does not build further on the systemic failures identified in the above literature.

This paper argues that two approaches to study innovation systems - structural and the functional analyses - can be combined together and provide analytical building blocks of a systemic policy framework that helps to (i) identify systemic problems and (ii) suggest systemic instruments to address the identified obstacles. The structural analysis has for long been used to evaluate and compare the composition of mostly national innovation systems in an attempt to clarify the determinants of varying rates of innovation (Nelson, 1993; Freeman, 1988, 1995; Schmoch, 2006). For analysis of technological innovations however the structural analysis proved insufficient, hence, the functional approach emerged to highlight the processes (rather than the structure) that are important for well performing (technological) innovation systems. The processes are categorised as functions of innovation systems (e.g. entrepreneurial activities, knowledge development, market formation), and they aim to clarify how well innovation systems are functioning (Johnson, 2001; Bergek, 2002; Hekkert, 2007; Bergek et al, 2008).

The structural and the functional analyses as well as the systemic problems and systemic instruments concepts have all the same systemic-evolutionary foundations but they were developed separately from each other and they are therefore poorly aligned. They are also used rather individually to inform policy process while each is of a different kind and concerns different aspect of policy process (analysis, identification of problems, design of policy tools). If linked into a consistent policy framework, they could together show a much more complete picture of the analysed system and its problems and by this lead to more effective policies to accelerate the process of sustainable technological change.

The best attempt so far to integrate the different concepts is presented by Bergek et al (2008). The authors began incorporating elements of structural analysis to a functional analysis of innovation systems to better explain inducement and blocking mechanisms in technological innovation systems, identify key policy issues and set policy goals. Their contribution, however, strongly criticises systemic problems for their structural characteristics; it rejects for that matter the so far most advanced categorisation of systemic problems by Klein-Woolthuis et al (2005) and proposes inducement and blocking mechanisms instead without clarifying how they differ from systemic problems. There is also lack of theoretical clarity with regards to the typology of the inducement and blocking mechanisms. Being derived from the empirical cases they encompass a mix of endogenous and exogenous factors hindering innovation systems and it is not clear whether all possible mechanisms have been identified or whether the list can further be extended. In case of mapping of the structural components the paper emphasises the importance of the presence of actors, networks and institutions. It does not however elaborate on the issue of actors' capabilities or institutional capacities and it gives no thought to infrastructure as an element of an innovation system despite some studies show that missing infrastructure may also cause systemic problem (Klein-Woolthuis et al, 2005; Chaminade and Edquist, 2007). Finally the authors identify key policy issues without any reference to the work on systemic instruments and on how useful or not such tools could be in addressing identified obstacles.

This paper aims to address these gaps. In particular it shows why structure is so important for explaining systemic problems. It also clarifies the relation between systemic problems and blocking mechanisms and proposes how to methodologically link the structural and functional analyses with systemic problems and systemic instruments into a consistent policy framework. Before proposing the framework, however, the paper reflects on the various conceptualisations of structural elements, functions and systemic problems and identifies categorisations which reinforce their mutual complimentarity and by this help build a consistent policy framework. Such a reflection is necessary because the concepts are not fully agreed upon in the communities that use them[3]. Since systemic instruments (Smits and Kuhlmann, 2004) are not very clearly defined in the literature either, this paper draws some preliminary implications for their desired characteristics.

The paper consists of 5 sections. Section 1 reviews the structural elements of innovation systems. Section 2 focuses on the functions of innovation systems and proposes a way to link them with the structure. Section 3 defines and categorises systemic problems. Section 4 reflects on the systemic instruments characteristics and their relation to the systemic problems. Section 5 presents the systemic policy framework and explains how it can be applied by policy makers. The paper closes with some concluding remarks on: the methodological choices made in sections 1-4 and on further research necessary to improve and test the framework.

2. Structural elements of innovation systems

1.1 Structural elements in the literature

‘Systems of innovation’ has been proposed by innovation scholars predominantly in reaction to the shortcomings of the neoclassical attempts to explain innovation and technological change (Edquist 1997). Since its identification, there have been a number of categorisations of innovation systems: National (Freeman 1988, Lundvall 1992, Nelson, 1993) or Regional Innovation Systems (Doloreux, 2002) when a geo space is a unit of analysis; Sectoral Innovation Systems (SIS) that often go beyond national borders (Malerba, 2002); and Technological Innovation Systems (TIS) not confined to national borders either but more specific in scope than SISs and most dynamic among all conceptualisations (Carlsson and Stankiewicz, 1991; Carlson et al, 2002).

With regards to elements of innovation systems, Lundvall (1992, p.12) makes a distinction between a narrow and a broad definition. The narrow definition includes organisations and institutions involved in searching and exploring – such as R&D departments, technological institutes and universities. The broad definition comprises all parts and aspects of an economic structure and the institutional set up affecting learning, searching and exploring – the production, marketing and finance system. Johansson and

[3] The inconsistencies in the literature are natural for a new scientific field but to grow and prosper more consensus is needed on concepts and how they relate. In this paper we hope to contribute to this goal.

Johnson (2000) are more specific and name three types of elements of TISs: actors and their competences, networks and institutions meant both as legislation, capital market or educational system as well as culture. This is along the lines of Carlson and Stankiewicz (1991), who define TIS as a social network composed of actors and institutions (rules of the game) constructed around a specific technology. Kuhlmann (2004), however, uses the modified Technopolis structure encompassing: demand, framework conditions, industrial system, intermediaries, education and research system, political system and infrastructure meant as policies and institutions (Kuhlmann and Arnold, 2001).

Comparisons of the structure of various (mostly national) innovation systems have for long been a source of information about the reasons behind a success or a failure of specific innovation systems. Policy makers however cannot easily learn from structures of other innovation systems because local specificities make it difficult to transfer elements of one system to another in expectation they would perform equally well. Also the great diversity of perspectives on the concept and composition of innovation systems is quite challenging when it comes to its practical applications or to designing a framework for analysis of systems, identification of problems and the design of policies.

We address these issues in three ways. Firstly, we narrow our focus to TIS. We do this because of the advances in literature in defining elements and functions of TISs, and because of an interest of the authors to empirically test the framework in the context of sustainability transition pathways that built around specific technologies. A TIS is a global system with strong regional variations in terms of structure and functioning. It may be analysed at a global level but also a regional delineation is possible. Secondly, we propose that the structural analysis of systems is based on mapping of its elements and evaluating their capacity to stimulate innovation rather than on comparing different systems. As will be shown later (Section 3.2), the structural elements, their presence or absence as well as their capacities are critical to functioning of the innovation systems. Thirdly, we link structural analysis with the functional analysis (in Section 2.2).

The following paragraphs discuss four structural elements of the TIS identified in the literature: (i) actors, (ii) institutions and (iii) interactions, operating within (iv) specific infrastructure.

2.1 Structural dimensions of TIS

There is no disagreement in the literature that <u>actors</u> play a role in innovation systems. Various sources emphasise the role of users (von Hippel, 1988), universities (Mowery and Sampat, 2005) or multinationals (Narula and Zanfei, 2005). The differences among various sources are rather in the categorisation of actors that are under scrutiny. Some present them from the perspective of a role they play in the innovation process: users, producers, intermediary and supportive organisations (Smits and Kuhlman, 2004). Sometimes these categories are complemented with classifications from the perspective of the role actors' play in the economic activity such as: companies, consumers or knowledge institutes (Klein-Woolthuis et al 2005). Given the current systemic phase of innovation where difference between producers and users is increasingly blurred (Smits and Kuhlman, 2004) the distinction made based on actors' roles in the innovation process is not most useful. For analysing TIS we therefore delineate categories of actors (individuals, organisations and networks) based on their role in the economic activity: civil society, government, NGO's, companies (start-ups, SME's, multinationals, large firms), knowledge institutes (universities, technology institutes, research centres, schools), and other parties[4] (legal organisations, financial organisations/banks, intermediaries, knowledge brokers, consultants). These different actors can all fulfil different roles.

Institutions encompass a set of common habits, routines and shared concepts used by humans in repetitive situations (soft institutions) organised by rules, norms and strategies (hard institutions) (Crawford and Ostrom, 1995). Institutional set-ups and capacities are determined by their spatial, socio-cultural and historical specificity (Lipsey et al, 2005) and are different from organisations (such as firms, universities, state bodies, etc) (Edquist, 1997). Organisations of various kinds are considered in this paper as a type of actor.

Since 'interaction' is dynamic, it is difficult to consider it as a structural element. A 'network' has been used in some literature positions (Johansson and Johnson, 2000) to describe the cooperative relationships and links between actors but a 'network' can also be seen as a higher form of actors' organisation. Interactions however do not only take place within networks. In the early stages of systems development there are no networks but e.g. bilateral interactions between actors can be traced. The focus here is on relationships and they can be analysed at the level of both networks and at the level of individual contacts.

Infrastructure does not have a steady position as a structural element of innovation systems and there is no conclusive agreement in the key literature positions as to what infrastructure covers. Kuhlmann (2004) or Schmoch et al (2006) use infrastructure to encompass what has in this paper been defined as 'institutions', namely so called 'framework conditions', institutional set ups (rules, norms and social conduct), public utilities and policies. O'Sullivan, (2005) uses the term infrastructure in connection with availability of finance for innovation in the form of venture capital, funds, subsidies or programmes. Link and Metcalfe (2008) analyse the whole set of dimensions of 'technology infrastructure' such as physical and virtual tools, methods and data. Smith (1997) emphasises the importance of the tangible physical and knowledge infrastructure. He argues that physical infrastructure such as buildings, (rail-)roads, bridges, harbours, airports, telecommunication networks, but also existing technologies meant as artefacts, instruments or machines play an important role in establishing the dominance of technologies and in shaping the technological trajectories, which have an effect on the overall performance of innovation systems. Some empirical studies explicitly show the significance of physical infrastructure (such as rail-tracks) for the functioning of innovation systems and refer to its deficiency as a systemic problem (Klein-Woolthuis et. al., 2005). Under the knowledge infrastructure Smith (1997) includes universities, research labs, training systems, libraries, etc – public and private organisations whose role is the production, maintenance, distribution, management and protection of knowledge. This conceptualisation has some characteristics of physical infrastructure but most importantly it emphasises the soft part of it – the skills, the expertise and the know-how they generate and store. Building on this literature but given the definition of institutions and actors above, this paper proposes to consider three categories of infrastructure: physical, financial and knowledge as structural components of the

[4] Miscellaneous category of parties that contribute to the innovation process.

innovation systems. The physical infrastructure encompasses: artefacts, instruments, machines, roads, buildings, telecom networks, bridges, harbours. The knowledge infrastructure includes: knowledge, expertise, know-how, strategic information. Financial infrastructure includes: subsidies, financial programs, grants, etc. Table 1 summarises all structural 'dimensions' of technological innovation systems.

Table 1. Structural dimensions of TIS

Structural dimensions:	**Subcategories:**
Actors:	- Civil society - Companies: start-ups, SME's, large firms, MNC's - Knowledge institutes: universities, technology institutes, research centres, schools - Government - NGO's - Other parties: legal organisations, financial organisations/banks, intermediaries, knowledge brokers, consultants
Institutions:	- Hard: rules, laws, regulations, instructions - Soft: customs, common habits, routines, established practices, traditions, ways of conduct, norms, expectations
Interactions:	- At the level of networks - At the level of individual contacts
Infrastructure:	- Physical: artefacts, instruments, machines, roads, buildings, networks, bridges, harbours - Knowledge: knowledge, expertise, know-how, strategic information - Financial: subsidies, fin programs, grants etc.

3. Functions of innovation systems

3.1. Functions in the literature

Functional analysis (Johnson, 2001; Bergek, 2002; Hekkert, 2007; Bergek et al, 2008) focuses on the processes that are important for well performing innovation systems. The processes are categorised as functions of innovation systems and they clarify the dynamics of the systems. Originally Johnson, (2001) proposed 6 functions. Hekkert et al, (2007) tested the list empirically and suggested 7 functions: F1 – entrepreneurial activities, F2 – knowledge development, F3 – knowledge diffusion, F4 – guidance of the search, F5 – market formation, F6 – resources mobilisation, F7 – creation of legitimacy. Bergek et al (2008) also list seven functions but their phrasing and order is slightly different. The functions show the state of a specific innovation system in a defined moment of time. Answers to a set of diagnostic questions provide a basis for evaluation of the functions quality (Hekkert et al., 2010, see also Section 5).

3.2. Functions and structure

The functional approach has been used in the literature to identify the so-called 'blocking mechanisms' and served as a framework to identify emerging policy issues (Bergek, 2002).We would like to argue however that functions alone are not sufficient basis to develop successful systemic innovation policies for two reasons. Firstly, functions cannot be influenced without alteration of a structural element. For example, a precondition for knowledge diffusion (function F3) is the presence and interactions of actors. Policy-wise the function of knowledge diffusion cannot be influenced otherwise than by stimulating the participation of relevant actors or creating stimulating conditions for their interaction. Lack of occurrence or 'weakness' of any of the functions should therefore be a signal and a reason for policy makers to look at the structure of the innovation system. Secondly, if the functions are used as a sole basis for policy, there emerges uncertainty with regards to the completeness of the identified list of blocking mechanisms and, what follows, of the policy issues.

To address the concerns we propose that after the functional pattern of a system is established as in Bergek et al (2008) or Hekkert et al (2007), each function is examined through the perspective of four structural elements for either explanatory (e.g. why entrepreneurial activities do not take place?) or policy reasons (how to alter entrepreneurial activities?). Thus, the reasons why a certain system function is absent or weak can be related to the structure of the innovation systems and more specifically to actors, interactions, institutions and infrastructure. Similarly, by alteration of the structural elements policy can create circumstances in which functions can take place or 'strengthen' (Table 2).

Table 2. Functions seen through structural elements of innovation systems

System function	Structural element
F1 Entrepreneurial activities	Actors
	Institutions
	Interactions
	Infrastructure
F2 Knowledge development	Actors
	Institutions
	Interactions
	Infrastructure

That implies that structure makes functions meaningful while a coupled functional-structural analysis gives quite a good overview of what happens in the systems and in particular what goes wrong and why. Such analysis also provides a much more precise and complete basis for policy suggestion as compared to classical functional analysis[5]. From the analytical perspective the number and exact phrasing of the functions are very important but do not seem to have impact on establishing the connection between the functions and the structural elements.

4. Systemic problems

4.1. Systemic problems in the literature

Problems that hinder the innovation systems development are in the innovation literature termed as systemic problems, failures or weaknesses. While their existence and the need of considering the systemic problems as a new innovation policy rationale is widely recognised in most 'systemic' innovation literature, the number of publications that make attempt at definition and classification of these problems can be brought down to a few: Jacobsson and Johnson, (2000) in their analysis of the Swedish renewable energy system identified a number of factors that block the development and/or

[5] The reasons may also lie outside the innovation system (developments in a broader system context) but since they are often beyond the immediate influence of policy makers, we focus here only on endogenous system factors that policy makers have the ability to alter directly.

diffusion of a new technology. The blocking factors are identified per element of the analysed TIS and include on the actors and markets side: poorly articulated demand or market control by incumbents; on the network side: poor connectivity or wrong guidance with respect to future markets; on institutions: legislative failures or failures in the educational system. These are quite in line with the Chaminade and Edquist (2010) list including: infrastructure provision and investment problems; transition problems, institutional problems (hard and soft); lock-in problems; capability and learning problems, network problems; unbalanced exploration-exploitation mechanisms, complementary problems. Smith (2000) lists four systemic 'failures': failures in infrastructural provision and investment; transition failures; lock-in failures; institutional failures. The early OECD report (1997) lists: lack of interaction between actors, mismatch between basic and applied research, malfunctioning of the technology transfer institutions, information and absorptive deficiencies on the part of enterprises as systemic failures. Klein-Woolthuis et al (2005) revised the various listings and proposed four general categories: infrastructural, institutional, interaction and capabilities problems. The authors removed 'lock-in' problems from the list arguing that this is not a reason but an outcome of other problems on the list.

4.2. Problems vs. structure

The different classifications of systemic problems in the literature are difficult to compare. Their diversity may also create confusion among policy makers interested in using the concept in practice. In this section we make an attempt to define systemic problems, develop their generic typology and explore how they compare with the listings from the literature.

We start by referring to a system studies perspective (Carlsson at al., 2002), according to which a system is made up of: components (operating parts of a system), relationships (links between components) and attributes (properties of the components). Attributes are considered by Carlsson et al. (2000) as properties of components only. We argue however that relationships, links or interactions may also have properties: they can be strong or weak for example. We therefore consider attributes as properties of not only the components but also of the relationships.

In case of an innovation system, in section 1 four structural dimensions have been identified: actors, institutions, infrastructure and interactions. The first three, namely actors, institutions and infrastructure can be easily considered as components (operating parts) of the system. Interactions – in the system studies language - are relationships or links between the components. All four can have specific attributes. Carlsson et al. (2002) also argue that system does not function as a system if there is a problem with any of these aspects. By analogy an innovation system may not function well when there is a problem (i) with any of its structural elements – when for example they are missing (presence issue); or (ii) with their attributes (properties) – e.g. they are too intense as in case of interactions or miss capacity when we talk about actors (capacity/capability issue). That means that if the innovation system does not function well (and we know it because the functions are absent or weak) we may analyse why by looking at each of the structural elements in two ways – whether it is because of its presence/absence or because of its properties. By this, problems arising in the context of an innovation system, the systemic problems can be conceptualised as related to:

- The presence or capabilities of actors;
- The presence or quality of institutional set up;
- The presence or quality of interactions;
- The presence or quality of infrastructure.

To express properties/attributes of the various structural elements terms like: capacity, quality or intensity are used in both the positive and a negative sense. For example an interaction can be too intense or too weak. An institution can be too stringent or too weak[6], etc.

Following these lines and using insights from Klein-Woolthuis et al (2005), systemic problems can be defined as factors that negatively influence the direction and speed of innovation processes and hinder the development and functioning of innovation systems. We suggest that they are classified along following categories:

1. **Actors' problems** (often inadequately referred to as capabilities problems). They may be of two kinds:
   - <u>Presence</u> related: relevant actors (within the categories listed earlier) may be absent;
   - <u>Capacity</u> related: actors may lack competence, capacity to e.g. learn or utilise available resources; to identify and articulate their needs and to develop visions and strategies. By some referred to as transition problems (Smith, 2000; Chaminade and Edquist, 2010)**.**

2. **Institutional problems (**hard and soft). They may be of two types:
   - <u>Presence</u> related: when specific institutions are absent;
   - <u>Capacity</u> related: when there is a problem with their capacity/quality:
     a. Stringent institutional problems may result in the so-called appropriability trap and favour incumbents;
     b. Weak institutional problems may hinder innovation by e.g. insufficiently supporting new technologies or developments.

3. **Interaction problems** (by some referred to as lock-in problems (Smith, 2000) or network problems (Chaminade and Edquist, 2010)). They may be of two types:
   - <u>Presence</u> related: interactions are missing because of cognitive distance between actors; differing objectives, assumptions, capacities, or lack of trust;
   - <u>Quality</u> related: there is a problem with interactions' quality/intensity:
     a. Strong network problems – when some actors are wrongly guided by stronger and fail to supply each other with the required knowledge. They may be caused by:
        i. Myopia - internal orientation favouring the incumbent set up and relationships and thus blocking the necessity to open up for external forces.
        ii. Too strong involvement of incumbent actors (Kemp and Nil, 2009)

[6] Broekel and Boschma (2009) and Nooteboom, (2000) discuss geographical and institutional proximity or optimal for innovation cognitive distance between agents. The authors argue that a high degree of proximity (strong ties) between agents does not necessarily increase their innovative performance, and may possibly even harm it.

iii. Lack of - external to incumbents - weak ties, valuable for breaking through a too strong internal organisation.
iv. Dependence on dominating partners due to assets specificity.

b. Weak network problems – caused by weak connectivity between actors hindering interactive learning and innovation. Also referred to as complimentarity problems by Chaminade and Edquist (2010).

4. **Infrastructural problems** – referring to physical, knowledge and financial infrastructure. They may be:

- Presence related when specific type of infrastructure is absent;
- Quality related when infrastructure is inadequate or malfunctioning.

This typology does not suggest that in practice all possible actors, all types of infrastructure or all existing institutions need to be 'present' in every system as otherwise there is a danger of systemic problem. Such a suggestion would contradict the emergent nature of innovation. It is also possible that involvement of specific actors or presence of some regulation can be in fact hindering for the system. Who to involve and in what capacity should therefore be dependent on the analysed system and its socio-economic and political environment. The complete overview of all system dimensions and all possible problems that may arise should be helpful for policy makers to firstly thoroughly analyse the system and secondly to stimulate such combinations of elements that in their view have the greatest chances to stimulate innovation and desired e.g. sustainable orientation of the system.

From a theoretical perspective, the above typology can be useful for assessment of the various listings of systemic problems available in the literature. Table 3 shows the comparison and reveals several gaps and a couple of overlaps in the classifications of systemic problems from the literature. Overall, all the analysed sources attempt to present generic categorisations of systemic problems but in fact and in most cases they name specific types or aspects of problems. A good example is the case of *lock-in problems* from the list of Chaminade and Edquist, (2010) and Smith (2007). Lock-in is an outcome of too strong interactions (caused by various reasons as explained above) and can therefore be classified as *interaction/intensity problem* and in particular: one of the types of strong network problems. *Complementarity problems* by Chaminade and Edquist (2010) refer to a lack of connection and compatibility between competencies within the system. They can therefore be also seen as a type of *interaction/intensity problem* but this time corresponding with weak network problems or *interaction/presence problems* when there is no interaction at all. On top of that the same authors list a more general category of *network problems* and refer them to too strong or too weak linkages within the system, which in our typology also corresponds with *interaction/intensity problems*. Similar can be noticed in case of *infrastructural problems* – different types of infrastructure are highlighted by different sources: physical (Smith, 2000; Klein Woolthuis et al, 2005, Chaminade and Edquist, 2010), knowledge/research (OECD, 1997; Jacobsson and Johnson, 2000; Chaminade and Edquist, 2010) and financial/investment (Smith, 2000; Chaminade and Edquist, 2010). It is only Chaminade and Edquist (2010) that highlight all the three types. No new types of infrastructure is mentioned in the analysed literature, which gives us a sense that we defined infrastructure well (as including physical, knowledge and financial aspects) and most important of all, that we included it as a structural element of the system. Very few authors from the table below take the presence aspect into account (OECD, 1997; Jacobsson and Johnson, 2000). Most focus on capability/capacity aspect of the problems, although it is difficult to judge whether the *legislative failures* of Jacobsson and Johnson (2000) or *institutional failures* of Smith (2000) refer also to missing institutions and thus the *institutional/presence* type of problem. The use of term 'failure' by both sources however suggests rather 'malfunctioning' of institutions or their 'insufficiency' which makes us categorise these problems as *institutional/capacity problems*. Unbalanced exploration and exploitation mechanisms[7] (Chaminade and Edquist, 2010) are difficult to classify because just like in case of lock-in, unbalanced exploration and exploitation is an outcome of a problem – it can be caused by e.g. incapability of actors or be a result of too strong/weak interactions. We therefore do not include it in the table 3 below.

One more note needs to be made when discussing systemic problems. In the literature dealing with these problems terms like systemic 'failure' (OECD, 1997; Bergek et al, 2008), 'weakness' or 'imperfection' are used (Klein-Woolthuis et. al, 2005; Smith, 1997). Failure according to the major dictionaries is defined as a lack of success in something, or an unsuccessful attempt at doing something; something that falls short of what is required or expected. Similarly imperfection or weakness falls short of something that should be perfect or optimal. It is by now widely recognised in innovation studies that when technology changes endogenously and in conditions of uncertainty there is no optimality and no equilibrium (Lipsey et al, 2005) so it is impossible to talk about a failure, a weakness or imperfection. This paper therefore (in line with Chaminade and Edquist (2010)) refers to these systemic failures and weaknesses as systemic problems.

[7] According to Chaminade and Edquist (2010)" …the system might be capable of generating diversity but not having the mechanisms to be able to make the adequate selections or it may have very refined selection procedures but no capability to generate diversity. Policy makers might support the emergence of spin-off companies, for example…"

Table 3. Comparison of systemic problems classifications from the literature with the typology identified in this paper

Systemic problem	(Type of) systemic problem	OECD, 1997	Smith, 2000	Jacobsson & Johnson, 2000	Klein-Woolthuis et al., 2005	Chaminade & Edquist, 2010
Actors problems	Presence					
	Capability	Information & absorptive deficiencies of enterprises	Transition failures	Poorly articulated demand	Capabilities' failure	Capability & learning problems Transition problems
Institutional problems	Presence					
	Capacity	Malfunctioning of technology transfer institutions	Institutional failures	Legislative failures	Hard institutional failures Soft institutional failures	Institutional problems (hard & soft)
Interaction problems	Presence	Lack of interaction between actors		Poor connectivity		
	Intensity/ quality		Lock-in failures	Wrong guidance Market control by incumbents	Interaction failures: weak/strong network failures	Network problems Lock-in problems Complementarity problems
Infrastructural problems (physical, knowledge, finance)	Presence					
	Quality/ capacity	Mismatch between basic & applied research	Failures in infrastructural provision & investment	Failures in educational system	Infrastructural failures	Infrastructure provision (physical, scientific, network[8]) & investment problems

[8] Refereed to what in this paper is covered under physical infrastructure: namely IT and telecom networks.

4.3. Functions, structure and systemic problems

Table 4 presents how a coupled functional-structural analysis could be used to identify the above defined systemic problems.

Table 4. Systemic problems based on functional-structural analysis of an innovation system

System function	Structural element	Systemic problem	(Type of) systemic problem
F1 Entrepreneurial activities	Actors	Actors problem	Presence?
			Capabilities?
	Institutions	Institutional problem	Presence?
			Capacity/quality?
	Interactions	Interaction problems	Presence?
			Intensity/quality?
	Infrastructure	Infrastructural problems	Presence?
			Capacity/quality?
F2 Knowledge development	Actors	Actors problem	Presence?
			Capabilities?
	Institutions	Institutional problem	Presence?
			Capacity/quality?
	Interactions	Interaction problems	Presence?
			Intensity/quality?
Etc.	Infrastructure	Infrastructural problems	Presence?
			Capacity/quality?

Following explanation in section 2.2 (functions and structure) once it is established whether the weakness of the function has something to do with actors, institutions, interactions or infrastructure, it can further be explored whether the problem occurs because any of these are missing (e.g. specific entrepreneurs are not involved, there is no regulation that allows registering a novelty or there are no funds to support pilot projects) or there is a problem with their capacity(e.g. actors' capabilities to innovate and to identify their strategies are insufficient causing that choices that they make are not leading to any successful outcomes, or some actors dominate over others, or despite there is a lot of knowledge developed about specific technology it is not easily accessible by actors). Such an analysis can be carried out for all functions in order to identify where exactly the problem is.

4.4. Blocking mechanisms and systemic problems

Some literature (Bergek et al, 2008, Hekkert et al, 2007) focus on identifying the mechanisms blocking the functions. Careful consideration of these mechanisms reveals that they, in fact, can be categorised as systemic problems even though the latter are criticised by the same authors for their static basis. For example the blocking mechanisms identified by Bergek et al, (2008) based on specific empirical case such as: *lack of actors and resources in the middle of the chain* can be categorised as actors/presence problem and infrastructure/presence issue. *Weak advocacy coalition* is an interaction/quality problem. *Lack of integration of sub-elements of the system* is an interaction/presence problem. *Lack of standards* refers to the absence of institutions. *Lack of standard software* concerns the absence of infrastructure. *Lack of competence/poorly articulated demand* is an actors/capabilities problem while *inadequate knowledge* is a knowledge infrastructure/quality or presence issue, etc.

We suggest therefore that application of the typology of systemic problems developed in this paper can significantly enhance such empirical analyses by assisting policy makers and innovation scholars in structuring of the outcomes of the coupled structural-functional analysis and, most importantly, in a systematic mapping of all possible 'blocking mechanisms' that may occur in a specifically defined innovation system. The comparison above also in a way validates the existence of relationship between functions and the systems structural elements confirming that intervention in the function without alteration of systems structure is not possible.

5. Systemic instruments

5.1. Systemic instruments for systemic problems

The identification of the type of systemic problems should be a precondition for a selection of strategies and tools that would target them and by this influence the overall functioning of the innovation system. Smits and Kuhlman (2004) called such tools 'systemic instruments' and suggested five processes that should be the aim of systemic policies : building and organising innovation systems; providing a platform for learning and experimenting; providing an infrastructure for strategic intelligence and stimulating demand articulation; managing interfaces; developing strategy and vision. How do these five processes correspond with the typology of systemic problems outlined in Section 3.2?

Building and organising innovation systems seems to refer to ensuring presence of the relevant actors, institutions or infrastructure. It could be made more specific depending on the problem it is supposed to address: for actors problem – it could be formulated as 'Stimulating and organising the participation of relevant actors'; for institutional problem it could be defined as 'stimulating presence of hard and soft institutions'; for infrastructural problems one could think of: 'Stimulating physical, financial and knowledge infrastructure'. *Providing a platform for learning and experimenting* could be seen as a way to address problems with actors' capabilities related to learning about new technological options. *Providing an infrastructure for strategic intelligence* and *stimulating demand articulation* link with two types of issues: capacity aspect of infrastructural (knowledge) problems and actors' capacity problems. Ability to articulate demand however is just one specific aspect of capability building. *Management of interfaces* is a way to stimulate occurrence of interactions within the system while *developing strategy and vision* is again about developing actors' capabilities.

The processes that systemic instruments should focus on proposed by Smits and Kuhlmann (2004) seem very broad and not sufficiently structured to be of much help for policy makers. Most importantly they do not correspond with many of the problems that may occur within innovation systems (for example none of the goals refers to the capacity aspect of institutional or interaction problems while provision of adequate physical and financial infrastructure is totally omitted). That suggests that in order to be able to address all 8 types of systemic problems, systemic instruments should focus on one or more of the following 8 goals (Table 5):

1. Stimulate and organise the participation of various actors (NGO's, companies, government, etc);
2. Create space for actors capability development (through e.g. learning and experimenting)

3. Stimulate occurrence of interaction among heterogeneous actors (by e.g. management of interfaces and building consensus);
4. Prevent too strong and too weak ties;
5. Secure presence of (hard and soft) institutions;
6. Prevent too weak or too stringent institutions;
7. Stimulate physical, financial and knowledge infrastructure;
8. Ensure adequate quality of the infrastructure (strategic intelligence serving as a good example of specific knowledge infrastructure).

Table 5. Goals of systemic instruments per (type of) systemic problem

Systemic problem	**(Type of) systemic problem**	**Goals of systemic instrument**
Actors problems	Presence?	Stimulate and organise the participation of relevant actors (1)
	Capabilities?	Create space for actors capability development (2)
Interaction problems	Presence?	Stimulate occurrence of interactions (3)
	Intensity?	Prevent too strong and too weak ties (4)
Institutional problems	Presence?	Secure presence of hard and soft institutions (5)
	Capacity?	Prevent too weak and too stringent institutions (6)
Infrastructural problems	Presence?	Stimulate physical, financial and knowledge infrastructure (7)
	Quality?	Ensure adequate quality of the infrastructure (8)

5.2. Goals vs. functions

The difference between functions of innovation systems and the above goals of systemic instruments is that the functions (together with structural analysis) are *descriptive* and provide an *analytical* tool to determine systems performance at a specific moment of time and to identify the systemic problems this system faces. Goals of systemic instruments are *prescriptive* and meant to support *policy design* and selection of tools that can address the identified problems in an integrated way. The relation of systemic instruments goals with the structural elements comes along as useful in targeting specific elements in a way that it improves the functioning of the system as a whole. We suggest therefore that while functions of innovation systems are processes that need to take place to ensure good systems performance, the goals of systemic instruments describe what the instruments should do to create the circumstances in which the innovation system functions have the highest chances of occurrence.

6. A systemic policy framework proposal

The link between systemic problems and the systemic instruments' goals allows for completing the systemic policy framework (Table 6). Within this framework the functions are analysed through the perspective of the structural elements. Such analysis leads to a very precise identification of factors that block specific functions and by that hinder the development of the analysed system. Different types of problems need to be addressed with different instruments. The goals of systemic instruments guide selection of individual tools in a way that allows for their mutual reinforcement, coherence and orchestrated impact. The purpose of such an integrated instrument is to create opportunities for system development by influencing elements and connections within the system that would not emerge spontaneously.

Table 6. A systemic innovation policy framework

System function	Structural element	Systemic problem	(Type of) systemic problem	Systemic instrument goals
F1 Entrepreneurial activities	Actors	Actors problems	Presence?	Stimulate and organise the participation of relevant actors (1)
			Capabilities?	Create space for actors capability development (2)
	Interactions	Interaction problems	Presence?	Stimulate occurrence of interactions (3)
			Capacity?	Prevent too strong and too weak ties (4)
	Institutions	Institutional problems	Presence?	Secure presence of hard and soft institutions (5)
			Intensity?	Prevent too weak and too stringent institutions (6)
	Infrastructure	Infrastructural problems	Presence?	Stimulate physical, financial and knowledge infrastructure (7)
			Quality?	Ensure adequate quality of the infrastructure (8)
F2 Knowledge development	Actors	Actors problems	Presence?	Stimulate and organise the participation of relevant actors (1)
			Capabilities?	Create space for actors capability development (2)
	Interactions	Interaction problems	Presence?	Stimulate occurrence of interactions (3)
			Intensity?	Prevent too strong and too weak ties (4)
	Institutions	Institutional problems	Presence?	Secure presence of hard and soft institutions (5)
			Capacity?	Prevent too weak and too stringent institutions (6)
	Infrastructure	Infrastructural problems	Presence?	Stimulate physical, financial and knowledge infrastructure (7)
			Quality?	Ensure adequate quality of the infrastructure (8)
etc				

6.1. Application of the framework

Since policymaking is a cyclic process and functional analysis shows just a particular moment of the system development – the effectiveness of the designed instrument can be evaluated over a period of time with the application of the same framework. The following figure 1 shows the framework as a cyclic process.

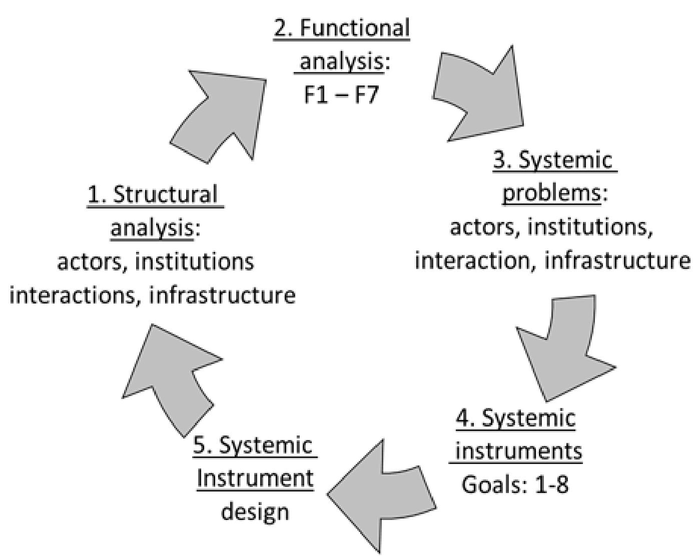

Figure 1. A systemic innovation policy framework

The figure also presents the consecutive stages of the framework application. We describe them shortly in the following paragraphs.

Stage 1 - Mapping structural dimensions and their capabilities

The analysis starts with mapping of the structural dimensions of the analysed innovation system: actors, institutions, interactions and infrastructure as well as their capabilities. Sources: bibliography including internet and interviews with actors. Results can be presented in a table like Table 1.

Stage 2 - Coupled functional-structural analysis

This stage starts with a functional analysis of the TIS at hand. Functions are evaluated by policy makers in cooperation with other actors using the 5-level scale (0-absent, 1-weak, 2-very weak, 3-moderate, 4-strong, 5-very strong) and based on responses to a set of diagnostic questions (Hekkert et al, 2010).

Function 1, Entrepreneurial activities: Are there enough entrepreneurs? What is the quality of entrepreneurship? What types of businesses are involved? What are the products? To what extent entrepreneurs experiment? What is the variety of technological options? Are any entrepreneurs leaving the system? Are there new entrepreneurs?

Function 2, Knowledge development: What is the knowledge base in terms of quality and quantity? Is the knowledge basic or applied? Are there many projects, research, patents, and articles? Is there a leading international position, trigger programs, many cited patents? Which actors are particularly active? Who finances the knowledge development? Does the technology get attention in national research and technology programs? Are there enough knowledge users?

Function 3, Knowledge dissemination: Are there strong partnerships? Between whom? Is the knowledge development demand-driven? Is there space for knowledge dissemination? Is there strong competition? Does the knowledge correspond with the needs of innovation system? Are there licenses issued?

Function 4, Guidance of the search: Is there a clearly articulated and shared goal of the system? Is it generic or specific? Is it supported by specific programs, policies, system's frontrunners? Is the objective inducing governmental activities? What are the technological expectations (negative/positive)? Does the articulated vision fit in the existing legislation?

Function 5, Market formation: How does the market look like? What is its size (niche/developed)? Who are the users (current and potential)? Who takes the lead (public/private parties)? Are there institutional incentives/barriers to market formation? Must a new market be created or existing one opened up?

Function 6, Resources mobilization: Are there sufficient financial resources for the system development? Do they correspond with the system's needs? What are they mainly used for (research/application/pilot projects etc)? Is there sufficient risk capital? Are there adequate public funding? Can companies easily access the resources?

Function 7, Creation of legitimacy: Is investment in the technology seen as a legitimate decision? Is there much resistance to change? Where from? How does this manifest itself? What is the lobbying power of actors in the system? Is there coalition forming?

A coupled functional-structural analysis is based on studying each function through the perspective of the four structural elements either for explanatory (e.g. why entrepreneurial activities do not take place?) or policy reasons (how to alter entrepreneurial activities?) It is important to identify which structural element causes the weakness or absence of the function.

Stage 3 – Identification of systemic problems

The coupled structural-functional analysis and the identification of reasons why certain functions perform better and other worse should allow for precise and systematic identification of problems that hinder the development of the systems. The final results of the analysis can be presented in the following table 7.

Table 7. Scheme for presenting results of the coupled functional-structural analysis and identification of problems per function

Function	**Functions evaluation (absent/very weak, etc)**	**Reasons why the specific function is absent/weak/strong etc ('blocking mechanism')**	**Systemic problems (presence/capability)**
F1 Entrepreneurial activities			
F2 Knowledge development			
F3 Knowledge diffusion			
F4 Guidance of the search			
F5 Market formation			
F6 Resources mobilisation			
F7 Creation of legitimacy			

Stage 4 - Systemic instruments' goals

So precisely identified systemic problems can be easily aligned with goals of systemic instruments and followed by a policy suggestion on how to support the development of entire system. The identified systemic problems and corresponding goals of systemic instruments can be summarised using Table 5.

Stage 5 - Systemic instrument design

To fulfil the goals of systemic instruments, a set of traditional, individual tools already present in the policy field may be of use. An overview of them is presented in Table 8. These tools have a supportive task in the creation of a systemic instrument for the analysed innovation system. Their selection however is not only dependent on the identified problems but also on the instruments' mutual interactions, the socio-political and economic conditions of the surrounding environment, impact of other, perhaps competing TISs. They need to be selected in the way that allows for their effectiveness, common reinforcement and orchestrated action. A systemic instrument is then such an integrated coherent set of tools designed for a specific (part of) innovation system. Its purpose is to create opportunities and conditions for system formation by influencing elements and connections within the system that would not otherwise emerge spontaneously. It is expected that application of a well-designed systemic tool will be manifested in the development of a system and higher rates of innovation. Analytically this should be seen in strengthening of the previously weak or absent functions.

Table 8. Potential of individual policy tools to contribute to the systemic instruments goals

Goals of systemic instruments	Examples of individual instruments
Stimulate and organise the participation of actors	Clusters; new forms of PPP, interactive stakeholder involvement techniques; public debates; scientific workshops; thematic meetings; transition arenas; venture capital; risk capital
Create space for actors capability development	Articulation discourse; backcasting; foresights; road-mapping; brainstorming; education and training programmes; technology platforms; scenario development workshops; policy labs; pilot projects
Stimulate occurrence of interactions	Cooperative research programmes; consensus development conferences; cooperative grants & programmes; bridging instruments (centres of excellence, competence centres); collaboration and mobility schemes; policy evaluation procedures; debates facilitating decision-making; science shops; technology transfer
Prevent too strong and too weak ties	Timely procurement (strategic, public, R&D-friendly); demonstration centres; strategic niche management; political tools (awards and honours for innovation novelties); loans/guarantees/tax incentives for innovative projects or new technological applications; prizes; CAT; technology promotion programmes; debates, discourses, venture capital; risk capital
Secure presence of (hard and soft) institutions;	Awareness building measures; information and education campaigns; public debates; lobbying, voluntary labels; voluntary agreements
Prevent too weak/stringent institutions	Regulations (public, private); limits; obligations; norms (product, user); agreements; patent laws; standards; taxes; rights; principles; non-compliance mechanisms
Stimulate physical, financial and knowledge infrastructure	Classical R&D grants, taxes, loans, schemes; funds (institutional, investment, guarantee, R&D), subsidies; public research labs
Ensure adequate quality of the infrastructure	Foresights; trend studies; roadmaps; intelligent benchmarking; SWOT analyses; sector and cluster studies; problem/needs/stakeholders/solution analyses; information systems (for programme management or project monitoring); evaluation practices & toolkits; user surveys; databases; consultancy services; tailor-made applications of group decision support systems; knowledge management techniques; TA's; knowledge transfer mechanisms; policy intelligence tools (policy monitoring & evaluation tools, systems analyses); scoreboards; trend charts

7. Conclusions

Building on the recent insights from the innovation studies this paper brought together four approaches developed based on the systemic, evolutionary view of innovation that aim to inform the policy making process: the structure and functions of innovation systems, systemic problems and systemic instruments into a systemic policy framework to analyse and stimulate technological innovation.

The paper showed that both the structural and functional analyses are promising analytical tools to evaluate system's performance. The view presented in this paper on the relationship between the two is that the functional analysis complements the structural one by being a manifestation of the way in which an innovation system is organised. Linking functions to the structure of innovation systems is not only necessary for analytical purposes but for practical reasons as well. Functions can only be influenced by policies through alterations of the structural components. By 'signalling' problems functions help facilitate the design of a systemic instrument that can address the problems in an integrated manner. The structural characteristic of systemic problems facilitates the problems' connection to the functional pattern, responsible for innovation levels. The systemic problems identified based on such coupled structural-functional analysis express therefore both structural problems as well as their effect on innovation processes. The mechanisms blocking the systemic functions can easily be expressed along the categories and types (presence, capacity) of systemic problems and therefore also link to the structural components of innovation systems. The advantage of the systemic problems typology proposed in the paper is that it provides a complete 'checklist' of all possible problems that may occur within a specifically defined system.

This theoretical exercise also confirmed the appropriateness of considering actors, institutions, interactions and in particular the physical, knowledge and financial infrastructure as explicit structural dimensions of innovation systems. By discouraging negative elements, securing presence of positive ones and by increasing their capacities, policy makers not only have the chance to provide better environment for innovation but they may also influence the direction of technological change towards e.g. more sustainable goals.

The proposed systemic policy framework should therefore be seen as a decision support tool to a new breed of policy makers who deal with such complex systemic problems as climate change or loss of biodiversity.

References

Bergek, A. 2002. Shaping and exploiting technological opportunities: the case of renewable energy technology in Sweden. PhD thesis, Department of Industrial Dynamics, Chalmers University of Technology, Göteborg.

Bergek, A, S Jacobsson, B Carlsson, S Lindmark, A Rickne. 2008. Analyzing the functional dynamics of technological innovation systems: A scheme of analysis. Research Policy, 37,407-429.

Broekel, T, R Boschma. 2009. Knowledge networks in the Dutch aviation industry: the proximity paradox. Papers in Evolutionary Economic Geography 09.15. http://econ.geo.uu.nl/peeg/peeg0915.pdf.

Carlsson B, R Stankiewicz. 1991. On the nature, function and composition of technological systems. Journal of Evolutionary Economics; 1(2),93–118.

Carlsson, B, S Jacobsson, M Holmen, A Rickne. 2002. Innovation systems: analytical and methodological issues, Research Policy, 31,233-45.

Chaminade, C, C Edquist, C. 2010. Rationales for public policy intervention in the innovation process: A systems of innovation approach, in Smits, R, S Kuhlmann, Shapira P. The Theory And Practice Of Innovation Policy, An International Research Handbook, EE

Crawford, S. Ostrom, E. 1995. A grammar of institutions. American Political Science Review, 98(3),582-600.

Doloreux, D. 2002. What we should know about regional systems of innovation, Technology in Society, 24,243-63.

Edquist, C. ed. 1997. Systems of innovation: Technologies, institutions and organizations, London: Pinter Publishers.

Freeman, C.1988. Japan, a new national system of innovation, in Dosi, G, C Freeman, R Nelson, G Silverberg, G Soete, eds. Technical Change and Economic Theory, London: Frances Pinter, 330-48.

Freeman, C.1995. The National System of Innovation in historical perspective. Cambridge Journal of Economics, 19(1),5–24.

Hekkert, M, R Suurs, S Negro, S Kuhlmann, R Smits. 2007. Functions of innovation systems: A new approach for analysing technological change, Technological Forecasting and Social Change, 74,413-32.

Hekkert M, F Alkemade, S Negro, R Suurs, K. Van Alphen.2010. Innovatiesysteemanalyse: een methode voor het monitoren/evalueren van transitieprocessen, Universiteit Utrecht, Departement Innovatie en Milieuwetenschappen.

Jacobsson, S, A Johnson. 2000. The diffusion of renewable energy technology: an analytical framework and key issues for research, Energy Policy, 28(9),625-640.

Johnson, A. 2001. Functions in innovation system approaches. In: Electronic Paper at the Proceedings of the Nelson and Winter Conference, Aalborg.

Kemp, R, J Nill. 2009. Evolutionary approaches for sustainable innovation policies: From niche to paradigm? Research Policy, 38,668-680.

Klein-Woolthuis, R, M Lankhuizen, V Gilsing. 2005. A system failure framework for innovation policy design, Technovation, 25,609-619.

Kuhlmann, S.2004. Rationales & evolution of public RTD policies in the context of their evaluation, in Polt W, J Rojo. Handbook on the evaluation of research and technology policy. Concepts, tools, and indicators. Cheltenham: EE.

Kuhlmann, S, E Arnold. 2001. RCN in the Norwegian Research and Innovation System. Brighton: Technopolis.

Link, AN, S Metcalfe. 2008. Technology infrastructure. Introduction to a special issue, Economics of Innovation and New Technology, 17(7),611 – 614.

Lipsey, R, KI Carlaw, CT Bekar. 2005. Economic Transformations. General Purpose Technologies and Long Term Economic Growth. OUP.

Lundvall, BA. 1992. National Systems of Innovation: Towards A Theory of Innovation and Interactive Learning, London: Pinter.

Malerba, F. 2002. Sectoral systems of innovation, Research Policy, 31,247-64.

Mowery, DC, BN Sampat. Universities and National Innovation Systems. In Fagerberg, J, D Mowery, RR Nelson, eds, The Oxford Handbook of Innovation. OUP, 209-239.

Narula, R, A Zanfei. 2005. Globalisation of Innovation. The role of multinational enterprises. In: J.Fagerberg, D Mowery, RR Nelson, eds, The Oxford Handbook of Innovation, OUP, 318-345.

Nelson, RR. ed 1993, National Systems of Innovation: A Comparative Study. Oxford: OUP.

Nooteboom, B. 2000, Learning and Innovation in Organizations and Economies. Oxford: OUP

OECD. 1997, National Innovation Systems. Paris: OECD Publications.

O'Sullivan, M. 2005. Finance and innovation. In Fagerberg, J, D.Mowery, R.R. Nelson eds., The Oxford Handbook of Innovation. OUP, 240-265.

Raven, R, S van den Bosch, R Weterings. 2010. Transitions and strategic niche management: towards a competence kit for practitioners. International Journal of Technology Management, 51(1),57-74.

Rockström, J, W Steffen, K Noone, Å Persson, FS Chapin, III, E Lambin, TM Lenton, M Scheffer, C Folke, H Schellnhuber, B Nykvist, CA De Wit, Hughes,T., S van der Leeuw, H Rodhe, S Sörlin, PK Snyder, R Costanza, U Svedin, M Falkenmark, L Karlberg, RW Corell, VJ Fabry, J Hansen, B Walker, D Liverman, K Richardson, P Crutzen, J Foley, 2009. A safe operating space for humanity. Nature. 461,472-475.

Smith, K. 1997. Economic infrastructures and Innovation Systems. In: Edquist, C., (1997) (ed.), Systems of innovation: Technologies, institutions and organizations, London: Pinter Publishers.

Smith, K 2000. Innovation as a Systemic Phenomenon: Rethinking the Role of Policy, Enterprise and Innovation Management Studies, Routlege, 1(1),73-102.

Smits, R, S Kuhlmann. 2004. The rise of systemic instruments in innovation policy. The International Journal of Foresight and Innovation Policy, 1(1/2), 4-32.

Schmoch, U, C Rammer, H Legler, eds. 2006. National systems of innovation in comparison: Structure and performance indicators for knowledge societies. Berlin: Springer Netherlands.

Van Mierlo, B, C Leeuwis, R Smits, R Klein-Woolthuis. 2010. Learning towards system innovation: Evaluating a systemic instrument, Technological Forecasting and Social Change, (77),318-334.

Von Hippel, E.1998. The sources of innovation. Cambridge, MA: MIT Press.

Voß, J-P, A Smith, J Grin. 2009. Designing long-term policy: rethinking transition management. Policy Sciences, 43(4),275-302.

Chapter III

Analysis of a nascent renewable energy innovation system: aquatic biomass in the Netherlands[9]

Abstract

Aquatic biomass is a promising renewable energy source in an early stage of development. This paper analyses what mechanisms determined the evolution of aquatic biomass in the Netherlands in the last 15 years. We use the Technological Innovation System (TIS) perspective to assess the nascent system, identify problems that hinder its development and suggest what policy can address them. The paper concludes that uncertainties about direction of the search, poor legitimacy processes and developments in the broader system context played critical role in the formation of this system. To develop further the system requires common strategic vision, better embeddedness in the international activities and a better management of a complex value chain.

Keywords: aquatic biomass, algae, seaweeds, systemic instruments, systemic problems, technological innovation system, transnational linkages, TIS context

1. Introduction

Biomass as an energy source is facing legitimacy problems due to large land use requirements, un-sustainability of trade and competition of land-grown biomass with food, feed, forestry and nature (Faaij et al., 2003). From early 2000 aquatic biomass received particular attention as an interesting and novel alternative energy source for the Netherlands (PGG, 2006a,b; 2007a; EZ, 2006, 2007). It began to be part of the national discussions about a transition to a sustainable national energy (VROM, 2001; EZ, 2004). Two forms of aquatic biomass: algae and seaweeds were considered as most promising for reduction of environmental footprint of the Dutch energy system (DHV, 2008; WUR-AFSG, 2009; Aquaphyto, 2010).

Aquatic biomass technology, however, is of a very emergent nature and therefore still inefficient, far from optimal and requiring serious R&D efforts. It is not ready to compete on an equal footage with land-grown biomass or any other form of renewables, let alone the heavily path-dependent, well-functioning and organized incumbent fossil fuel technologies (Unruh, 2000).

Innovation theory suggests that new technological fields can only be serious competitors to the incumbents when they themselves become well organized and, with time, institutionally embedded. That implies the necessity to not only improve the technology but also to develop a dynamic network of agents as well as institutional and economic infrastructure that supports the technology. The interplay

[9] This chapter has been submitted as: Wieczorek, A.J., Hekkert, M.P., Negro, S.O., Heimeriks, G., Analysis of a nascent renewable energy innovation system: aquatic biomass in the Netherlands, 2014

of these conditions is coined as a Technological Innovation System (TIS). The strength of such as system and the success of innovations are determined by the system's structural configuration and its functioning (Bergek et al., 2008a; Hekkert et al., 2007). If the innovation system does not develop, that implies it experiences systemic problems (often labelled as system failures (Klein-Woolthuis et al., 2005; Negro et al., 2012)), which require systemic strategy (Bergek et al,2008; Wieczorek and Hekkert, 2012).

The research on aquatic biomass has so far mainly focused on selected aspects of its value chain, such as the conversion of aquatic biomass to energy carriers (e.g. Yue et al, 2014; O'Connor, 2013; Lakaniemi et al., 2013), use of algae for biofuels production (Yi-Feng and Wu, 2011), microalgae biomass cultivation (Vieira Costa and Greque de Morais, 2014), its environmental impacts (Grerson et al., 2013) or general role of algae in sustainability (Jacquin et al., 2014). The only *systemic* assessment found in the literature focuses on algal biofuels in the US context (Haase et al., 2013) while aquatic biomass encompasses more than algae and there are more sustainable applications possible than biofuels. It may therefore be an important element of many governments future climate mitigation strategies, especially in the Netherlands. Given, however, that there is no study that systematically and systemically evaluates the Dutch aquatic biomass efforts in the context of energy transition the research question of this paper is:

What factors have determined the evolution of aquatic biomass in the Netherlands and what strategy can be suggested to stimulate further innovation in this field?

We address the question using the Technological Innovation System approach. In particular, we analyse the structure and the dynamics of the innovation system in the period of 1998-2012 with the aim to identify system weaknesses that hinder its development and potential policy strategies that could address the problems in a systemic way.

The case of aquatic biomass is also interesting from a theoretical perspective. It is a nascent system with unorganised and complex value chain, actors are preoccupied rather with R&D efforts than market development and there are issues with legitimacy of the aquatic biomass technologies. Literature describes and studies this stage as a formative phase (see e.g. Bergek and Jacobsson, 2003; Jacobsson and Bergek, 2004, 2011; Jacobsson, 2008; Suurs and Hekkert, 2009; Suurs et al., 2010). What makes aquatic biomass different from the currently described cases, however, is that this system has not yet moved into the following, growth phase. Furthermore, being a juvenile system, it may be particularly vulnerable to the impact of the developments in a broader system context such as world crises, changing climate debate, EU subsidies, oil scarcity or a lobby of incumbent systems (Bergek, et al., 2008a; Raven, 2005). The theme of context of Technological Innovation Systems has recently received increased attention in the literature (see e.g. Wirth and Markard, 2011, Jacobsson and Bergek, 2011; Binz and Truffer, 2012; Binz et al., 2012; Coenen et al, 2012; Gosens and Lu, 2013; Binz et al., 2014; Wieczorek et al., 2014a). The main argument of these studies is that explicit acknowledgement of context of nationally delimited TIS is essential for understanding the pace and direction of technology development and has impact on the analysed problems of an innovation system as well as the policy recommendations that follow from the analysis. Although this is not the main aim of this paper, we make modest contribution to the discussion on the characteristics, problems and policy for innovation systems that are in a very early, formative stage and taking account of the system context.

The article consists of 7 sections. Section 2 explains the theoretical framework. Section 3 presents methodology. Section 4 characterises the aquatic biomass. Section 5 describes how the Dutch aquatic biomass innovation system developed in the last 15 years. Section 6 presents the system functional pattern in 2012, summarises the underlying system problems and proposes systemic strategy that could address them. We conclude in Section 7.

2. Technological Innovation Systems perspective

The Technological Innovation System (TIS) approach is a theoretical approach that helps describe, analyse and understand the diffusion of (a) particular innovation. It was developed in the 1990s by the evolutionary economist interested in the process of innovation and industrial dynamics (Freeman, 1987; Lundvall, 1992; Nelson, 1993). A Technological Innovation System is defined as 'a dynamic network of agents interacting in a specific economic/industrial area under a particular institutional infrastructure and involved in the generation, diffusion, and utilisation of technology' (Carlsson and Stankiewicz, 1991). The actors, networks, institutions and technology constitute the structural components of the TIS (Edquist, 1997). *Actors* involve organizations contributing to a technology directly (developers, adopters) or indirectly (regulators, financers, etc.). Actors through their choices and actions generate, diffuse and utilize technologies. *Institutions* encompass a set of common habits, routines and shared concepts used by humans in repetitive situations. They are thereby different from organizations such as firms or universities. Formal (hard) institutions encompass: rules, laws, regulations, and codified instructions. Informal (soft) institutions cover: visions, customs, habits, routines, established practices, traditions, ways of conduct, norms, and expectations. *Interactions* take place between actors through networks. These interactions are essential for e.g. knowledge exchange, learning, innovation, and shared vision building. *Infrastructure* covers: physical, financial and knowledge infrastructure. Physical infrastructure comprises: artefacts, instruments, machines, roads, buildings, telecom networks, bridges, and harbours. Knowledge infrastructure includes: knowledge, expertise, know-how, and strategic information. Financial infrastructure covers: subsidies, financial programs, grants, and VC (Wieczorek and Hekkert,2012).

An original development in the TIS perspective concerns its attention for the functional performance of the innovation system's components, conceptualized through a set of *key processes of innovation systems* or *system functions* (Bergek et al., 2008a; Hekkert et al., 2007) (see Table 1).

A coupled structural-functional assessment creates insight in the strengths and weaknesses of the innovation system, also referred to as systemic problems or failures (Jacobsson and Johnson, 2000, Klein-Woolthuis et al, 2005; Chaminade and Edquist, 2007). Since problems are caused either by the absence of a structural element or by its inappropriate properties, a structure-related typology of four main systemic problems: actor problems, interaction problems, institutional problems and infrastructural problems was proposed by Wieczorek and Hekkert (2012). Each of these problems can be broken down into a presence or capacity issue.

Table 1. Key processes of innovation systems

Key process	Description
Entrepreneurial activities F1	In this process entrepreneurs translate knowledge into business opportunities, and eventually innovations, through market-oriented experiments.
Knowledge development F2	This process refers to learning activities, mostly on emerging technology, but also on markets, networks and users. The activities include learning-by-searching and learning-by-using. Both are at the heart of any innovation process.
Knowledge diffusion F3	This process encompasses all activities that relate to the diffusion of knowledge among actors through learning by interacting.
Guidance of the search F4	This function refers to those processes that lead to a clear goal for the development of new technology based on actors' expectations, articulated user demand and societal discourse. This process enables selection, which guides the distribution of resources.
Market formation F5	This process involves activities contributing to the creation of demand for new technology. In early phases of developments these can be small niche markets but later on larger markets are required to facilitate cost reductions and incentives for entrepreneurs to move in.
Resource mobilization F6	This function is about allocation of financial, physical and human capital as necessary basic inputs for all processes in the innovation system. Unavailability of these resources hampers all other system activities.
Legitimacy creation F7	Innovation is by definition uncertain. This process refers to activities that counteract resistance in the incumbent system and provide a certain level of legitimacy for actors to commit investment and adopt the new technology.

Systemic problems require systemic policy and instruments to solve them (Smits and Kuhlman, 2004). A systemic instrument is an integrated, coherent set of tools designed for a specific innovation system (or a part of it). Its purpose is to create opportunities and conditions for system formation by influencing elements and connections within the system that would not emerge spontaneously. The selected strategy should allow involved actors coordinate their activities and align their individual objectives along the goal of the system development (Wieczorek and Hekkert, 2012).

Given, however, that the innovation systems can be in various stages of development: formative (also called nascent, juvenile or infant), growth or mature, they experience different types of problems and hence require a different policy strategy. For example, while strong market formation processes and institutional change are important for systems in a growth or more mature stages (see e.g. Jacobsson,2008; Dewald and Truffer, 2011; Wieczorek et al., 2013; Jacobsson and Karltorp, 2013), they are less so for the nascent systems. Jacobsson (2008), Suurs et al. (2010) and Jacobsson and Bergek (2011) argue that nascent systems are mostly preoccupied with accumulation of knowledge, formation of the value chain and networks (Musiolik, et al., 2012), alignment of institutions and gaining legitimacy. Furthermore, the technology in such an embryonic stage is often not well developed and appears more in the form of ideas. Very few formal institutions exist and cognitive elements such as expectations and promises dominate.

Nascent systems, according to the earlier studies, are also likely to be particularly vulnerable to the working of so-called *exogenous forces* (Raven, 2005; Bergek et al., 2008b; Jacobsson, 2008; Jacobsson and Bergek, 2011; Suurs et al, 2010). Jacobsson (2008) further argues that the *external* inducement mechanisms of a formative stage are beginning to be supplemented by endogenous ones as the system moves to the growth phase. The more recent studies of TIS, using insights from economic geography, have moved away from the concept of *exogenous forces* and focused rather on understanding and conceptualising the developments in a broader context along two lines of research. The first relates to the concept of transnational linkages (Gosens and and Lu, 2013; Wieczorek et al., 2014a,b) or spatial characteristics of TIS structural elements (Binz et al., 2012, 2014; Binz and Truffer, 2012). The main argument of this literature is that the TIS structure (actors-networks, institutions, knowledge, technology, capital) and therefore functioning is not limited to national borders but reveals considerable spatial variation. Through these couplings national actors access a global knowledge pool and foreign assets such as capital or technology. These linkages contribute to the enhancement of local capabilities and complement for missing resources (Wieczorek et al., 2014a,b). Through these linkages the various nationally delimited TISs can coevolve and influence each other and over time may form a broader, global technological innovation system .

A second line of research is concerned with the impact of other TISs and sectors of either competing or complementary nature. Wirth and Markard (2011) argue that the various *adjacent* TISs and sectors (for example incumbent gas and oil regime) are characterized by different structures and influence the extent to which an emerging technology is embedded into a specific sector. If the novel technological field provides solution for urgent problems in a sector, it is likely that actors and institutions from this sector will play a major role in the new technological field.

Building on these insights we propose, however, that before transnational linkages begin to tie currently unconnected TISs in the same technological field, that these unconnected TISs are also considered as *other* or *adjacent* TIS. Developments in those systems may also impact the emerging technological field. Furthermore, as much as this dual conceptualisation of the *TIS context* confirms its spatial, often global spread (transnational linkages) as well as the impact of the dynamics in other TISs and sectors, at the same time it misses out on such broad type of relevant factors as the earlier mentioned world crisis, changing climate change debate or oil scarcity. These factors influence but are not directly and very strongly influenced by the TIS. The transition literature conceptualises these impacts as landscape type of developments (Geels, 2002) and describes their influence on the shape of local practices (Lawhon and Murphy, 2011) . We treat them as a third type of context developments and argue for their serious treatment in the TIS context analyses.

3. Methodology

In this paper we apply the coupled functional-structural analysis to assess the Dutch aquatic biomass technological innovation system in the period of 1998-2012.

Aquatic biomass is not a single technology field. It comprises of many technologies that can be used for production, processing, utilisation and retail of this renewable. The system boundaries are therefore defined by the value chain presented in Figure 1. While the production of fine chemicals and food additives is a well-known area of application of aquatic biomass, its use for manufacturing of bulk chemicals, energy carriers, livestock feed or for water and air purification are relatively new fields driven by the sustainability debate in the context of energy transition in the Netherlands. This broad system delimitation is driven by the very early stage of its development where different market niches have not evolved yet. Also many of the individual technologies are either not formed yet nor adjusted to the wet forms of biomass.

The functional analysis was completed based on longitudinal media events analysis. The events were identified using Lexis-Nexis, which is an online database containing searchable content consisting of records of nearly 10000 newspapers, magazines, legal documents and other printed sources. The search keywords included English and Dutch: *algae/algen, seaweeds/zeeweer, aquatic biomass/aquatische biomassa* (time range 1998-2012). Each event (domestic or international) was coded as either +1 when positive or -1 when negative for the analysed system and allocated to a particular function. Events that could not have been allocated to any function or which referred to broad developments such as financial crisis or EU directive, were collated as *context* occurrences. Although we have not applied any rigorous set of indicators to map them, the historical development of the systems was carried out in a context sensitive way by identifying these events as either related to the (i) spatial variation of the analysed TIS, termed as transnational linkages; (ii) impact of other TISs (in the same or different technological fields) or (ii) broader, landscape type of developments.

Identification of events was supported by the insights from scientific and industrial literature. Figure 3 presents cumulative number of all events identified in that way. Based on this overview we identified most significant occurrences that had impact on the system functioning and hence on its overall development in the Netherlands. Personal communications based on semi-structured interviews with 9 experts, all in managerial positions, representing major actors categories: government (2), research (3), industry (3) and NGOs (1), and involved in the aquatic biomass activities, helped verify and qualitatively asses the events for the purpose of constructing a story line presented in section 5. The experts were also asked to evaluate the system functions using 5-tier scale of absent-weak-moderate-strong-excellent and express views on the system's structure, problems and policy. This evaluation contributed to the functional pattern presented in section 6.

Structural analysis (actors, networks, institutions and infrastructure) was performed based on the review of available literature and insights from personal communications with experts. The actors and networks identification was supported by additional analysis of projects in the EU Cordis database and key-word analysis in scientific articles in the ISI Web of Science in the same period. This search, next to the analysis of patents in the EPO database was also useful to create insight in the stage of development of the knowledge infrastructure. The search keywords included: *algae*, *seaweeds*, *the Netherlands*.

4. Aquatic biomass

Aquatic biomass encompasses plants grown in ditches and canals, bio-saline agriculture, microalgae (<50 µm, often called algae), and macroalgae (>50 µm, referred to as seaweeds). In the context of transition towards a biobased economy in the Netherlands, only the last two forms received increased attention and are therefore the focus of this paper.

Both forms can be produced in large amounts on a limited area and they can complement the extensive traditional agricultural activities of the small, densely populated and water-based Netherlands (Muylaert and Sanders, 2009). Algae can be cultivated at sea, non-agricultural land or in bioreactors. Possible applications (see Figures 1-2) include: high-value fine chemicals currently produced on a limited scale or health foods, and fish feed. Algae also have the potential to turn flue gas into useful biomass and purify waste water from heavy metals, nitrogen and phosphorus (Aquaphyto, 2010). The biomass, if purified from heavy metals, could be further used as fertiliser or for production of bulk chemicals. Being rich in fatty acids and starch, microalgae are a good source of a bio-oil and proteins that can be used in fermentation, agro-chemicals, as functional ingredients of biopolymers or for production of such energy carriers as biofuels (although not as successfully as seaweeds (ECN, 2010; WUR-PRI, 2010)).

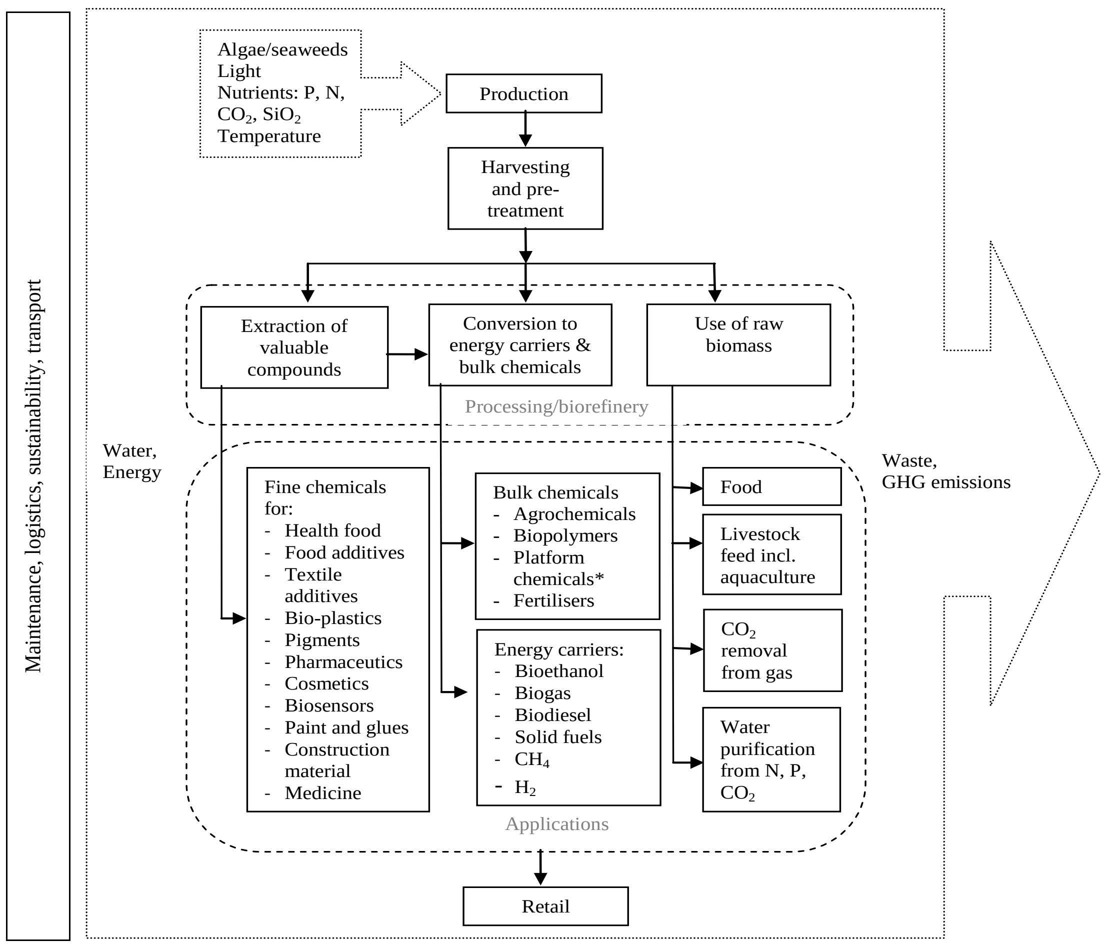

Figure 1. Value chain for aquatic biomass including five general steps: production, harvesting and pre-treatment, processing (bio-refinery), applications, and retail.

Seaweeds, on the other hand, are (in ca. 80%) a low-value material that can be used for e.g. fermentation (ECN, 2010). Seaweeds can be grown at sea and thereby they do not compete with agricultural products for land. Of particular potential is a large-scale cultivation of seaweeds combination with the offshore wind parks (Reith et al., 2008). Currently, seaweeds are mainly produced abroad for consumption, as food additives, and as fine chemicals for pharmaceutical purposes (see Figure 2). Currently they are in 50% harvested from natural populations (ECN, 2005). The world market for seaweeds grew between 1993-2002 by 26% and yielded U$6 billion per annum. Cultivation and processing of seaweeds is a growing business in China, Philippines, Japan, Indonesia, US, and Europe (Italy, Spain, Ireland, Norway, Germany). In Germany and the USA works are underway to realise seaweeds production off shore. The currently produced seaweeds, however, are hardly used for sustainable energy production. The new possible applications include energy carriers (biodiesel, biogas), bulk chemicals, health products, livestock feed and water and gas purifying agents (ECN, 2010; WUR-PRI, 2010; Hortimare, 2010). Figure 2 presents the potential CO_2 neutral products that can be derived from aquatic biomass. It shows that its added value drops with volume, which implies that the production of energy can be beneficial only after utilising the high value substances.

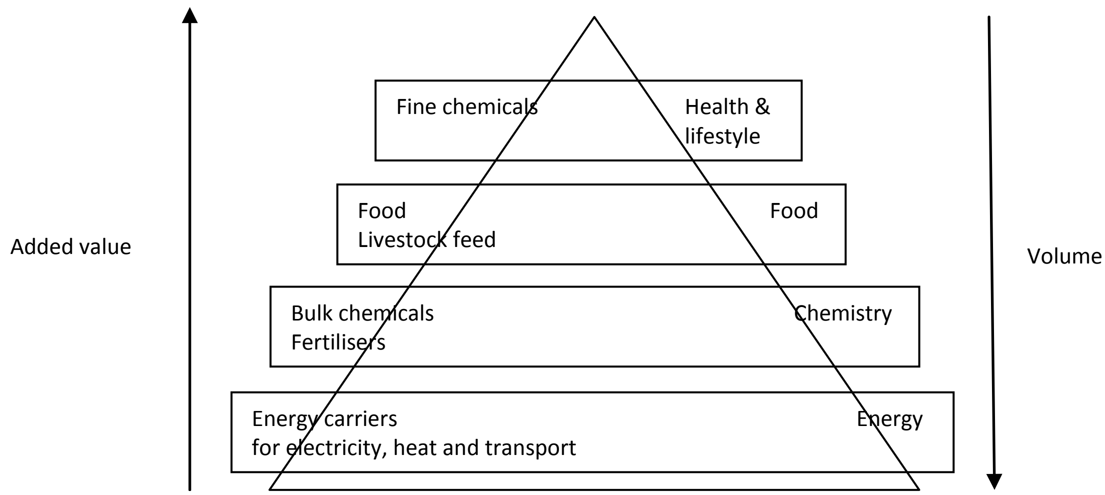

Figure 2. Aquatic biomass value pyramid (ECN, 2010)

5. Historical overview of the system development (1998-2012)

Three periods are distinguished in the history of aquatic biomass in the Netherlands: 1998-2006: predevelopment, when the field was gaining attention in the context of energy innovation agenda; 2007-2008: increased activities as an outcome of Green Resource Platform (Platform Groene Grondstoffen: PGG) operation; 2009-2012: a slow-down due to change of cabinets of 2010 and shift in priorities, with a slight take-off at the end of the period when the first pilots began to be set up and scientific reports released. Figure 3 presents a cumulative activity pattern for all seven functions in the analysed period and based on a number of events. Plotted on the figure are major financial programs with dedicated funds to aquatic biomass activities because their availability had significant impact on the system development, especially the Energy Innovation Agenda. For explanation of the functions F1-F7 see Table 1.We discuss the specific functions in the three identified periods below.

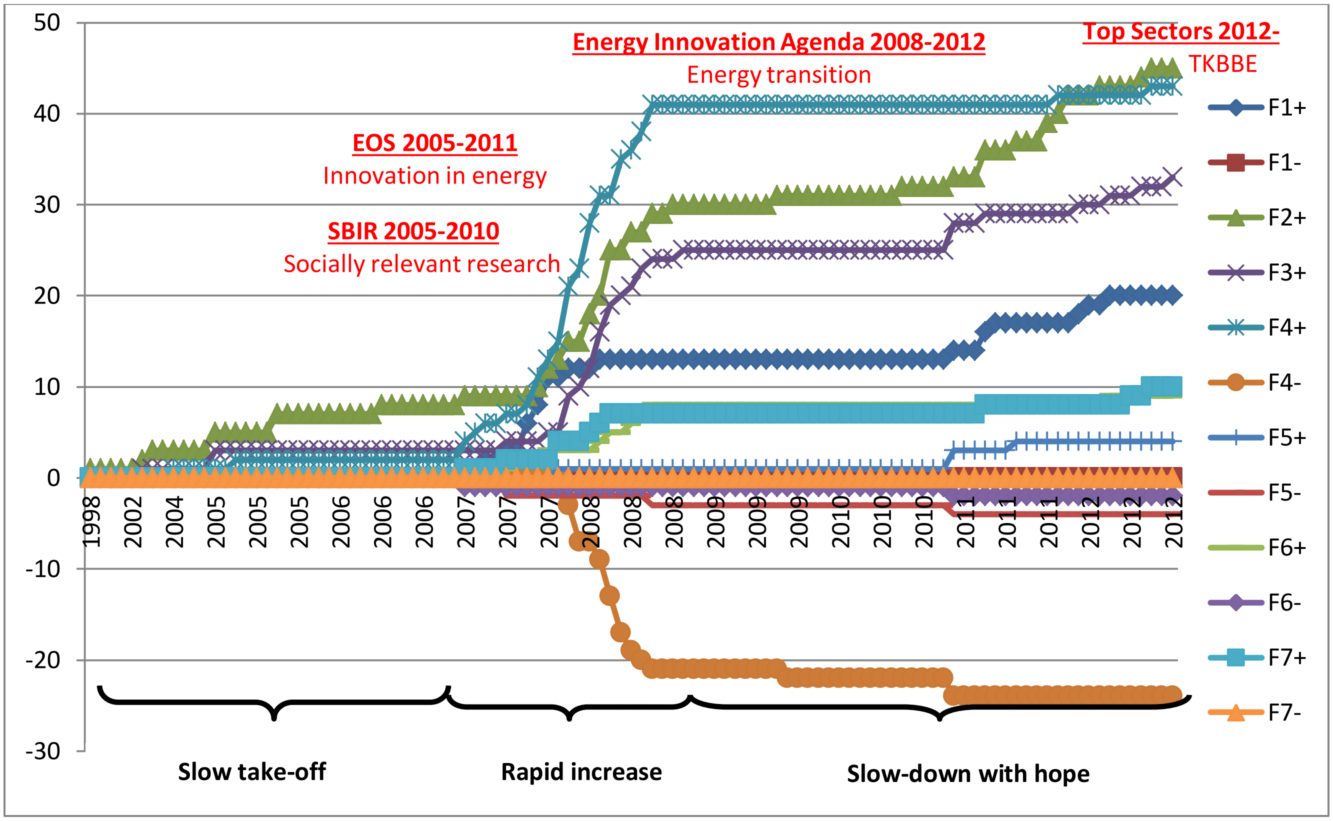

Figure 3. Cumulative activity pattern for aquatic biomass system in 1998-2012. Y-axis above 0: number of positive events, below 0: number of negative events; years 1998-2004 are compressed[10]

5.1. Slow take-off (1998-2006)

In the late 1990s, in the context of world-wide climate debate (*landscape factor*), the attention of the Dutch government is directed to the ways in which energy needs are provided in the country (VROM, 2001). Among the potential, radically different and sustainable alternatives is aquatic biomass. Algae receive special attention. They are known, used for high value applications, offer multiple markets and quick revenues (F4). While abroad, especially in Germany and the USA[11], cultivation and application of algae biomass is known from early 50's (Burlew, 1953; Davis and Guillard,1958; Mayer, 1960; Walne 1963) (*impact of other TISs*), the emergence of what could be defined as a Dutch aquatic biomass innovation system can be marked by a year 1998. In that year professor Wijfels of Wageningen University and Research (WUR) begins a precursory research on algae with one PhD student[12] (WUR-AFSG, 2009) (F2). Later, in 2003, the Spatial Planning Bureau (governmental advisory body) releases a book on the use of the North Sea with a vision of, among others, integrated seaweeds and algae production in offshore wind parks for energy purposes (Ruimtelijk Planbureau, 2003) (F3). In March

[10] TKBBE–Top Consortium Bio-Based Economy

[11] E.g. in 1968-90 USA carried a US marine Biomass Energy Program. The aim was to evaluate the technical and economic potential of methane production via anaerobic digestion from large-scale seaweeds production. Between 1978-1996 US carried an Aquatic Species Programme to develop transportation fuels from algae (impact of other TISs).

[12] In 2012 there are around 20 PhDs and research is carried out on all aspects of algae all along the value chain.

2004, new methods for production for biodiesel from algae win two prizes (F2). These events fuel first expectations that algae and seaweeds can be a promising source of energy in the Netherlands (F4).

In 2004, following the 4th National Environmental Plan (VROM, 2001), the Dutch energy transition initiative is launched with the overall goal of sustainable energy provision (F4) (Loo and Loorbach, 2012; Loo, 2012) and €1.4mln for projects on aquatic biomass between 2008-2012 (EZ, 2009; AgentschapNL, 2010) (F6). The establishment of a Green Resource Platform (PGG) provides critical stimuli for aquatic biomass activities (F4) including plans for founding of a Sea Culture Institute that would motivate new 'sea activities' (F3). The PGG platform calls for broad stakeholder participation. Given, however, the very early stage and the lack of knowledge on detrimental effects of aquatic biomass production, and despite the fact that energy transition is framed in the context of sustainability, the NGO's and organisations for ecological monitoring such as RIVO and RIKZ refrain from taking any position in these discussions (WUR-AFSG, 2009; WUR-PRI, 2009; Aquaphyto, 2010; ECN,2010; Hortimare, 2011). An important environmental NGO Stichting Natuur en Milieu argues that too little attention is given to sustainability aspects of aquatic biomass value chain (EZ, 2009) (F7). Thus, while aquatic biomass is pushed with a sustainable perspective in mind, it is a lack of legitimacy in especially this dimension that characterises this system.

In May 2005 the Dutch Energy Institute (ECN) publishes first report on the potential of large-scale seaweeds production at wind parks of North Sea (Reith et al., 2005; ECN, 2010). The report is a first comprehensive analysis of the entire seaweeds value chain challenges, related infrastructure, institutional context and sustainability (F2/F3). By predicting 5000m^2 large-scale production of seaweeds in 2040 it stimulates the expectation that due to specific competences in the Netherlands related to intensive agriculture and water management, the country can develop significant capacities in the area of energy and chemicals production from seaweeds (F4). Based on these positive expectations the PGG platform releases a vision on the role of seaweeds and algae in energy provision (PGG, 2007a) (F4) and aquatic biomass actors receive an estimated €2-3mln from the Energy Research Subsidy (EOS) budget in the period 2005-2010 (See Figure 3) (F6). The legitimacy for this emerging field is built on competences and earning capacity.

In summary, this first period can be characterised with a positive guidance on the part of the government and a build-up of positive expectations (F4) that lead to the availability of research funding (F6) and the execution of several research projects in the following years (F1). Despite a few knowledge creation processes (F2) still little is known about the productivity and possible cultivation methods of aquatic biomass in the Netherlands. Furthermore, the research subsidy scheme EOS does not match the needs of the system: due to its technological focus, it does not allow for the development of entire value chain and its socio-institutional context (Visser et al., 2012) and till winter 2009 all its resources are used up to its limits. In this first period very few companies are part of the system, no networks are created and there are no regulations developed in support of this system. The context factors in the form of unfolding climate change debate (*landscape factor*), knowledge development and entrepreneurial activities abroad (*impact of other TISs*) provide positive background to the Dutch developments.

5.2. Rapid increase (2007-2008)

In 2007, in the context of the energy transition program and based on the PGG vision (2007a), the Dutch government publishes its 2040 vision on a biobased economy (LNV, 2007). The vision emphasises an important role of aquatic biomass as a green energy resource (F4). Algae become an important topic in national debates. The lack of competition for land with food crops are increasingly mentioned as their additional advantages. Entrepreneurs claim possibilities of high oil yields p/ha as compared to rapeseed, corn or jatropha. Direct incineration of dry algal matter is seen as a promising option for sustainable energy production (F4). This optimism, however, is mainly based on huge interest from the market (energy companies, airlines) and an increased national and international attention to environment and health (*impact of other TISs*). It is not yet backed up by the technology development or entrepreneurial successes.

The promises stimulate increased resources mobilization in 2007 for algae and their potential energy applications (F6). Funds for research projects are made available through provincial budgets and within the National B-basic program[13], ca €100k is earmarked for research on biodiesel from algae. Furthermore, private actors start to invest. Ingrepro receives the first public-private innovation credit from Rabobank while Japanese Teijin Company invests millions of euro's in the Dutch algae producer Aquaphyto (*transnational linkages*). Availability of funds drives entrepreneurial experimentation: more than 10 different installations are set up by industrial actors (F1). For example, Ingrepro begins production of algae-based biodiesel while Shell (*transnational linkage*) with financial support from the Dutch government initiates a pilot installation for large-scale algae production in Zeewolde (F1). These developments are accompanied by a range of research activities mostly by Wageningen University (WUR) but also by commercial firms such as DHV consultancy who wins an award for a waste-heat-based algae production system. Some early networks are formed as a few cooperative research projects are set up (F3). Furthermore, human resources are mobilized through the development of professional courses on the production of algae and their conversion to biodiesel by Bioking and LGem (F3). Guidance of the search is strengthened by three governmental studies (PGG, 2007a,b; VROM, 2007) (F2, F3) emphasising importance of aquatic biomass developments as an energy source (F4). These events result in build-up of a positive momentum and first lobby activities: the chairman of the PGG platform calls upon farmers to switch to algae cultivation and upon the Dutch government to increase investments in algae-biodiesel production companies, entrepreneurs call for more tank stations where algal biodiesel would be made available (F7).

2008 is a year of continued interest in sustainable energy from algae. Politics at both national and EU level become particularly enthusiastic about algal biofuels because that fits the climate change debate by giving a promise of saving tropical forests (*landscape factors*). Entrepreneurs continue to emphasise high yields and possibility of competitive prices. CO_2 reduction potential is seen as an extra source of revenue (F4). Even Boeing becomes interested in the production of kerosene from algae (*impact of other TISs*) while incumbent energy utilities (Essent, Eneco) and other end-users (mostly multinational

[13] An independent NWO-ACTS program run in 2004-2010 with a total budget of €50mln focused on the development of new biobased production concepts for the chemical (and energy) industry, http://www.b-basic.nl

such as AkzoNobel, Nestle, BASF, Delta, Unilever) (*transnational linkages*) consider combined algae-based purification of waste water and CO_2 reduction in the flue gas and production of algal biodiesel (F1) (WUR-AFSG, 2009; Aquaphyto, 2010).

These prospects stimulate further entrepreneurial experimentation (F1): AkzoNobel builds a pilot facility in Delfzijl testing large-scale algae production in open ponds, and Ingrepro starts algae production in open ponds using flue gas from a power station. Knowledge creation (F2) accelerates but is dominated by academic institutes. The most active and collaborating with each other on publications and European Cordis projects are WUR (PRI, AFSG), Institute of Ecological Research (NIOO KNAW) and Groningen University (RUG) (ISI Web of Science, 2011) (F2) (*transnational linkages*). Companies and consultancies often rely on universities for knowledge development (Aquaphyto, 2010, Hortimare, 2011). Those firms that begin own R&D activities face competition with universities for scarce R&D funds (InnovatieNetwerk, 2011) (F2). In spite of that, a number of cooperative research projects take off on mainly cultivation and harvesting methods, e.g. DHV works on the use of cooling water for growth of algae; while the University of Applied Sciences (HZ) focuses on algae harvesting methods. Algae applications for production of biodiesel continue to be of a strong interest. RUG and Royal Netherlands Institute for Sea Research (NIOZ) investigate possibilities of commercial offshore production of algae for biodiesel; consultancy Econcern with Aquaphyto and Teijin (*transnational linkages*) investigate possibilities to produce airplane fuels within the Rotterdam Climate Initiative[14]; KLM examines options to use algae for kerosene production. A number of new studies, increasingly prepared by consultancies, become available (Florentinus et al., 2008; DHV, 2008; Raad voor de Wadden, 2008; Bos et al., 2008). New ideas are highlighted by awards like one granted to DHV for an idea to use cooling water for production of algae (F2, F3). Four conferences take place where aquatic biomass receives considerable attention and one algae course in Zeeland is initiated (F3). The Dutch developments are further positively influenced by projects funded abroad. Bill Gates allocates U$100mln for biofuels production from algae (*impact of other TISs*). An American company, Green Fuel Technology, closes a U$92mln contract for production of algae at a cement company in Spain (*impact of other TISs*). The first biodiesel fuelled airplane (by Virgin) lands at Amsterdam airport (F4) (*impact of other TISs*).

All these events indicate that the algae innovation system starts to develop. The events start to trigger new actions and positive feedback loops accelerating the system development. The positive internal dynamics of the innovation system raise very high expectations about the potential for commercial energy production that can be met by algae in the Netherlands. Increasingly, however, researchers and entrepreneurs begin to voice concerns about the potential of algae as an energy source. These concerns relate to high costs of algae biodiesel, the still experimental stage of development, overly high expectations, poor demand-supply ratio, high transportation costs, lack of sustainability standards, high dependence on subsidies, negative energy balance and the missing logistics of the entire value chain (AgentschapNL, 2010). The contingency of overrated expectations is marked by the bankruptcy of AlgaeLink (Bioking), which according to some actors, claimed impossible production costs and yields (F4). The energy transition initiative, although seen as important for achieving the biobased economy

[14] An initiative to make Rotterdam the most sustainable world port city, http://www.rotterdamclimateinitiative.nl/en accessed 11/2012.

vision, begins to be considered insufficient to make a difference. In particular, the varying interests pursued by the different ministries[15] and the strong focus on high-value algae are criticized. Several actors suggest that if the government is interested in sustainable *energy* alternatives, it should refocus its agenda away from algae towards seaweeds (ECN, 2010) (F4, F7). The well developing innovation system thus starts to suffer from a drop in positive expectations due to the bankruptcy of a key entrepreneur and uncertainties about the right direction of search.

Meanwhile, seaweeds production in the North Sea receives increased attention. Connection with wind parks and other forms of aquaculture are envisioned (F4). The Small Business Innovation Research Program (SBRI)[16] makes funds available for feasibility studies on cultivation and harvesting systems of seaweeds as a green resource for a total budget of €1.32mln (EZ, 2009, 2011) (F5, F6). Possible locations are identified by various studies (Wald, 2010; Hart and Schipper, 2011; Raad voor de Wadden, 2008; DHV, 2008, 2010; Bass&Gill, 2008) but the identified space is considered insufficient for the production of larger quantities of energy (Muylaert and Sanders, 2009; WUR-PRI, 2010). To become a business case, the cultivation of seaweeds would require substantial additional research and it would have to progress to international waters that are beyond direct jurisdiction of the Netherlands (ECN, 2010) (F4).

Summarising, this second period in the development of the Dutch aquatic biomass system has similar dynamics to the first one. However, guidance of the search (F4) is even more dominated by high expectations on the part of entrepreneurs and actors involved in the energy transition program, particularly with regards to the potential of algae as an energy source (ECN, 2010; AgentschapNL, 2010). This guidance again leads to initial resources mobilisation (F6), a number of pilot projects (F1) and increased research activities (F2). Compared to the first period, there is more interaction in the system, especially between research and industry (F3) and first lobby activities occur (F7). In 2008, however, algae begin to suffer from being hyped as energy source (F4). The uncertainties about the direction of search grow as actors begin to express concerns about costs, commercial scale and lack of attention to complete value chain (ECN, 2010). Seaweeds enter the national debates but the discussions do not result in any uniformity in feasible yields and cost figures. As much as the consultancy reports contribute to a better understanding of aquatic biomass potential, the existing knowledge is very fundamental and with no significant patents. Keywords analysis of the scientific papers on aquatic biomass shows lack of clear context of application, sustainability aspects are not much written about. Also, the value chain remains incomplete. Although there are in the Netherlands a number of companies converting biomass to various products such as the internationally operating AlgaeLink, Algaetec, Nedalco, Purac (see Appendix 1) (*transnational linkages*), none of them converts aquatic biomass on a larger scale (WUR-PRI, 2010). The number of lectures and educational courses does not cover the demand for training of e.g. marine engineers who could operate integrated offshore wind and seaweeds farms (AgentschapNL, 2009; ECN, 2010). Despite increased interactions, the university-industry collaborations remain rather poor. Basically, we observe that the expectations regarding aquatic biomass develop much faster than

[15] Despite the Inter-departmental Directorate Energy Transition (IPE), EZ is interested in stimulating knowledge economy and the energy innovation agenda; VROM in sustainability and in addressing global environmental problems, while LNV is concerned with competitiveness of national agriculture.
[16] Governmental program of 2005-2010 supporting socially relevant research by innovative business by means of public procurement.

the rest of the innovation system. The context developments in the form of algae-oriented activities (*impact of other TISs*) and EU's interest in algae biofuels (*landscape factor*) contribute to this uneven development. Hic-ups in the development of the innovation system slows down the inflated expectations.

5.3. A slow down with hope (2009-2012)

In April 2009 a directive on the promotion of energy from renewables (EU, 2009) is released (*landscape factor*), followed by a National Action Plan for Energy from Renewable Sources (Rijksoverheid, 2009). Both provide first broad context for the set-up of missing regulatory framework for aquatic biomass in the Netherlands but do not result in any concrete laws (F4). In 2010 a new coalition cabinet (Rutte I) is appointed and the Dutch national priorities regarding sustainable development and the role of innovation shift (F4)[17]. Implications of the 2008 crisis[18] (*landscape factor*) make the government increasingly focus on the reduction of public debt. It decides that the national R&D should be driven by demands and needs of the main business strengths of the Netherlands and less by societal challenges. As the result of this decision the Dutch innovation policy begins to focus on ten top sectors of the Dutch economy (Weaver et al., 2012; Proinno Europe, 2011) of which Energy is one. The general innovation focus becomes less long term and less fundamental and more applied and of direct interest for large industrial players. Within the top sector energy, biobased economy is still considered an important theme due to the interest of large multinational chemical and energy companies. The biobased innovation activities are coordinated by the Top consortium Knowledge and Innovation in Biobased Economy (TKI-BBE[19]) (see Figure 3). TKI-BBE takes over the earlier aquatic biomass-related activities of PGG but has a strong emphasis on enhancing the impact of research on the economy and society (Proinno Europe, 2011; TKI-BBE, 2011). The short-term focus increases uncertainties around highly promising but still expensive renewables such as aquatic biomass (Weaver, 2011). The government is criticised for creating unfavourable investment climate in the country, lack of consistent long-term vision on renewables and continuous support to the incumbent gas-and-oil-based regime[20] RLI (2011) (F4) (*impact of other TISs*). Result being a lack of entrepreneurial activities (F1) and new research projects (F2) on aquatic biomass in that period. The many studies that are released in 2009-2010 are an outcome of the earlier period activity (Muylaert and Sanders, 2009, Annevelink et al., 2009; van der Zee et al., 2009; EuropaBio, 2009; H2O and Imares, 2009; Kamermans et al.,2009; Gunter et al., 2010; Annevelink and Harmsen, 2010; SER, 2010; DHV, 2010) (F3).

After this dry period, 2011 sees some renewed take-off. In April 2011, the Energy Council (Energie Raad) advises the government on two new instruments for stimulation of renewable electricity production to meet the national and EU targets of CO_2 reduction. The advice has some positive impact on

---

[17] In Figure 3 the negative events such as F4 here are shown below x axis (-F4). The overall lack of system development can be seen is small or no change on the positive side of x axis.

[18] The financial crisis of 2007–2008, also known as the Global Financial Crisis and 2008 financial crisis, considered by many economists the worst financial crisis since the Great Depression of the 1930s.

[19] Topconsortium voor Kennis- en Innovatie Biobased Economy

[20] CE Delft and Ecofys (2011) estimated that 79% (€4.6 milliard) of the governmental financial interventions in the energy market were in the benefit of the end-use of energy while 3.5% (€163mln) for energy saving and renewables.

reconsidering aquatic biomass as renewable source of energy (F4). Additionally, the crisis of 2008 (*landscape factor*) causes high oil prices (*landscape factor*) and a belief that the third generation biofuels can stand chances on the market on condition their production is sustainable and cost effective[21] (F4) (*landscape factor*). This motivates resources mobilisation (F6) for further research (F2) and new experiments (F1). Company Maris Projects initiates research on the use of algae to capture CO_2 from waste water in Den Bosch while WUR starts a 5-year project on the production of green energy from algae and seaweeds (F2) and opens the first Dutch seaweed farm in Oosterschelde (F1). A number of studies are released on biobased economy (Harmsen and Bos, 2011, Hart 't and Schipper, 2011, VROM Raad, Raad voor V&W, 2011) (F3). They provide background for discussions on the lack of convergence of current national policy with the goals of the biobased economy vision (F7). Companies Dow, Yara, EastmanGargil, Heros, Total, AlageLink (*transnational linkages*, all companies operate internationally) meet to discuss these developments and identify a plan of action that would allow meeting the ambitions (F7). 2011 is also a year of slight market development: Ingrepro, the biggest algae producer in Europe increases its operations (F5) but sells most of the volume to Germany, the UK, the USA and Japan (*transnational linkages*). Interest in the use of aquatic biomass for livestock feed and waste water purification grows, but it is the production for fine chemicals that remains most economic (F4).

2012 is a year of renewed attention to seaweeds. Science publishes an article on commercial production of biofuels from seaweeds (Wargacki et al, 2012) (*impact of other TISs*) and Barosso of the EU states that acquisition of energy from seas may stimulate job creation (F4) (*landscape factor*). These events keep aquatic biomass alive in the Netherlands, and provide stimuli to some experimentation (F1): e.g. in March 2012 a consulting firm Ecofys starts seaweed cultivation at offshore wind parks near Texel island while ECN and Ecofys establish seaweeds production zones in Oosterschelde. In the same year University of Applied Sciences Van Hall Larenstein (VHL) and Groningen University (RUG) nominate two researchers to examine the potential of seaweeds as a source of biogas while WUR appoints a professor on the application of algae for the reuse of resources from waste (F2). Three international conferences are organised in the Netherlands (F3) (*transnational linkages*).

Summarising, this last period in the development of the Dutch aquatic biomass system started with negative guidance of the search on the part of the government (change of cabinets and priorities) (F4), which led to changed funding scheme (TKI-BBE) (F6) and blocking of entrepreneurial and research activities (F1, F2). It ends, however, rather positively thanks to the supportive influence of context developments: the EU's commitment to renewable energy sources (directive) (*landscape factor*) and the world crisis (high oil prices and hope for 3rd generation biofuels) (*landscape factors*). Particularly industry begins to lobby with the government (F7) and first demonstration projects (including seaweeds) are materialised (F1).

---

[21] According to Wijfels et al. (2010) and Norsker et al. (2010) a cost-effective, large-scale production of algae starts from 0.3€/kg (vis-à-vis current 4-8€/kg (Appropedia, 2013)). Low cost is partly achievable by strategically locating closed cultivation systems and by optimal use of nutrients. Seaweeds are considered cheaper than algae.

6. Dutch aquatic biomass in 2012 and beyond

The historical overview of the Dutch aquatic biomass system shows that the system have embarked on a moderate development pathway but it remains in a very embryonic stage. This case empirically validates the theoretical claims regarding characteristic features of nascent systems. In particular, it demonstrates that the technology is not well developed and appears more in the form of ideas and expectations and that there are very many uncertainties, particularly about the direction of search (F4). In such conditions it is difficult for actors to commit resources (F6). Those financial resources that were made available domestically, despite their level and relative continuity (see Figure 3) have been used up to their limits. The changes, in which the resources were made accessible, further served for increased risks and great uncertainties among private initiators of sustainable projects making co-financing from financial organisations additionally difficult. Two dominating processes in 2012 are entrepreneurial (F1) and research activities (F2) with early knowledge diffusion activity (F3) and struggles for critical mass with few lobby activities (e.g. on the part of industry) (F7). Since legitimacy is created via conscious actions by various organisations and individuals in a socio-political process of legitimating (Bergek et al., 2008b), the lack of stable guidance, lack of clear long-term policies and a consistent vision on the part of the government (F4) hinders legitimacy creation. Due to the novelty of the field and still limited knowledge on detrimental impacts of commercial aquatic biomass production, the potential public support is in infancy. This makes the societal acceptance of aquatic biomass products virtually non-existent and hence too weak to drive the system's formation (F7). The power of incumbent industrial actors such as energy utilities could potentially play a role if there was a common vision developed and a collective action started aiming at system formation. Market (F5) is indeed absent and dominated by intentions and promises, especially for new, more sustainable energy applications. Figure 4 presents a summary of the functions fulfilment in 2012.

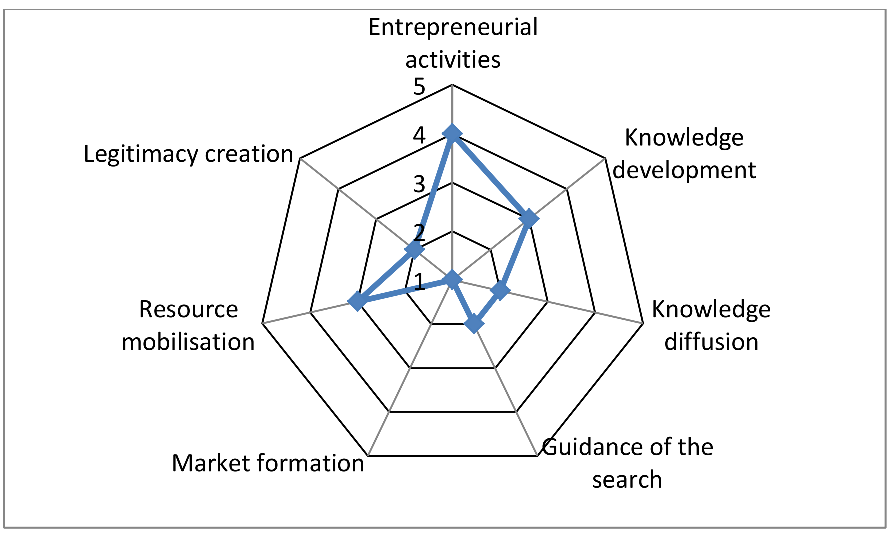

Figure 4. Function fulfilment in the Dutch aquatic biomass TIS in 2012, 1-absent, 2-weak, 3-moderate, 4-strong, 5-excellent.

In that view we conclude that for the system to move to another stage of development two processes are critical: guidance of the search (F4) and creation of legitimacy (F7). Given however, that the strength of the functions is determined by structural composition of the system and the impact of *exogenous forces* (Bergek, et al., 2008b), in the following paragraphs we first discuss structural causes of the aquatic biomass system weaknesses in 2012 (following categories of systemic problems: actors, interaction, institutions and infrastructure) and then the impact of developments in a broader context. They include: impact of other TISs, landscape developments and the spatial characteristics of the TIS structural elements (in the form of transnational linkages). The section closes with a brief systemic policy suggestion.

6.1. Structural causes of functional weaknesses

Actors

The structure of the Dutch aquatic biomass innovation system in 2012 is highly emergent and therefore very fluid. The value chain is building up, but remains incomplete: actors move in and out and there is a great variety of new entrants and incumbents, mostly utilities (both active internationally), who want to diversify their business (see Appendix 1) (*transnational linkages*). Few companies grow algae in the Netherlands (Ingrepro, LGEM, Aquaphyto, AlgaeLink etc) and only one seaweeds (Hortimare) (WUR-AFSG, 2009; Aquaphyto, 2010; InnovatieNetwerk, 2011; WUR-PRI, 2011; Hortimare, 2011). Despite the promise of a large scale production of energy, the companies utilise aquatic biomass mainly for current high-value applications with algae receiving more attention than seaweeds. Few companies such as Technogrow, Evodos, Maris Projects, Genius Vos, provide infrastructure and accompanying maintenance services. Processing of aquatic biomass, especially for energy purposes or combined high and low value applications, is still at experimental stage. One of the policy challenges is the management of the complex value chain that is built of a number of application pathways.

Interactions

The actors do realise the potential of collective action and they see common problems. There emerges a clear need for structuring of the system in the Netherlands, for creating consortia and partnerships that could help manage the interactions, train new experts, exchange knowledge and acquire new project partners. However, no formal networks are built yet. Actors rather cooperate on R&D. WUR-AFSG is one of the first to cooperate with business on translating fundamental research to potential applications of algae in the context of the Algae Parc centre (WUR-AFSG, 2009). Still, the university-industry interactions are problematic due to somewhat premature fear on the part of industry of losing its competitive advantage (InnovatieNetwerk, 2011, AgentschapNL, 2009; Aquaphyto, 2009). To gain access to top professionals and knowledge, Dutch actors often join these international networks[22]

[22] Such as: the European Aquatic Biomass Association (EABA) (strong focus on algae), Algal Biomass Organization (ABO), Seaweed Industry Association (global), Netalgae (European seaweeds industrial network) or EnAlgae (a network of pilot scale algal culture facilities across North Western Europe).

(*transnational linkages*).Other countries have more advanced innovation systems with stronger research and industrial collaboration[23] (*impact of other TISs)*.

Institutions

Informal institutions like expectations and promises driven by developments abroad dominate and are the main driver of the system's development (*transnational linkages*). Very few formal institutions are formed yet. The regulations in the form of permits or health and safety standards exists only for algae's high-value applications. There are no laws for low-value uses such as energy and livestock feed or fertilisers (DHV, 2010; WUR-AFSG, 2009; ECN, 2010; Aquaphyto,2010; EZ, 2009; WUR-PRI, 2010, Hortimare, 2011, AgentschapNL,2009). Procedures to obtain algae production licenses are considered too long compared to other countries (*impact of other TISs*) while for production of seaweeds they are non-existent. Although sustainability criteria have been developed for land grown biomass by the Cramer commission (PGG, 2006c; SNM, 2008) and adopted in the EU directive (2009/28/EC), there is no certification system and no guidelines for aquatic forms of biomass. Some rules for calculation of GHG balance (including CO_2, N_2O, CH_4 emissions) for bio-energy were established and aquatic biomass projects are expected to participate in the CDM market but the carbon trade system for aquatic biomass is not operationalised yet (F4).

Infrastructure

There are further in 2012 high uncertainties around the technology, localisation of production sites and the supportive physical infrastructure[24]. When cultivated at sea, the climatic variability makes algae and seaweeds production difficult and expensive. The existing production infrastructure is available for commercial purposes but is much more expensive than traditional agriculture and too expensive for low-value applications (Florentinus et al., 2008; DHV, 2008, 2010; WUR-AFSG, 2009; Muylaert and Sanders, 2009; H2Organic and Imares, 2009). Harvesting, pre-treatment and processing infrastructure (various types of conversion) is available for land grown biomass, but requires adjustment for aquatic forms and especially for seaweeds (Annevelink and Harmsen, 2010; Annevelink et al., 2009; Hortimare, 2011). Combined extraction of high-value compounds and further use of the biomass to low-value applications such as energy carriers is technically possible and attractive but at R&D stage (ECN, 2005, 2010; WUR-PRI, 2010; Hortimare, 2011, Hart and Schipper, 2011; DHV, 2010 H2Organic and Imares, 2009; WUR-AFSG, 2010). The infrastructure for production of bulk chemicals is unavailable but expectedly the existing technology might be sufficient (PGG, 2007a). There is no infrastructure for transportation of seaweeds (dedicated ships at concept stage) nor monitoring and logistics systems for the entire value chain (DHV, 2008; AgentschapNL, 2009; WUR-PRI, 2010; ECN,2010; InnovatieNetwerk, 2011). Hence, no alignment of technology and institutions could have taken place.

In 2012 these problems particularly created a mismatch between expectations and actual activities (F4) and hindered legitimacy formation processes (F7). The great number of studies (F2/F3) and pilot

[23] E.g. Nordic Algae Network, Norwegian Seaweeds Network, Danish Seaweed Network

[24] At the same time abroad, in Hawaii and Israel, companies use big reactors for large scale production of algae (1000 litre) in comparison with small Dutch bioreactors (100 litres). Also Australia has two location of 400ha algae production from.

projects (F1/F2) aimed at reduction of uncertainties, have in fact, contributed to their increase. They were, however, needed because they clearly showed what knowledge gaps need to be filled in either domestically or by cooperation with international counterparts.

6.2. Role of developments in a broader context

Three types context impacts could have been identified in this case. First type relates to the spatial variation of the structural configuration of the TIS, we term these factors *transnational linkages*. They are of various kinds: many incumbent actors who diversify their business to aquatic biomass activities, have strong international relations with foreign markets and access to international knowledge. Via CORDIS collaborations also the knowledge institutes have a chance to establish broader networks and access knowledge assets of other countries. These collaborations, however, are not very well established yet and the Dutch aquatic biomass system does not seem to be well-connected internationally.

The system however, is under a strong influence of the *other TISs activities* (the second type of context impacts). These can be of two types. First concerns the impacts of knowledge development, entrepreneurial activities, legitimation processes, resources mobilisation, etc. in aquatic biomass in other countries. These impacts are strongly related with transnational linkages. Since however the linkages are still weak and underdeveloped in the Dutch TIS, these impacts remain exogenous to this system. The second are impacts from TISs built around other technologies, often incumbent, such as the Dutch oil-and-gas regime. Both of these impacts, on the one hand brought attention to aquatic biomass as a radically different and sustainable alternative to fossil fuels, but on the other, they added to very high Dutch expectations and kept the system from developing .

Finally, factors of a *landscape type*, next to impact of other TISs have had a relatively strong influence on the development of this system. First, the climate change debate stimulated the Dutch government to pay attention to persistent environmental problems and motivated energy innovation agenda. With time, European commitment to renewables was institutionalised into a directive and expectations regarding promising sea activities were officially voiced. These developments kept the Dutch aquatic biomass system alive when the world crisis stroke and the new Dutch cabinet changed national priorities and continued its support to incumbent oil and gas industry. The same crisis, however, brought about high oil prices and renewed hope in the 3rd generation biofuels also from aquatic forms of biomass.

6.3. Systemic strategy for systemic problems

In that view, we suggest that systemic policy in support of such a nascent system should focus on further internal system formation by supporting knowledge development (F2), diffusion processes (F3) and the entrepreneurial experimentation (F1) but in an internationally informed way. These activities should shed more light on the technical possibilities of aquatic biomass in the Netherlands and contribute to the alignment of the divergent expectations. Common (national) strategic vision is necessary for better guidance of the search (F4) and gaining legitimacy creation (F7) for the technology. The internal support should, however, be strongly informed by international context[25], draw on resources, skills and knowledge developed by other countries. Such embeddedness could help the Dutch system use the strength of other countries to solve domestic problems and fill in the value chain gaps (Wieczorek et al., 2014a).

A systemic instrument in the form of Aquatic Biomass Organisation could help the Netherlands advance this novel and promising area. Such an organisation would have to focus on two key issues. First is the alignment of the divergent expectations and the development of a common strategic vision for this system so as to avoid overrated hopes in conditions of underdevelopment of the field. Second issue is the formation of the value chain, coordination of domestic activities and their solid embeddedness in the broader, international TIS. Such an Organisation could be funded from EU and provincial government sources and be independent of the decisions of the national government.

7. Conclusions

In this article we focused on understanding an evaluating the development of the embryonic aquatic biomass innovation system in the Netherlands using spatially informed TIS approach. We took national TIS perspective to inform national policy but to the extent possible the analysis accounted for the developments in the context of this system. Our empirical material, firstly, confirms that technological innovation systems in such a formative stage are preoccupied with gaining legitimacy (F7), have large needs for financial and human resources (F6), markets are small or absent (F5) and the primary processes are knowledge creation (F2) and diffusion (F3). The aquatic biomass system has not left the formative stage and has not moved to the growth phase. No institutionalisation processes took place yet as in the case of biomass in Nordic countries described by Jacobsson (2008) nor have the *external inducement mechanisms* been supplemented by endogenous ones. The system is in need of common vision and consequent value chain creation.

Secondly, this empirical case also confirms that the assessment of the system and the policy recommendation that flows from this analysis need to account for the system's phase of development and the dynamics in the system context. This case demonstrates that the Dutch aquatic biomass is not yet very well connected internationally (low level of transnational linkages) but seems to be very vulnerable to what happens in the neighbouring TIS and even more so to the influence of the broader landscape type of factors. Spatially informed TIS analysis reveals that policy makers have an option to decide whether they want to focus on building national capabilities or draw on assets and resources developed by other countries.

Methodologically, transnational linkages, being linked to the systems' structural elements (actors, technology, capital, knowledge, institutions) are best manifested in the structural analysis. Impact of

[25] In the USA the goal is 30% of fuel use by 2030 from sustainable sources, which means that only in the USA the production will have to be enlarged from 4 milliard litre in 2005 to 60 milliard litter in 2030. The department of energy expects the worldwide market for biofuels at the level of U$70 per year since 2010 which creates a basis for algae related activities in the USA (DHV, 2008).

other TIS activities and landscape factors are better captured by the functional analysis, especially when carried out based on events analysis.

Further research could be carried out to better understand when and how the contextual inducement mechanisms are endogenised in favour of the further system formation and what role hype-disappointment cycles play in the early TIS formation (as in Konrad, 2006; Verbong et al., 2008; Konrad et al., 2012).

References

AgentschapNL, 2009. Biomass in the Netherlands

AgentschapNL, 2010. Personal communication with a representative involved in aquatic biomass activities

Aino-Maija Lakaniemi, A-M., Tuovinen, O.H., Puhakka, J.A., 2013. Anaerobic conversion of microalgal biomass to sustainable energy carriers–A review. Bioresource Technology, 135:222-31

Annevelink, E., Broeze, J., van Ree, R., 2009. Opportunities for Dutch Biorefineries. Wageningen UR, Energy research Center of the Netherlands Report 1022, ISBN: 978-90-8585-407-4

Annevelink, E., Harmsen, P., 2010. Bioraffinage: naar een optimale verwaarding van biomassa, Wageningen UR, Platform Groene Grondstoffen 10

Appropedia, 2013. http://www.appropedia.org/Algae_fuel, accessed 05/2013

Aquaphyto, 2010. Personal communication with a company manager

Bass&Gill BV, 2008. Quickscan: Emissions to Biofuels Opportunities of algae cultivation for Rotterdam Industrial Complex

Bergek, A., Jacobsson S., 2003. The emergence of a growth industry: a comparative analysis of the German, Dutch and Swedish wind turbine industries in J.S. Metcalfe, U. Cantner (Eds.), Change, Transformation and Development, Physica-Verlag (Springer), Heidelberg:197–228

Bergek, A., Jacobsson, S., Carlsson, B.; Lindmark, S. Rickne, A., 2008a. Analyzing the functional dynamics of technological innovation systems: A scheme of analysis. Research Policy, 37:407-429.

Bergek, A., Jacobsson, S., Sandén, B.A., 2008b. ‘Legitimation’ and ‘development of external economies’: two key processes in the formation phase of technological innovation systems, Technology Analysis and Strategic Management, 20:575-592

Binz, C., Truffer, B., 2012. Conceptualizing leapfrogging with spatially coupled innovation systems: the case of onsite wastewater treatment in China. Technological Forecasting and Social Change 79(1):155-71

Binz, C., Truffer, B., Coenen, L., 2014. Why space matters in technological innovation systems—Mapping global knowledge dynamics of membrane bioreactor technology. Research Policy 43:138–55

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. Technological Forecasting and Social Change, 79(1):155-71

Bos, H., Slingerland, M., Elbersen, W., Rabbinge, R., 2008. Beyond agrification: twenty five years of policy and innovation for non-food application of renewable resources in the Netherlands, Biofuels, Bioproducts and Biorefining, 2(4):343–357

Burlew, J.S., (ed) 1953. Algal culture from laboratory to pilot plant. Carnegie Institute. Washington Publ.

Carlsson, B., Stankiewicz, R., 1991. On the nature, function, and composition of technological systems. Journal of Evolutionary Economics 1:93-118

CE Delft and Ecofys, 2011. Overheidsingrepen in de energiemarkt: onderzoek naar de Nederlandse speelveld voor fossiele brandstoffen, hernieuwbare bronen, kernenergie en energiebesparing

Chaminade, C, C Edquist, C. 2010. Rationales for public policy intervention in the innovation process: A systems of innovation approach, in Smits, R, S Kuhlmann, Shapira P. The Theory And Practice Of Innovation Policy, An International Research Handbook**,** Edward Elgar

Coenen, L., Benneworth, P., Truffer, B., 2012. Toward a spatial perspective on sustainability transitions. Research Policy 41:968–79

Compendium voor de Leefomgeving, 2011. Centraal Bureau voor de Statistiek , Planbureau voor de Leefomgeving, Wageningen UR, state of indicators: 26/09/2011

Davis, H., Guillard, R., 1958. Relative value of ten genera of microorganisms as foods for oyster and clam larvae. US. Fish Wildlife Serv., Fishery Bull., 136(58):293-304

Dewald, U., Truffer, B., 2011. Market Formation in Technological Innovation Systems—Diffusion of Photovoltaic Applications in Germany. Industry and Innovation,18(3):285–300

DHV, 2008. Kansen voor algen in Noord Nederrland. DHV-Nonagon Knowledge Transfer (in opdracht van de Provincie Groningen)

DHV, 2010. Algenproofboerderij Eemsdelta. Haalbaarheidsverkenning grootschalige algenteelt t.b.v. veevorderbereiding, Platform Groene Grondstoffen

ECN, 2010. Personal communication with aquatic biomass researcher at Energy research Centre of the Netherlands

Edquist, C., 1997. (Ed.), Systems of Innovation: Technologies, Institutions and Organizations. Pinter Publishers, London

EU, 2009. Directive 2009/28/EC of the EP 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

EuropaBio, 2009. Industrial biotechnology in The Netherlands

Evodos, 2011. Personal communication with the company manager

EZ, 2004. Energy Innovation Agenda. Ministerie van Economische Zaken

EZ, 2006. Biomass, hot issue. Smart choices in difficult times. Ministerie van Economische Zaken

EZ, 2007. Koers Noord: op weg naar pieken, duurzame groei door omschakeling naar een kenniseconomie. Ministerie van Economische Zaken, Samenwerkingsverband Noord-Nederland

EZ, 2009. Personal communication with a representative of Ministry of Economic affairs responsible for aquatic biomass in the Netherlands

EZ, 2011. SBIR, The power of public procurement: innovative solutions to societal challenges (http://www.agentschapnl.nl/sites/default/files/bijlagen/SBIR%20brochure%20The%20power%20of%20public%20procurement.pdf

Faaij, A., Minnesma, M. Wieczorek, A.J., 2003. Sustainability of large-scale international trade in energy from biomass. Novem, the Netherlands, International workshop report (2GAVE03.07)

Florentinus, A., Hamelinck, C., de Lint, S., 2008. Worldwide potential of aquatic biomass. Ecofys

Freeman, C., 1987. Technology Policy and Economic Performance. Pinter Publishers, London

Geels, F. W. 2002. Technological transitions as evolutionary reconfiguration processes: a multi-level perspective and a case-study. Research Policy, *31*(8-9):1257-74

Gosens, J., Lu, Y., 2013. From lagging to leading? Technological innovation systems in emerging economies and the case of Chinese wind power, Energy Policy, 60:234-50

Grierson, S., Strezov, V., Bengtsson, J., 2013. Life cycle assessment of a microalgae biomass cultivation, bio-oil extraction and pyrolysis processing regime. Algal Research, 2(3):299-311

Gunter, G.A., Meijering, L., Helmendach-Nieuwehuize C.L.J., van der Maas A., 2010. Clustervorming rondom algenteelt. Logistieke kansen voor algenteelt in Zeeland. Impuls.

H2Organic and Imares, 2009. Algencultuur op drainwater uit glastuinbouw. Naar een pilot algenteelt voor de glastuinbouw.InnovatieNetwerk, SIGN, ISNB: 978-90-5059-401-1

Haase, R., Bielicki, J., Kuzma, J., 2013. Innovation in emerging energy technologies: A case study analysis to inform the path forward for algal biofuels. Energy Policy, 61, 1595-607

Harmsen, P., Bos, H., 2011. Communicatie Biobased Economy. Overzicht informativefolders BO-12.05-002-002

Hart 't, P., Schipper, J. 2011. Zeewieren in gesloten systemen. InnovatieNetwerk. ISBN: 978-90-5059-446-2

Hekkert, M., R. Suurs, S. Negro, R. Smits, Kuhlmann, S., 2007. Functions of Innovation Systems: A new approach for analyzing technological change, Technol. Forecasting and Social Change, 74(4):413-43

Hortimare, 2010. Personal communication with the company owner

InnovatieNetwerk, 2011. Personal communication with a representative involved in aquatic biomass activities

Jacobsson, S, A Johnson. 2000. The diffusion of renewable energy technology: an analytical framework and key issues for research, Energy Policy, 28(9):625-40

Jacobsson, S., 2008. The emergence and troubled growth of a 'biopower' innovation system in Sweden, Energy Policy, 36:1491–508

Jacobsson, S., Bergek, A., 2004. Transforming the Energy Sector: The evolution of technological systems in renewable energy technology. Industrial and Corporate Change, 13(5):815-49

Jacobsson, S., Karltorp, K., 2013. Mechanisms blocking the dynamics of the European offshore wind energy innovation system – Challenges for policy intervention. Energy Policy, 63:1182-95

Jacquin, A-G., Brulé-Josso, S., Cornish, M.L., Critchley, A.T., Gardet, P., 2014. Chapter One - Selected Comments on the Role of Algae in Sustainability. Advances in Botanical Research, 71:1-30

Kamermans, P., Blanco, A., Brummelhuis, E., 2009, Draining sustainable profit Fase 2: laboratorium experimenten betreffende benutting van drainbwater voor het kweken van algen voor oestertelt. Rapport C021/09, Wageningen Imares

Klein-Woolthuis, R., Lankhuizen, M., Gilsing, V., 2005. A system failure framework for innovation policy design. Technovation, 25:609–19

Konrad, K., 2006. The Social Dynamics of Expectations: the Interaction of Collective and Actor-Specific Expectations on Electronic Commerce and Interactive Television. Technology Analysis & Strategic Management, 18(3/4):429-44

Konrad, K., Markard, J., Ruef, A., Truffer, B., 2012. Strategic response to hype and disappointment: the case of stationary fuel cells. Technological Forecasting & Social Change 79:1084-98.

Lawhon, M., Murphy, J., 2012. Socio-technical regimes and sustainability transitions: insights from political ecology. Progress in Human Geography. 36(3):354-78

LNV, 2007. Overheidsvisie op de Biobased Economy in de energietransitie ‘de keten sluiten’ (mede namens het Ministerie van Infrastructuur en Milieu (VROM), Economische Zaken (EZ), Ontwikkelingssamenwerking en Verkeer en Waterstaat (V&W), Ministerie van Landbouw, Natuur en Voedselkwaliteit (LNV). Report, 36

Loo, F.A. van der, 2012. Op reis naar het zuiden: Energietransitie 2000-2010, MGMC uitgeverij

Loo, F.A. van der, Loorbach, D., 2012. The Dutch Energy transition project (2000-2009). In: Verbong and Loorbach (ed): Governing the Energy transition: reality, illusion or necessity?. Routledge Sustainability

Lundvall, BÅ., (Ed.), 1992. National Systems of Innovation – toward a Theory of Innovation and Interactive Learning. Pinter Publishers, London

Mayer, A.M. 1960. Achievements and problems in the mass-culture of algae, p.167-173. In Kachroo (ed), Proc. Symp. Algology. Indian Council Agric. Res. and UNESCO South Asia Sci. Coop. Office, New Delhi

Musiolik, J., Markard, J., Hekkert, M. 2012. Networks and network resources in technological innovation systems: Towards a conceptual framework for system building. Technological Forecasting and Social Change, 79(6): 1032-48

Muylaert, K., Sanders, J., 2009. Inventarisatie Aquatische Biomassa. Vergelijking tussen algen en landbouwgewassen. K.U.Leuven Studie uitgevoerd in opdracht van AgentschapNL, Nederland, 12/2009–01/2010

Negro, S.O., Alkemade, F., Hekkert, M.P., 2012. Why does renewable energy diffuse so slowly? A review of innovation system problems. Renewable Sustainable Energy Review, 16:3836-46

Nelson, R.R., (Ed.), 1993. National Systems of Innovation. A Comparative Analysis. Oxford University Press, Oxford

Norsker, N.H., Barbosa, M., Vermue, M., Wijfels, R., 2010. Microalgal production. Wageningen UR

O'Connor, P., 2013. Chapter 1-A General Introduction to Biomass Utilization Possibilities. The Role of Catalysis for the Sustainable Production of Bio-fuels and Bio-chemicals, 1-25

PGG, 2006a. Duurzame productie en ontwikkeling van biomassa, zoweel in Nederland als in het buitenland. Platform Groene Grondstoffen

PGG, 2006b. Biomassa in de Nederlandse energieshouding in 2030. Platform Groene Grondstoffen

PGG, 2006c. Roadmap duurzame biomassa import. Platform Groene Grondstoffen

PGG, 2007a. Groenboek energietransitie. Platform Groene Grondstoffen

PGG, 2007b. Kansen voor regionale initiatieven in Noord-Nederland. Platform Groene Grondstoffen

Proinno Europe, 2011 Mini Country Report/The Netherlands under Specific Contract for the Integration of INNO Policy TrendChart with ERAWATCH (2011-2012)

Provincie Groningen, 2006. Actieplan Biomassa 2007-2010

Raad voor de Wadden, 2008. Het Waddengebied als proeftuin voor biomassa. Advies 2008/4

Raven, R,. 2005. Strategic niche management for biomass. Eindhoven: Technische Universiteit Eindhoven

Reith, J.H., Deurwaarder E.P., Hemmes K., Curvers A.P., Kamermans P., Brandenburg W., Zeeman G., 2005. Bio-offshore. Grootschalige teelt van zeewieren in combinatie met offshore wind parken in de Noordzee. ECN-C-05-008

Rijksoverheid, 2009. Nationaal actieplan voor energie uit hernieuwbarebronnen. Richtlijn 2009/28/EG

Ruimtelijk Planbureau, 2003. Ontwerpen aan de kust. Naar zee. Nai Uitgevers, Rotterdam

SER, 2010. Biobased Economy in Noord Nedderland, De Sociaal Economische Raad voor Noord-Nederland, 2010

SNM, 2008. De Provinciale Milieufederaties and Stichting Natuur en Milieu. Heldergroene Biomassa

Suurs R., Hekkert, M.P., 2009. Competition between first and second generation technologies: Lessons from the formation of a biofuels innovation system in the Netherlands. Energy, 34(5):669-79

Suurs, R., Hekkert, M.P., Kieboom, S., Smits, R., 2010. Understanding the formative stage of technological innovation system development: The case of natural gas as an automotive fuel, Energy Policy, 38(1):419-31

TKI-BBE, 2011. Top Consortium Bio-Based Economy http://www.top-sectoren.nl/energie/sites/default/files/documents/TKI%20BBE_factsheet_def%201.pdf

Unruh, G.C., 2000. Understanding carbon lock-in. Energy Policy, 28:817–30

Van der Zee, M., Wijfels, R., Barbosa, M., 2009. Overzicht van organisaties die zich bezighouden met (toepasing van) algenteelt. Wageningen UR, Report 1014

Verbong, G., 2004. Biedt de energietransitie kansen voor de Nederlandse industrie? Kansen en keuzen vanuit een lange termijn perspectief, Essay geschreven in opdracht van de Algemene Energieraad en de VROM-raad, Stichting Historie en Techniek, Technische Universiteit Eindhoven, http://www.rli.nl/sites/default/files/Energietransitie%2012-2004%20achtergrondstudie%204.pdf

Verbong, G., Geels, F.W., Raven, R., 2008. Multi-niche analysis of dynamics and policies in Dutch renewable energy innovation journeys (1970-2006): Hype-cycles, closed networks and technology-focused learning. Technology Analysis and Strategic Management, 20(5):555-73

Visser de V., Harmelink M., Winkel T., Noothout P., Blok K., 2012. Ex-post evaluatie DEN-A en EOS, Ecofys, in opdracht van: Ministerie van Economische Zaken, Landbouw en Innovatie

VROM Raad and Raad voor V&W, 2011. Remmen los. Advies over versnelling van de transitie naar een duurzame energiehuishouding in Nederland

VROM, 2001. Een wereld en een wil. Werken aan duurzaamheid. Nationaal Milieubeleidsplan 4. Ministerie van VROM, Den Haag

VROM, 2007. Nieuwe energie voor het klimaat. Werkprogramma Schoon en Zuining. Ministerie van VROM

Wald, J., 2010. Evaluatie naar mogelijkheiden voor grootschalige zeewierteelt in het zuidwestelijke Deltagebied, in het bijzonder de Oosterschelde. Wageningen UR-PRI, Rapport 341

Walne, P.R., 1963. Observations on the food value of seven species of algae to the larvae of Ostrea edulzk. J, Marine Biological Association UK, 43:767-784

Wargacki, A.J, Effendi L., Maung, N.W., Regitsky, D.D., Santos, C.N.S., Kim, P.B., Cooper, S.R., Raisner, R.M., Herman, A., Sivitz, A.B., Lakshmanaswamy, A., Kashiyama, Y., Baker, D., Yoshikuni, Y., (2012) An Engineered Microbial Platform for Direct Biofuel Production from Brown Macroalgae, Science, 335(6066):308-13

Weaver, P.M., Huynen M., van Zeijl A., 2012. VISION RD4SD Country Case Study the Netherlands.

Wieczorek, A.J, Negro, S.O., Harmsen, R., Heimeriks, G.J., Hekkert, M.P., 2013. A Review of the Western European Offshore Wind Innovation System. Renewable and Sustainable Energy Reviews, 26:294-306

Wieczorek, A.J., Hekkert M.P., 2012. Systemic instruments for systemic innovation problems: A framework for policy makers and innovation scholars. Science and Public Policy, 39:74-87

Wieczorek, A.J., Hekkert, M.P., Coenen, L., Harmsen, R., 2014a. Broadening a national focus in technological innovation system analysis: the case of offshore wind. Environmental Innovations and Societal Transitions, accepted for publication

Wieczorek, A.J., Raven R., F. Berkhout, submitted. Transnational linkages in sustainability experiments. A typology and the case of solar photovoltaic energy in India. Environmental Innovation and Societal Transitions, 2014b

Wijfels, R., Barbosa, M., Eppink, M., 2010. Microalgae for the production of bulk chemicals and biofuels. WUR

Wirth, S., Markard, J. 2011. Context matters: How existing sectors and competing technologies affect the prospects of the Swiss Bio-SNG innovation system. Technological Forecasting and Social Change 78:635–49

WUR, 2009, www.algae.wur.nl, Wageningen UR

WUR-AFSG, 2009. Personal communication with algae researcher at Wageningen UR, Agrotechnology and Food Sciences Group

WUR-IPR, 2010. Personal communication with seaweeds researcher at Wageningen UR, Plant Research International

Yi-Feng, C., Wu, Q., 2011. Chapter 17 - Production of Biodiesel from Algal Biomass: Current Perspectives and Future, Biofuels, 399-413

Yue, D., You, F., Snyder, S.W., 2014. Biomass-to-bioenergy and biofuel supply chain optimization: Overview, key issues and challenges, Computers & Chemical Engineering, 66(4):36-56

Appendix 1

Overview of major actors along aquatic biomass value chain until 2012

VC step	Industry	Knowledge and educ. institutes	Support organisations
PRODUCTION			
Open raceway ponds (algae)	Aquaphyto, Feyecon, Ingrepro, Mosselakker, Shell (Hawaii), Kiniklijk Maatschap de Wilhelmina Polder	Deltares, ECN, WUR Imares, KNAW, University Twente, UvA	Ekwadrat, Global Energy Partners, IVAM, Plankton Solutions, SIGN
Photobiore actor(algae)	AlgaeLink, Delta, Ingrepro, LGEM	Deltares, KNAW, RUG, UvA, WUR-AFSG	Plankton Solutions, Global Energy Partners, SIGN, Technogrow, DHV
Open-sea systems (algae)	-	RUG	Plankton Solutions
Seaweeds production systems	Hortimare, Seafarm, Grovisco	ECN, NIOZ, RUG, University Twente, UvA, WUR PRI & Imares	Bioclear, Hoogeschool Van Haal Larenstein, Impuls Zeeland, Koers en Vaart, TCNN, Oosterhof Holman Milieutechniek, Projectbureau Zeeland
Potential, new locations, chain efficiency (algae and seaweeds)	Essent, Feyecon, Hortimare, Ingrepro	ECN, RIVO, LeAF, VU, IVAM, NIOO KNAW, NIOZ, OASE, RUG, University Leiden, University Twente, WUR-AFSG & PRI & Imares, University Utrecht, RUN	Altran Advies Bureau, Bass&Gill, DHV, Ecofys, E-connection, FAO, Econcern, Global Energy Partnes, Impuls Zeeland, Noordzeewind, Innovatie Netwerk, Projectbureau Zeeland, Plankton Solutions, WET-SUS Procede Enschede, Rabobank, Royal Haskoning, Saeftinghe Zilt Aquaculture Products, We@Sea
HARVESTING AND PRETERATMENT (algae unless indicated otherwise)			
Dewatering	AlgaeLink, Aquaphyto, LGEM, Evodos (also seaweeds), Feyecon, Ingrepro	Hoogeschool Van Haal Larenstein, TU Delft, UvA, WUR PRI (all seaweeds)	Holman Milieutechniek Oosterhof (seaweeds), Kema, WETSUS, DHV, Plankton Solutions, Bioclear (seaweeds), TCNN (seaweeds)
PROCESSING (algae unless indicated otherwise)			
Biorefinery & white technology methods dominant	AkzoNobel, Algae Link, Algaetec, Delta, DSM Life Sciences, Dow Chemicals, Eneco, Essent, Friesland Foods, Invent, Hubert Landustrie, Nedalco, Neste Oil Corp, Purac, Syngenta, Techno	Hanze Hogeschool, HZ, University Twente, WUR-FBR (seaweeds) & AFSG & DLO & PRI (seaweeds), Hoogeschool Van Haal Larenstein (seaweeds), LeAF (seaweeds), University Twente (seaweeds)	Bioclear (also seaweeds), Crassus Advice 4you, TCNN (seaweeds) Ekwadrat, Kema, ATO, Oosterhof Holman Milieutechniek (also seaweeds), Process Groningen, WETSUS
APPLICATIONS (algae unless indicated otherwise)			
Fine chemicals	AkzoNobel, Aquaphyto, Alcom, BASF, Feyecon, Ingrepro, LGEM, Purac, Techno Invent, Unilever	ECN (seaweeds), Hanze Hooge-school, TNO, Hoogeschool Van Haal Larenstein, IVAM, University Twente (also seaweeds), Porifarma, WUR A&F (seeweeds) & AFSG & DLO & PRI (seaweeds)	Bioclear, Fishery organisations, IVAM , TCNN, Oosterhof Holman Milieutechniek, Technogrow, Process Groningen
Bulk chemicals	Avantium Chemicals, Paques, Purac	Hanze Hoogeschool, Hoogeschool Van Haal Larenstein, WUR-AFSG & DLO & PRI (seaweeds)	Bioclear, TCNN (seaweed), Oosterhof Holman Milieutechniek, PNO Consultants
Energy carriers (CH_4, H_2, biogas,	AlgaeLink, Alliander, Aquaphyto, Biovalue /Delta, Bioking, Biosoil, de Alg, Delta, DSM Life Sciences, Eneco, Essent, Evodos, Feyecon, Friesland Campina, Hygear, Neste	ECN (also seaweeds), Hanze Hoogeschool Groningen, Hoogeschool Leiden, HZ, KNAW, RUG, TNO, TU Delft (also seaweeds), Van Hall Larenstijn	Altran Advies Bureau, Bioclear, CCC, Crassus Advice4you, DLV Plant, IVAM, Kema, Oosterhof Holman Milieutechniek, Process Groningen, Spring New Business

solid fuels bio-diesel/ ethanol)	Oil Corp., Shell, Unilever, Zeeland Refinery, Nedalco, Ingrepro, KLM, Kelstein Algae, Rosendaal Energy	Hoogeschool, WUR-AFSG & DLO & PRI (seaweeds), TU Eindhoven	Development Eelde, TCNN (seaweed), WETSUS
Food	Aquaphyto, Feyecon, Ingrepro, LGem, Martek Biosciences, Purac, Yalisco	TU Delft (also seaweeds), WUR-AFSG & PRI (seaweeds)	Projectbureau Zeeland (seaweeds)
Livestock feed	Agrifirm, Aquaphyto, Alcom, Avebe, Ingrepro, Grovisco, Kiniklijk Maatschap de Wilhelmina Polder, LGem, Mosselakker, van Maris, Nutrico, Prins en Dingemanse, Saeftighe Zilt Aquaculture Products, Seafarm, Zeeland's Roem (Roem van Yerske), Groningen Seaports, Waterbedrijf Groningen	RUG, WUR Imares & AFSG & PRI (seaweeds) & ATO	DHV, Impuls Zeeland (Seaweeds), Projectbureau Zeeland, Rabobank, SIGN, Stichting Zeeschelp,
Agro applications	Agrobio Products, Alcom, Ceradis, Ingrepro, Saeftighe Zilt Aquaculture Products, Vette & Verhaart, Purac	WUR DLO & AFSG & PRI (seaweeds)	Biofruit Advies, Louis Bolk Institute, Rabobank
CO_2 uptake	Aa en Maas Waterschap, Essent, AlgaeLink, Chemiepark Delfzij, Delta, Lans, Feyecon, Kelstein Algae	Rosendaal Energy, TNO, WUR-AFSG & PRI (seaweeds)	Bass&Gill, DLV Plant, Plankton Solutions, Procede Enschede, Rabobank
Water purification	Aa en Maas Waterschap, Sluiskil, Heineken, Dow Chemicals, KLM, Evides, Evodos, Lans, Feyecon, Gasunie transport, Kelsten Algae, Heros gr. Ingrepro, Lamb Weston Meijer, Paques	ECN, HZ, LeAF (seaweeds), Van Hall Larenstijn Hoogeschool, WUR-AFSG & Imares & PRI (seaweeds), UvA	Bass&Gill, Impuls Zeeland, Kema, Procede Enschede, Projectbureau Zeeland, Rabobank, SIGN, STOWA, Vette & Verhaart
MAINTENANCE, LOGISTICS, SUSTAINABILITY AND TRANSPORT (all algae unless indicated otherwise)			
Maintenance & infrastructure	Algae Food & Fuel, AlgaeLink, Priva, Biofuels, Evodos, Bio-king, GreenFuel-Systems, Paques, Cytobuoy, Hesy Bergambacht, AkzoNobel, Technogrow, LG Sound (seaweeds), Fabricom (seaweeds), Maris Projects, Palm Instruments, Genius Vos (seaweeds), Drema Water-behandeling, V. Reekum Materialen (seaweeds)	Deltares, WUR PRI (seaweeds)	Global Energy Partners, Kema
Logistics & transport	-	WUR PRI (seaweeds)	-
Sustainability, ecology, health, safety	Europroxima	HZ, KNAW, TNO, RIVM, LeAF (also seaweeds), NIOO KNAW, NIOZ (also seaweeds), RUG, University Leiden, University Utrecht, WUR Imares & Alterra & PRI (seaweeds) & RIKILT	Ekwadraat, Innovatie Netwerk, Koeman en Bijker, NOM, Plankton Solutions, WUR ATO (seaweeds), WUR Alterra

Chapter IV

Dutch offshore wind innovation in the European context: challenges and opportunities for policy[26]

1. Introduction

Offshore wind energy is a relatively young but rapidly developing and increasingly competitive sector. While in the early 90's the industry was still in its infancy with the first offshore wind turbine set up in Denmark, in 2011 the total installed offshore wind capacity in Europe reached 3294MW (EWEA 2011a). The future (2020) European potential for offshore wind power is estimated by the European Wind Energy Association (EWEA) at the level of 40GW. Realization of this potential would allow meeting over 4% of the EU's total electricity demand and reduce CO_2 emissions (EWEA, 2011b). It would also provide with huge employment opportunities (EWEA, 2011a) and help various countries diversify their energy sources.

With substantial construction expertise and 247MW realized at two major North Sea wind parks: Egmond aan Zee and Princes Amalia (EWEA, 2011a), the Netherlands was, till 2011, among the main players on the European offshore wind market. Other significant actors included the UK (largest market, 1586MW installed capacity), Denmark (major turbine manufacturer, 20 years of knowledge and experience, 854 MW installed capacity), Germany (major turbine manufacturer, 195MW installed capacity) and Belgium (significant recent increase in installed capacity over the last decade up to 195MW). Together the countries complement each other and are mutually interdependent contributing thereby to a formation of a competitive European offshore wind Technological Innovation System (TIS), which in turn, provides an important context for the national Dutch activities (Wieczorek and Hekkert, 2014).

Domestically, these activities were shaped by a long history of the wind industry. The Netherlands holds a strong knowledge base on wind energy and in particular a solid expertise on construction of wind farms. Delft Technical University and the European Research Center (ECN) have a strong international reputation in the offshore wind field. The Dutch companies are active in the international market constructing wind farms in such countries as the UK or Germany. A number of foreign companies such as Vestas or Siemens also have offices in the Netherlands (Wieczorek et al., 2013). In spite of these rather favourable conditions, however, the government's attention, under influence of the world crisis, has in 2011, shifted its attention away from offshore wind energy. High costs of electricity and heat production make it unattractive energy source compared to conventional energy sources (gas for example, that is available in the Netherlands for another 26 years). The Netherlands therefore became a

[26] This chapter has been published as: Wieczorek, A.J., Negro, S.O., Harmsen, R., Heimeriks, G.O., Hekkert, M.P., 2012. Systemic weaknesses in the Dutch off shore wind innovation system opportunities for policy and strategy. Utrecht University Report, 15 January, 2012

rather unattractive offshore wind market while its government blamed for lacking a clear vision, consistent strategy and a stable framework for any renewable activities. In October 2011, under the pressure of over 50 Dutch companies and the Netherlands Wind Energy Association (NWEA) the government signed a Green Deal Offshore Wind Energy committing itself to cooperation on substantial cost reduction through innovation and policy changes, further experimentation and shaping of legislation. As much as the Green Deal was a sign of the determination of the Dutch industry, at the same time it was criticised for being a camouflage for the government's lack of determination to act and take its earlier renewable energy commitments and obligations seriously (Eize de Vries, 2012). Focus on reduction of CO_2 emissions on lowest possible costs and lack of attention to the development of national industry led politicians to focus on cheaper technologies.

Given the importance of domestic markets for the formation of a well-functioning European offshore wind innovation system (Wieczorek and Hekkert, 2014), critical for meeting of the European climate goals (Jacobsson and Karltorp, 2013), this chapter analyzes the state of the Dutch offshore wind innovation system at the end of 2011 in the context of European developments. The main research question is therefore:

Using insights from the internal system's dynamics and taking international context into account, what challenges and opportunities influence the development of the Dutch offshore wind innovation system and what strategy can be proposed in support of the system's further growth?

The chapter applies the Technological Innovation System approach (TIS) to identify national systemic problems that hinder the development of the system. By analysing the challenges in the broader international context it proposes a direction to the national policy that could best contribute to the formation of the common offshore wind European market.

From a theoretical perspective the Dutch offshore wind innovation system is an emergent system in a growth phase as opposed to nascent or mature types of systems (Markard and Hekkert, 2013) such as aquatic biomass (Wieczorek et al., 2014) or land-grown biomass (Negro et al., 2007) respectively; and with well developed linkages with neighbouring TISs in Germany, Denmark and the UK (Wieczorek and Hekkert, 2014). The type of problems, therefore, are pertaining to the stage of system development so eventual policy suggestion to tackle them must not only take the endogenous structure-related dynamics into account but also the impact and many opportunities arising from the surrounding milieu. This paper makes some contributions to this conceptual debate.

The chapter is composed of 8 sections. Section 2 explains basic theoretical notions. Section 3 presents methodology. Section 4 analyzes the structural configuration of the innovation system. Section 5 investigates the system's internal dynamics using seven system functions. Finally, Section 6 identifies the problems that block the proper functioning of the Dutch offshore wind innovation system and discusses them in the context of interaction of the Dutch TIS with the neighbouring systems. Section 7 discusses implications of the challenges for domestic policy that could help form a European offshore wind innovation system. Section 8 concludes the paper.

2. Theoretical notions

Technological Innovation System (TIS) is a particular case of an innovation system built around specific technology. TIS is also a theoretical approach that helps describe, analyse and understand the diffusion of particular technological innovations (Hekkert at al. 2007; Bergek et al, 2008). The TIS approach has been translated into an analytical model - a systemic framework (Wieczorek and Hekkert, 2012). The framework aims to help identify barriers that hamper the development of the system and arrive at a tailor-made systemic policy instrument that can accelerate the diffusion and implementation of new technologies (see Figure 1). The framework connects four existing innovation system concepts: structure, functions, problems and instruments and is meant to complement the normal policy cycle by better aligning the instruments in the policy mix to all the barriers in the system. The framework builds on the scheme of analysis by Bergek et al (2008) but it goes a step further by: i) encompassing a broader set of structural elements of the TIS including physical (technology), financial and knowledge infrastructure; ii) by explicitly analysing the capacity/capability aspect of the systems structure; iii) by clarifying methodologically their relationship with functions; iv) by categorising systemic problems in a way that allows for a design of a targeted systemic instruments; v) by defining systemic instruments.

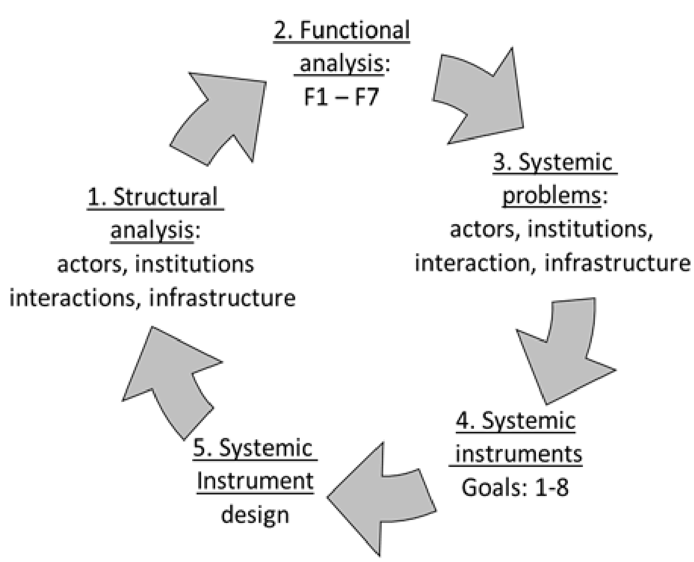

Figure 1. A systemic innovation policy framework (Wieczorek and Hekkert, 2012)

Stage 1 – structural analysis

Every innovation system is built of certain structural elements: actors, institutions, infrastructure[27] and interactions. Actors interact with each other in a specific institutional and infrastructural context. The elements' presence or absence as well as capacity or capabilities (when we talk about actors) have

[27] Infrastructure includes: physical (artifacts), knowledge (know-how) and financial (capital) elements.

impact on the system's proper functioning. In the context of this framework therefore the structural analysis denotes: (i) mapping of the structural dimensions of the analysed system (are they present or missing?) and (ii) evaluating their capabilities (Can actors innovate? Are regulations supportive? Are interactions strong enough?).

Stage 2 – functional analysis

Systems can be built in a similar way but they differ in terms of dynamics. Structural analysis is thus complemented by an analysis that helps evaluate how the system functions – the so-called functional analysis. In this stage seven functions are assessed by policy makers and innovation experts: entrepreneurial activities (F1), knowledge development (F2), knowledge diffusion (F3), guidance of the search (F4), market formation (F5), resource mobilisation (F6) and legitimacy creation (F7) (as described by Hekkert et al., 2007). A set of diagnostic questions are developed for each of the functions that help assess whether e.g. entrepreneurial activities are strong or weak (see Appendix A). The functional analysis may also be carried out based on a longitudinal analysis of events specific to each of the functions (as in e.g. Negro and Hekkert, 2007).

Stage 3 –systemic problems' identification

The functions *signal* problems but because they cannot be directly modified by policies they need to be studied through the perspective of the earlier mapped structural dimensions (e.g. are entrepreneurial activities weak because entrepreneurs are missing or because they have poor innovation capabilities?). Relating functions to the structural dimensions is also critical for the identification of problems that hinder the development of the analysed system. Because problems within any system are caused by issues with the systems' elements or their properties, four types of systemic problems can be identified in innovation systems: actor problems, institutional problems, interaction problems and infrastructural problems. Each of the problems can be caused by the absence of the structural dimension, e.g. entrepreneurs are missing (presence aspect) or by its inappropriate attributes, e.g. institutions are too stringent or interactions are too weak (capacity/capability aspect of a problem).

Stage 4 –systemic instruments' goals

Systemic problems call for systemic policy instruments. A systemic policy instrument is defined as an integrated coherent set of tools designed for a specific innovation system. Systemic instruments to be able to address all types of systemic problems, should focus on one or more of the eight goals that are strongly linked with the typology of the problems (see Table 1).

Table 1. Goals of systemic instruments per (type of) systemic problem (Wieczorek and Hekkert, 2012)

Systemic problem	(Type of) systemic problem	Goals of systemic instrument
Actors problems	Presence?	1. Stimulate and organise the participation of relevant actors
	Capabilities?	2. Create space for actors capability development
Interaction problems	Presence?	3. Stimulate occurrence of interactions
	Intensity?	4. Prevent too strong and too weak ties
Institutional problems	Presence?	5. Secure presence of hard and soft institutions
	Capacity?	6. Prevent too weak and too stringent institutions
Infrastructural problems	Presence?	7. Stimulate physical, financial and knowledge infrastructure
	Quality?	8. Ensure adequate quality of the infrastructure

Stage 5 –systemic instruments' design

In stage 5 systemic policy is designed based on a selection of individual policy tools that together can address the identified obstacles in an organised way. The proposed systemic instrument should be a mechanism that allows involved actors coordinate their activities and align their individual objectives with the goal of the system development. It should be seen as a contribution to the normal policy cycle, within which instruments are further evaluated in terms of their efficiency and effectiveness.

3. Methodology

The analysis followed the five stages of the systemic framework. The structural configuration of the analysed system (Section 4) was mapped based on the Global Offshore Wind Farms Database 4C, version October 2010, further referred to as *4C database,* journal publications in the Web of Science (for knowledge networks identification), CORDIS database (for European project participation) and European Patent Organisation (for patents identification). *Offshore wind* served as a key word. The research was narrowed down to Dutch context.

This review was complemented with functional analysis based on Lexis Nexis media events analysis for 2010-2011 and personal communications with over 30 offshore wind stakeholders. Among the interviewees were representatives of leading industries, financial organisations, knowledge institutes and NGOs in the four studied countries. They were all experts in managerial positions (Appendix A). The interviewees were asked to assess the Dutch offshore wind TIS but acknowledging the European dynamics. A five-tier scale of 1-5 (absent to excellent) and a set of diagnostic questions (presented in Appendix B) guided the discussion.

To assess the functionality of the system (Section 5), a series of personal communications with actors involved in the field were carried out (Appendix A) using a set of diagnostic questions (Appendix B). An additional media events analysis was done by means of Lexis Nexis database (period 2010-2011, key word *offshore wind*). 10 reviewers, engaged in the offshore wind innovation system, have reviewed the findings. The review process as well as scientific and grey literature and internet sources were additional sources of qualitative information about how the system functions and what challenges it faces.

The identification of policy goals and systemic instruments (Section 5) was made based on the insights from a meeting with five Dutch offshore wind experts (Flow, TUDelft, Van Oord, Wind power Monthly Consultant, Utrecht University, Vattenfall) that took place on 21 June 2012 in Utrecht.

4. Structural configuration of the Dutch offshore wind TIS

This section presents the structural configuration of the Dutch offshore wind TIS: actors, networks, institutions as well as (physical, knowledge and financial) infrastructure.

4.1. Actors

Actors through their choices and actions generate, diffuse and utilize technologies. Their presence and capabilities directly or indirectly contribute to the system development as well as influence its pace and direction. Six different categories of actors are distinguished and analysed in this paper: governmental bodies (politics), knowledge institutes (research), educational organizations (education), industry and market actors (supply and demand), and support organisations. In the analysis we include only main actors that have been involved in offshore wind up until 2011.

4.1.1. Government

Two of the Dutch ministries were in 2011 part of the system: the Ministry of Economic Affairs, Agriculture and Innovation was responsible for the stimulation regulations for renewable energy (SDE and SDE+) and for the electrical infrastructure (the grid); the Ministry of Infrastructure and the Environment was the manager of the North Sea. It controlled the building permits and was responsible for spatial planning as well as environmental impact assessments of the wind farms. Policies were implemented and carried out by AgentschapNL, that also served as an executive office of the offshore wind subsidy scheme, tendering procedure and tax dedicated policy.

4.1.2. Knowledge institutes

Knowledge institutes include universities, technology centres, research centres and institutes. Consultancies are included in the support organisations category. To identify the main Dutch knowledge institutes that perform research on the offshore wind, journal publications as archived in the Web of Science from Thomson Scientific we screened with *offshore wind* as a topic indication an the time period of 1994-210. The search results were narrowed down to the Dutch knowledge producers.

Two organisations dominate the research component of the Dutch TIS: the Delft University of Technology (TU Delft) and the public research organization Energy Research Center (ECN) (See Table 2).

Table 2. Number of scientific publications on the offshore wind by the Dutch actors

Organization	Nr of publications
Delft University of Technology	44
ECN	16
University Utrecht	13
Netherlands Institute Sea Res	7
University Twente	6
Ecofys	6
University Groningen	5
Eindhoven University of Technology	3
University of Amsterdam	3
Free Univ Amsterdam	2
Royal Netherlands Meteorological Institute	2
Shell Int. Explorat & Prod BV	2
TNO	2
TenneT	2

The TU Delft is involved in wind energy research and education from 1977. Over the years its research interests gradually expanded from rotor aerodynamics to blade material and full-scale fatigue analysis. In 1984 the Institute for Wind Energy (IvW) was founded at TU Delft to perform the growing amount of contract research with respect to Wind Energy. In 1990 the world's first chair dedicated to wind energy was established at the university with Jan Dragt acting as the first world's wind energy professor and a close cooperation with the section offshore technology was established. In 2000 all wind energy research at the university was brought together under the umbrella of DUWIND, the new Delft University Wind Energy Research Institute. The current research activities of TU Delft include: large electricity generating wind turbines of a multi megawatt scale, offshore wind power application, wind turbine aerodynamics and dynamics, wind power in the built environment and smart rotor blades. Except for technology development, also fundamental aspects of wind energy conversion are part of the university's research program (TU Delft, 2011)[28].

ECN is the Dutch national institute for energy innovation focused on the needs of the government and industry. ECN has been active in the field of wind farms for a number of years. It contributed to research, software development, service provision, trainings and testing of prototypes. ECN, next to large offshore and electricity companies, is one of the co-founders of the FLOW consortium (Far and Large Offshore Wind). Presently, ECN in cooperation with the Dutch start-up BMO Offshore, is profiling itself in the development of new measuring services for the offshore wind industry. In the last years, the unit Wind has worked with the industry as a service provider which led to the establishment of EWIS (ECN Industrial Support Group) in 2009. Currently, over 60% of large developers of offshore wind farms use software developed by ECN when they want to establish their maintenance strategy. Due to its in-depth knowledge, ECN is increasingly consulted for designing new wind turbine models. The ECN Wind Turbine Test Farm Wieringermeer (EWTW) customers included: Siemens, with a 3.6 MW wind turbine

[28] http://www.lr.tudelft.nl/en/organisation/departments-and-chairs/aerodynamics-and-wind-energy/wind-energy/about/history/ accessed 30 dec 2011

and a new rotor with a diameter of 120 metres, and the Xemc-Darwind, a member of the FLOW consortium, which started constructing an offshore direct drive wind turbine of 5 MW (ECN, 2010)[29].

4.1.3. Educational organisations

Actors providing offshore wind educational courses and trainings in the Netherlands can be divided into three groups: academic (TU Delft, DUWIND), polytechnic (HAN, Outsmart) and vocational (NHL hogeschool, MCN, HAN, STC group, DUWIND, ECN, DHTC), (van Bussel, 2010[30]).

Academic (BSc, MSc)

TU Delft and Duwind over the years of their involvement in the field developed several wind energy courses at the BSc and the MSc level and participated in a few curricula on sustainable and renewable energy technologies such as EUREC (TU Delft, 2011[31]). From 2004 TU Delft offers two MSc courses, which are purely devoted to the offshore wind industry. The first one is *Offshore Wind Farm Design* focused on all aspects of offshore wind farm layout and planning, installation, maintenance and designing structures for the offshore environment. The second course is *Offshore Wind Support Structures* and addresses the design of steel bottom mounted support structures for offshore wind turbines.

At the level of PhD, TU Delft is in 2011 a single leader with 14 studentships specifically focused on the offshore wind energy aspects funded within the FLOW project.

Polytechnic

Hoogeschool van Arnhem and Nijmegen (HAN) in collaboration with OutSmart (a company focusing on the technical management of a wind farm north of the Wadden Sea) plans to give in 2012 an English BSc course on the *Offshore Wind Project Management*. This minor is for engineering, economics and management students and is unique in the world.

Vocational

Vocational education is a key supplier of qualified professionals for business and society. The majority of Dutch young people follow a course of vocational education. In the field of offshore wind NHL Hoogeschool Leuwarden in cooperation with Maritime Campus Netherlands (MCN[32]), HAN, STC-Group (consultancy, HR developer), ROC Kop Noord Holland (Regional Vocational Education Center) offers students of Mechanical Engineering, Electrical Engineering and Computer Science a new specialization in Offshore Wind starting in 2011/12. This is to meet the demand for skilled workers now and in the future. Support for this course comes from the European Regional Development Fund (ERDF).

---

[29] http://www.ecn.nl/nl/corp/ecn-breeduit/jaarverslagen/jaarverslag-2010/ accessed 30 dec 2011
[30] http://www.we-at-sea.org/leden/docs/conference2010/12.pdf accessed 30 dec 2011
[31] http://www.lr.tudelft.nl/en/organisation/departments-and-chairs/aerodynamics-and-wind-energy/wind-energy/about/history/, accessed 30 dec 2011
[32] The Maritime Campus Netherlands (MCN) is collaboration between a number of research institutes, education institutes (from secondary vocational up to university level), businesses and government bodies.

Duwind based at TU Delft plans in 2012 a 14th edition of a 2-day course on technology for offshore wind energy aimed at professionals with an interest in this industry. The course has a very technical content and focuses on the activities of project engineers and designers and covers wind turbine, electrical and offshore engineering aspects.

DHTC is an international provider of a wide variety of safety courses for the offshore oil and gas, shipping, offshore wind industry and related companies. Ascent Safety provides consultancy, equipment, training, inspection and testing services to public and private sector organizations of all types that are involved in working at heights, rescue and emergency response. Since 1999, DHTC and Ascent Safety provide in Den Helder a safety training to construction and maintenance staff on offshore wind farms. The *Offshore Wind Safety Course* has been developed in consultation with leading companies in the offshore wind sector and is directed to personnel that operates and maintains the offshore wind turbines (DHTC, 2011)[33].

ECN does not hold any educational activities but it does provide accompanying trainings and courses with the maintenance strategy software.

Because of practical nature of the field, the industry has its own initiatives and trains people in-house. Almost each bigger company has local training facilities. Examples of most prominent ones include Van Oord Academy (Van Oord, 2011) or Siemens with a number ofprograms and trainings (Siemens, 2011).

4.1.4. Industry

In order to map all industrial and market actors in the Dutch offshore wind system a value chain with three broad steps has been used. First step is the development of the wind farms which encompasses owners, project developers and managers of the farms. Second is the construction phase including installers, manufacturers of supply parts and substation developers. Third is the operation and maintenance covering all actors involved in execution of the farms.

[33] www.dhtc.nl, accessed 30 dec 2011

Figure 2. Dutch actors involved in the national and international projects along the value chain

Overall, as shown on Figure 2, the value chain in the Netherlands is relatively complete. Most of the Dutch companies have expertise and are involved in the construction stage but in particular in the manufacturing of foundations (Smulders Group and Sif Group) and installation of entire farms (Van Oord, Mammoet van Oord and Bouwcombinatie Egmond[34]). These companies have built a strong knowledge base and an international experience in offshore technology in years of exploration and production of offshore oil and gas. With substantial offshore infrastructure many of them are nowadays also managers of the projects. However, as Figure 1 indicates, many of the Dutch companies are rather involved in the foreign than in the national projects. It applies to all stages of the value chain but is particularly visible in the construction phase (see e.g. SMIT, VSMC or Stemat).

Taking a different perspective: the Dutch wind farms are not solely constructed by the Dutch companies (see Figure 3). For example the German Bard consortium won in 2010 a subsidy for the development of two parks with 120 windmills in the North Sea in 2012 and until 2011 many international firms such as Swedish ABB, Norwegian OceanTeam, British Global Marine, Danish Vestas, A2Sea, DBB and Bladt Industries were involved in the construction process of the Dutch farms in various capacities (installation of foundations, provision of vessels or supply of wind turbines). The following paragraphs identify and analyse the various actors per stage of the value chain.

[34] Joint venture of Ballast Nedam and Vestas

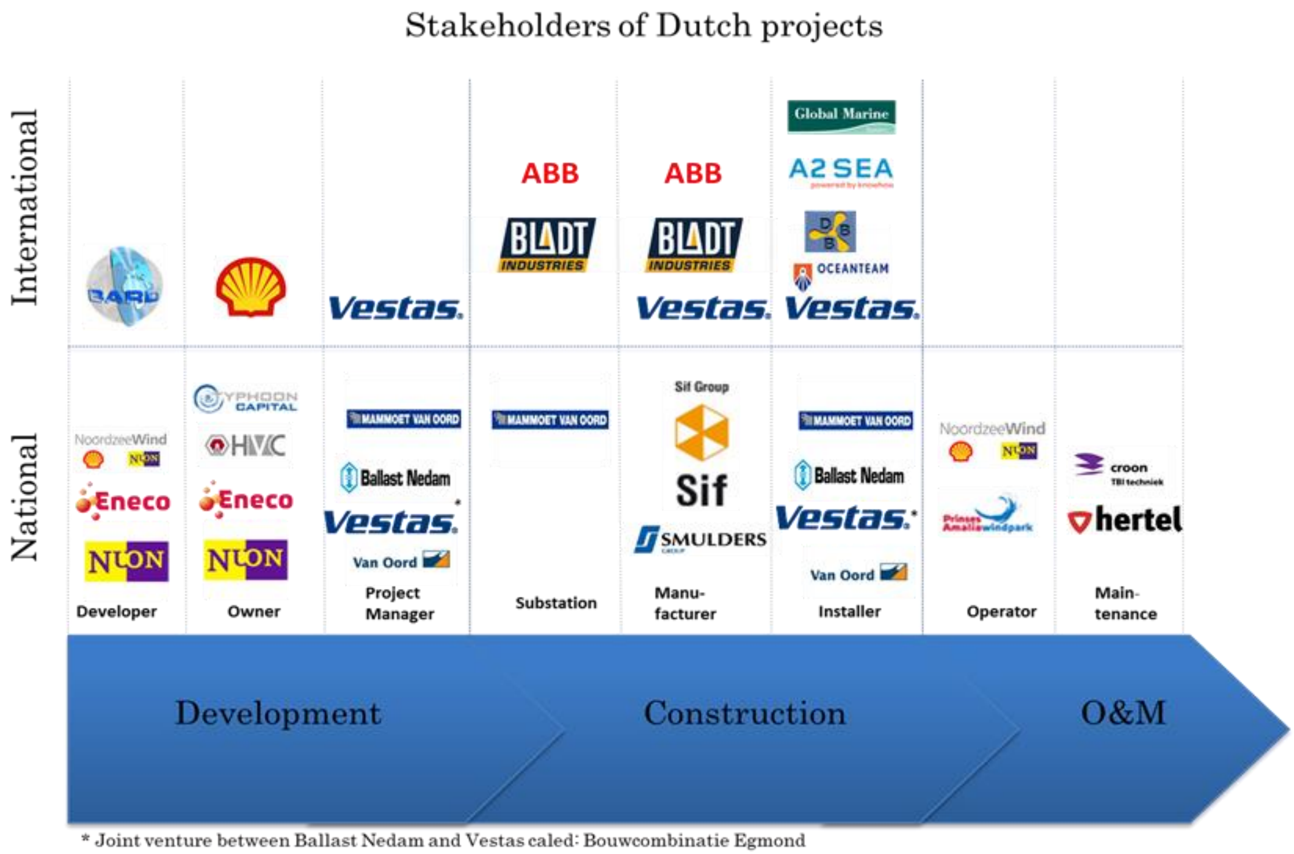

Figure 3. Dutch and international actors involved in the Dutch projects along the value chain.

Development stage

All four domestic wind farms[35] have been developed and are mainly owned either by the Dutch utility companies Nuon and Eneco (earlier in cooperation with Econcern who went bankrupt), or by the Nordzeewind[36] which is a joint venture between Nuon and oil company Shell (Figure 3). Nuon and Eneco are leading energy companies that supply electricity, gas, heat and auxiliary services to customers in the Netherlands and Belgium. Shell is one of the world's largest energy suppliers, with customers in more than 140 countries. All the companies have the necessary expertise and experience to develop, build and manage the offshore wind farms successfully. Nuon and Eneco have expanded their offshore wind activities to foreign markets and next to the other Dutch organisations such as SHV (green utility), Rabobank, PGGM (pension administrator), Meewind (investment company), Blue H (wind farms developer) and Shell became shareholders of many international projects (see Figure 2). Typhoon capital

[35] Egmond aan Zee, Amalia Park, Irene Vorrink, Lely (see also subsection 2.4.2 Physical infrastructure)
[36] NoordzeeWind has been set up specifically for the development, construction and management of the Egmond aan Zee Offshore Wind Farm.

(independent green investment company) and Dutch utility HVC bought stakes in the two upcoming Bard-offshore wind farms making it fully Dutch owned [37].

Project management is mainly done by Mammoet van Oord, Ballast Nedam, Van Oord and Bouwcombinatie Egmond for both Dutch and international wind farms. Seaway Heavy Lifting is the only Dutch company that manages international projects (see Figure 21).

Construction stage

The start of the offshore wind farm construction requires the installation of an offshore substation that transforms the power generated by the wind turbines and exports it to the national grid through a transmission/export cable. The only Dutch specialist that has been involved in the installation of the substations for the Dutch wind farms is Mammoet van Oord (Figure 3). The following stage is installation of mono-piles, mostly cylindrical steel foundations which provide a base for the turbine towers and the assembly of the wind turbines. Next to the Danish manufacturer Bladt Industries, two Dutch companies Sif Group and Smulders Group (Figure 4) are widely known for their expertise in the foundations manufacturing. Two other Dutch foundation manufacturers: Blue H and HSM Offshore (not included in the figures) are also part of the Dutch system but only active abroad.

Figure 4. Manufacturers of cabling, foundations and turbines for the Dutch wind farms

[37] http://www.offshorewind.biz/2011/08/30/typhoon-offshore-and-hvc-acquire-600mw-offshore-wind-farm-from-bard-denmark/ accessed 30 dec 2011

As figure 4 shows only one Dutch company the NedWind provided the wind turbines for the existing national projects (in fact only for the first project Lely). Most of the turbines for the wind farms in the Netherlands come from the Danish Nordtank and Vestas. Furthermore, none of the Dutch firms manufactures cables. These are being brought to the Netherlands from Italy (Prysmian) and from Sweden (ABB). Cabling of the Dutch farms, however, is executed by the Dutch Van Oord (see Figure 5). Figure 4 shows another Dutch cabling installer VSMC but this firm in 2011 operateed only abroad.

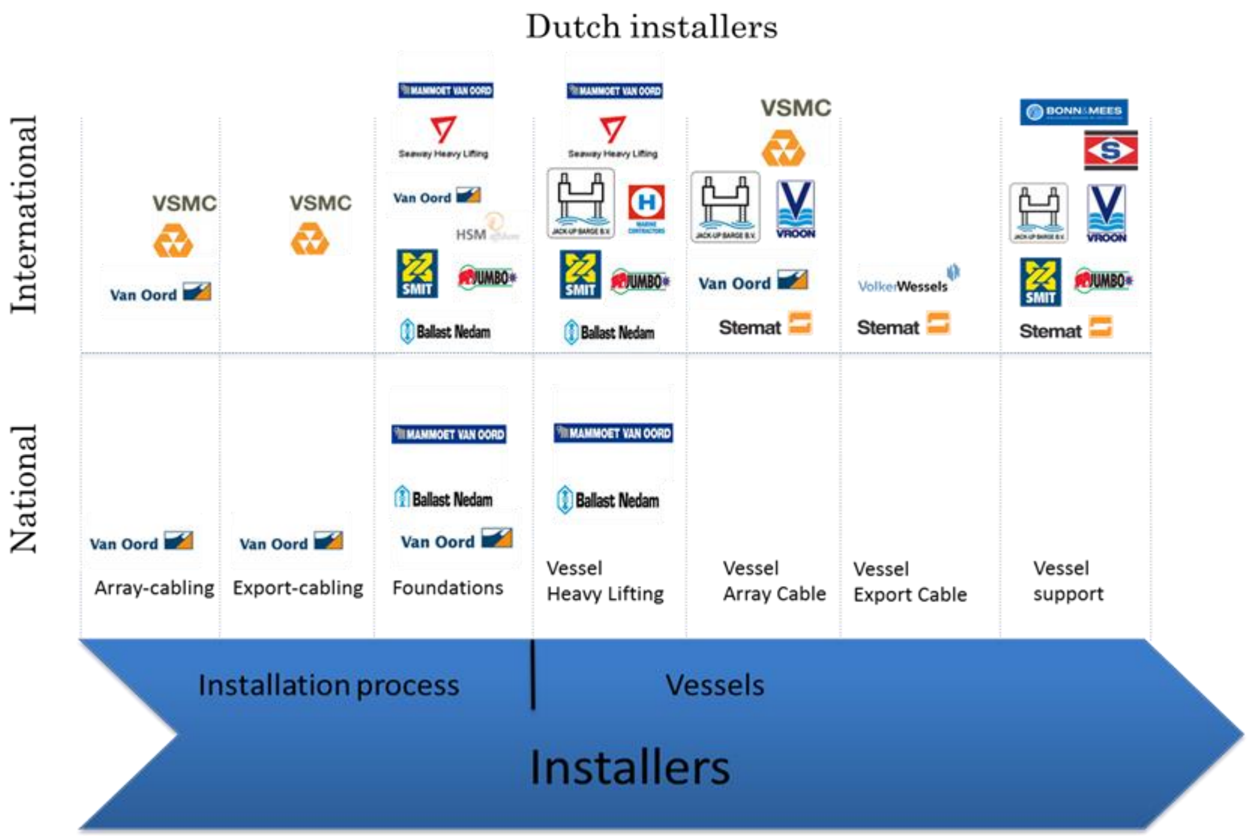

Figure 5. Dutch installers in (inter)national projects

Installation of a substation and mono-piles as well as lying of the export cables, each requires specialised vessels. Figure 5 gives an overview of a great number of Dutch vessel companies. However, except for Ballast Nedam and Mammoet van Oord, all of them are working on international projects. These are: JUMBO, Jack-up Barge BV, Seaway Heavy Lifting, Marine Contractors, Smit, VSMC, Semat, VolkerWessels, Vroon, S, Bonn&Mees.

What is also noticeable is that despite significant experience Dutch firms providing vessels and installing cables are not first in the world in terms of a number of projects they operated[38] (see Figure 6).

[38] All data concern finished projects.

Operation and maintenance stage

Noordzeewind (JV of Nuon and Shell) and Eneco are main operators of the Dutch farms (Figure 2). Croon TBI Techniek (the biggest and most experienced Dutch electro-technique company) and Hertel (a global industrial services company with locations around the world) perform maintenance of all the Dutch wind farms. Stemat and Smit (service companies for the maritime sector), maintain only international wind farms.

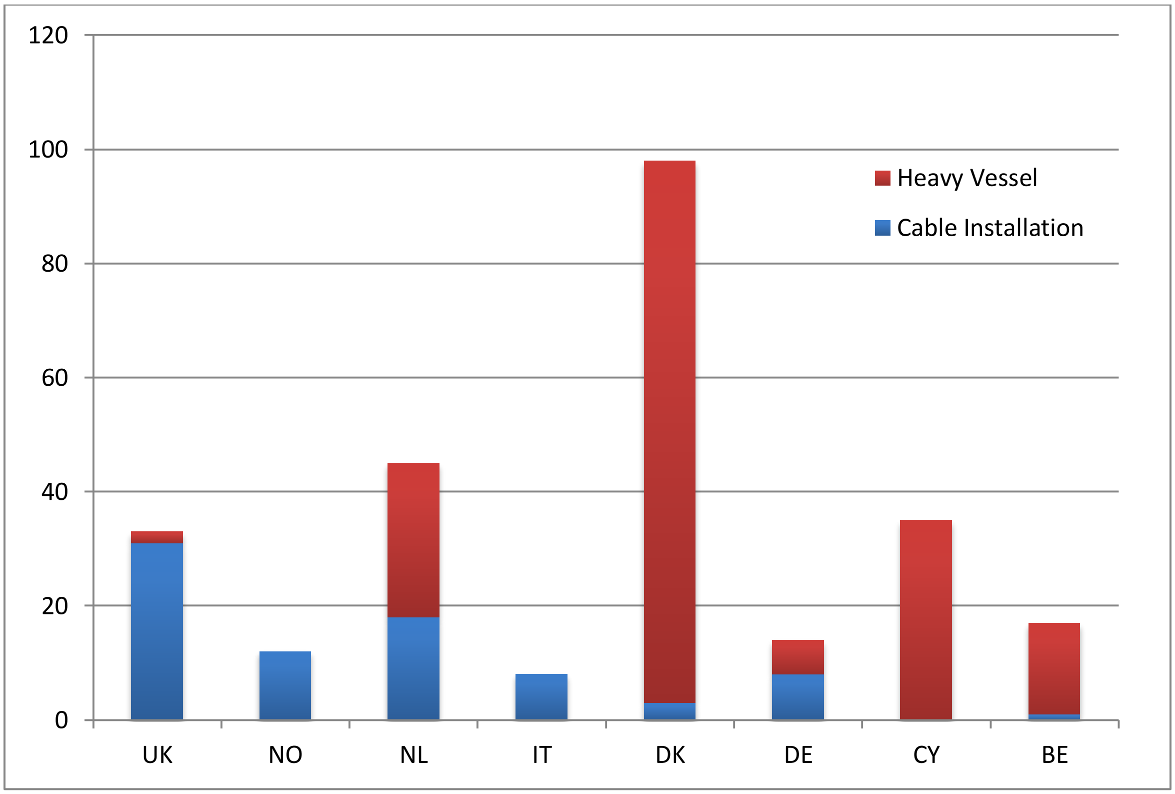

Figure 6. Number of heavy vessel and cable installation projects per country

4.1.5. Support organisations

Support organisations are all organisations that are not covered by the above actor categories but that in some capacity do contribute to the development of the TIS. These are legal organisations, financial organisations/banks, intermediaries, knowledge brokers and consultancies.

Dutch consultancies most active in the offshore wind both domestically and internationally include: Ecofys, Grontmij, Kema and Mecal. International consultancies that also participate in the Dutch projects are: Swiss SGS (the world's leading inspection, verification, testing, and certification company), Swedish NIRAS (an international, multidisciplinary consultancy company), British renewables consultancy PMSS, British Mott Mac Donald (global engineering and development consultancy) and Norwegian DNV (global provider of services for managing risk).

Financial organisations providing funds for the Dutch wind farms are of different kinds. While utilities often finance their own projects, autonomous project developers acquire funds from banks and investment companies. In case of the Netherlands all existing projects are owned by the Dutch utilities (Figure 2) with shares of other organisations. For example the Eneco owned Princes Amalia wind park was co-funded by: Rabobank, Dexia Bank, BNP Paribas and Danish state-owned enterprise EKF (Eksport Kredit Fonden)(PrincesAmaliaWindPark, 2011[39]). The Egmond aan Zee wind park was financed by Nuon and Shell using internal funds but its construction costs were supported by the governmental grant. The upcoming in 2012 Bard-offshore wind farms have been co-financed by Meewind and in 2011 stakes in Bard have been bought by the Typhoon Capital (a green investment company) and Alkmaar based utility HVC. Dutch organisations are also often funders of international projects. For example ASN bank (ASN Bank, 2011[40]) and Meewind invest in the Belgian Belwind wind farm (Meewind, 2011[41]) while a company jointly owned by the Dutch pension administrator PGGM and Ampère Equity Fund (managed by Triodos Investment Management Bank) is a co-founder of the Walney Offshore Windfarms Limited in the UK (Dong Energy, 2011[42]). In 2011 many banks due to the financial crisis reduced their renewable energy funds (Rabobank interview).

There are no specific legal organisations devoted to the offshore wind in the Netherlands. Each company deals with their own legal issues while for the wind farms these are the project developers who are responsible for acquiring all permits and assessments and for ensuring legal compliance of the farms construction.

4.2. Networks

While the presence and the capacities to innovate of various actors are very important for the functioning of the TIS, its development is also dependent on the interactions and cooperation between the actors. These may take place at various levels: within actors groups (for example among scientists only), among actors' groups (e.g. university-industry collaborations) or across the entire system. The interactions may also be formalised into networks or remain informal bi-, trilateral collaborations. In the following paragraphs we identify the most significant formalised collaborations across the entire Dutch offshore wind system: knowledge production networks, lobby networks and value chain networks.

4.2.1. Knowledge production networks

Knowledge production networks were be mapped by means of: journal publications and CORDIS project collaborations till 2011. This section also includes national collaboration projects in the field of offshore wind.

[39] http://www.prinsesamaliawindpark.eu/nl accessed 30 dec 2011
[40] http://www.asnbank.nl/ accessed 30 dec 2011
[41] http://www.meewind.nl accessed 30 dec 2011
[42] http://www.dongenergy.com/walney/about_dongenergy/pages/who%20we%20are.aspx accessed 30 dec 2011

Journal publications

Journal publications as archived in the Web of Science from Thomson Scientific in the form of the *Science Citation Index* are not only useful to identifying main national knowledge producers (see subsection 1.1.2) but they are also a good source of information on their R&D collaborations.

Collaborations in the Dutch offshore wind innovation system, as indicated by co-authored publications, remain relatively sparse. Furthermore, insofar collaborations in knowledge production exist; a strong geographical bias is visible. Collaborations overwhelmingly take place over short distances, with most co-authorship within the country. Co-author networks suggest that university-industry collaborations are relatively rare. In the Netherlands the main offshore wind knowledge institute TU Delft visibly dominates the field but is mainly collaborating with other Dutch institutes, ECN being most important. There is hardly any international collaboration in The Netherlands (see Table 3).

Table 3. Dutch collaborators of the TU Delft on journal publications

Organization	Co-author organization	Country	No of co-authored papers
TU Delft	TU Delft	Netherlands	44
TU Delft	ECN	Netherlands	6
TU Delft	Eindhoven University of Technology	Netherlands	3
TU Delft	Cranfield University	UK	2
TU Delft	University Durham	UK	2
TU Delft	TenneT	Netherlands	2

There is also dynamic internal TU Delft collaboration. Section Wind Energy of TU Delft co-operates with several other sections of the faculty of Aerospace Engineering where it is based. The section has research projects together with the faculty of Mechanical Engineering (control), Civil Engineering (offshore technology), Electro-technical Engineering (grid issues, electric conversion) and Technology, Policy and Management (scenario development for offshore wind power).

European research projects

CORDIS, the Community Research and Development Information Service for Science, Research and Development, is the official source of information on the framework programmes. It offers interactive web facilities that link together researchers, policymakers, managers and key players in the field of research. This data permit a detailed assessment of the collaborations among institutions within the fields under study and its growth over time.

In general, Dutch organizations are substantially involved in the European project collaborations. Figure 7 presents a collaboration network of organisations aggregated on country level. The Netherlands is fourth country following UK, Denmark and Germany. Again TU Delft and ECN as shown on Figure 8 dominate the European research project collaborations.

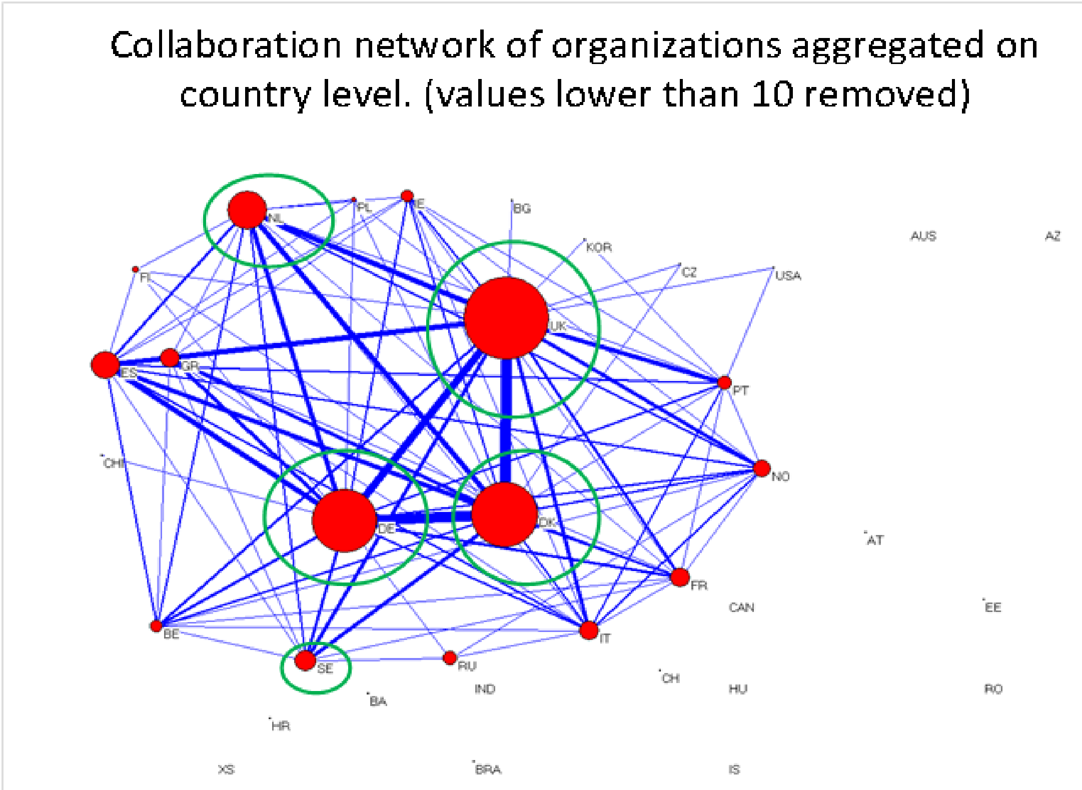

Figure 7. Collaboration network of organisations aggregated on country level till 2011

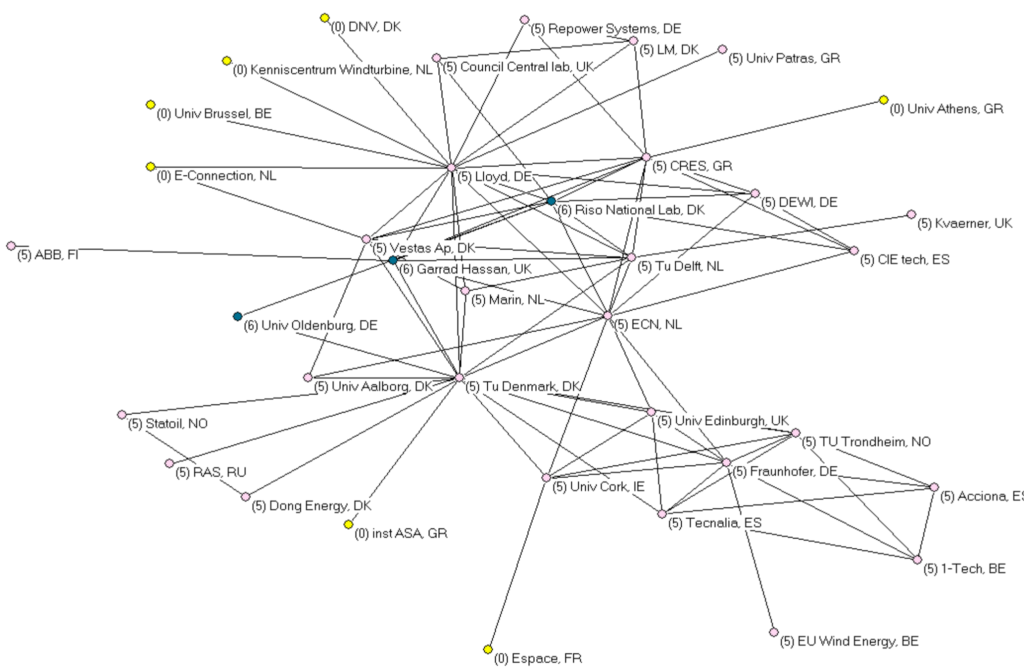

Figure 8. The core of CORDIS collaboration network till 2011 (values lower than 3 removed, all unconnected nodes are not shown).

There are more project- than scientific- cooperation but still this is not at a very high level. Table 4 shows main Dutch participants in CORDIS project collaborations. In addition to the main organizations involved in journal publications, there is a large number of companies and research organizations that do not publish. A few of them include: Hollandia-Kloos NV, Oceanographic Company BV, Royal Netherlands Meteorological Institute, or Mammoet Europe BV.

Table 4. CORDIS project collaborations

Organisation	Origin	Country	Number of projects participated in
TECHNISCHE UNIV DELFT	Delft	NL	11
ENERGY RESEARCH CENTRE OF THE NETHERLANDS	Petten	NL	10
E-CONNECTION PROJECT B.V.	Bunnik	NL	4
STICHTING WATERLOOPKUNDIG LABORATORIUM	Delft	NL	4
ECOFYS NETHERLANDS BV	Utrecht	NL	4
MARITIME RESEARCH INSTITUTE NETHERLANDS	Wageningen	NL	3
KEMA NEDERLAND BV	Arnhem	NL	3
POLYMARIN BEHEER BV	Medemblik	NL	2
STICHTING KENNISCENTRUM WINDTURBINE MATERIALEN EN CONSTRUCTIES	Wieringerwerf	NL	2
LAGERWEY WINDTURBINE B.V.	Barneveld	NL	2
VOLKER STEVIN OFFSHORE B.V.	Woerden	NL	2

4.2.2. Other networks

Far and Large Offshore Wind (FLOW)

FLOW is an innovative university-industry collaboration (follow up of the We@Sea programme) aimed at combination of research and development with a far-offshore demonstration farm. Its objective is to develop technology and skills needed for economically viable far-offshore wind energy to reach 6,000 MW by 2020. The first step is to build a 100-300 MW far-offshore demonstration farm with 20 to 60 turbines and make them operational in 2013. The consortium running the initiative is made up of companies and knowledge institutions: Essent , Eneco , TenneT, Ballast Nedam, Van Oord, IHC Merwede, 2-B Energy, XEMC Darwind, ECN and Delft University of Technology. The initiative was awarded €23.5 mln subsidy by the (previous) government. The budget is earmarked for the first (four-year long) phase of the project. This phase includes R&D of efficient wind turbines in the North Sea, innovative foundation concepts, installation techniques for wind farms at a greater water depth and at a greater distance offshore, control technologies, and maintenance strategies. The connection of these wind farms to the power grid also forms part of the project (FLOW, 2011[43])

The Netherlands Wind Energy Association (NWEA)

NWEA is an important offshore wind lobby network in the Netherlands is. NWEA is the Dutch voice of the wind industry. It is actively promoting the utilisation of wind power in the Netherlands, on land and

[43] http://flow-offshore.nl/images/2011-08/flow_samenvatting.pdf

offshore. Among the members of NWEA are developers of wind parks, owners of wind turbines, manufacturers, constructors, research institutes, electricity providers, consultants and maintenance companies. The activities of NWEA are aimed mainly at the national government (NWEA, 2012[44]).

North Seas Countries' Offshore Grid Initiative

The North Seas Countries' Offshore Grid Initiative started with the Political Declaration (Memorandum of understanding MoU) signed by the Ministers of the nine North Seas Countries on December 7, 2010. The Ministry of Economic Affairs of the former government participated in this initiative on behalf of the Netherlands. The objective of the initiative is to achieve a coordinated effort in the development of offshore electricity infrastructure and a compatible political and regulatory basis for long-term development of offshore electricity infrastructure, involving all relevant stakeholders (AgentschapNL, 2012[45]).

Dutch Maritime Network

There is a very good collaboration across the entire value chain. Green Deal (see next section on institutions 4.3) is one of the most positive outcomes of this cooperation. As shown on Figures 2 and 3 above the Dutch companies cooperate on a number of national and international offshore projects. An example of a Dutch value chain collaboration is the Dutch Maritime Network. DMN was founded in 1997 after the successful launch of the new Dutch shipping legislation. It consists of a number of industries including: automotive, ports, shipbuilding, offshore, inland waterways, dredging, Royal Navy, water sports and fishing industry. The objective of this foundation is to strengthen and promote Dutch Maritime Cluster (Dutch Maritime Network, 2012[46]).

4.3. Institutions

Institutions encompass a set of common habits, routines and shared concepts used by humans in repetitive situations organised by rules, norms and strategies (Crawford and Ostrom, 1995). Institutional set-ups and capacities are determined by their spatial, socio-cultural and historical specificity and are different from organisations (such as firms, universities, state bodies, etc). Their presence and good functioning is necessary for proper performance of every TIS. In the following paragraphs we outline the institutions applicable to the Dutch offshore wind TIS.

4.3.1. Renewable energy target

In the Clean and Efficient Programme of the government led by Prime Minister Balkenende (fourth period 2007-2010), the Dutch aimed for 20% renewable energy in 2020 as a share of total *primary* energy use. In the programme an indicative 6 GW offshore wind was announced as a means to achieve this target. Parallel to the Clean and Efficient Programme, the Climate an Energy Package of the European Commission was adopted by the European Parliament and the Council. The Renewable Energy

[44] http://www.nwea.nl accessed 9 Jan 2012
[45] http://www.agentschapnl.nl/programmas-regelingen/electricity-grid-and-integration accessed 9 January 2012
[46] http://www.dutch-maritime-network.nl accessed 9 January 2012

Directive (part of the Package) set binding targets for each Member State in order to contribute to the overall EU27 2020 target of 20% renewable energy as a share of *final* energy production. For the Netherlands the target is 14%. It should be noted that this 14% target is comparable to the 20% target of Balkenende IV as long as the emphasis in meeting the target is on renewable electricity. This is explained by the different definitions used for the national target (a percentage of primary energy use) and the target set by the EU (a percentage of final energy use). In the European definition the weight of renewable electricity is the same as the weight of renewable heat or transport fuel, whereas in the national definition each kWh of renewable electricity contributes around 2.5 kWh to the renewable target whereas for heat and transport the weighing factor is close to one.

In 2010 the Netherlands submitted their first National Renewable Energy Action Plan (NREAP), a reporting obligation under the Renewable Energy Directive. In this NREAP 5.2 GW of offshore wind was announced in the basket of renewable energy options in order to achieve the 14% target. The Dutch NREAP has been prepared in the final period of the Balkenende IV Government and is highly consistent with the earlier projections how to realize the renewable energy target set in the Clean and Efficient Programme, i.e. a strong focus on renewable electricity. The new government of Prime Minister Mark Rutte cancelled the Clean & Efficient Programme, not only with respect to the 20% renewable target but also regarding the -30% GHG reduction target, and committed itself to the (binding) targets set by the European Commission. Consequently, the new government recognized the stronger weight of renewable heat in the European context and moved their focus from relatively expensive electricity options such as offshore wind to more cheaper renewable options (at least per kWh of final energy produced) such as biogas and geothermal heat.

The current government (2011) is considering a renewable electricity obligation on electricity suppliers (starting in 2015) in order to realize the 14% renewable energy target. It is expected that 35% renewable electricity is needed for meeting the target (i.e. electricity should over-deliver compared to heat and transport fuels) and studies show that offshore wind is a crucial element in achieving 35% renewable electricity, being not (yet) recognized by the government.

4.3.2. Subsidy

For offshore wind two subsidy instruments are currently available: a stimulation regulation for renewable energy (SDE+), from 1 July 2011 and an investment deduction scheme.

The SDE+ regulation is the follow up regulation of the SDE regulation, which had followed up the earlier MEP regulation. Main difference between the MEP and the SDE is that the MEP only focused on renewable electricity, whereas the SDE also includes renewable gas and heat, and the MEP subsidy was fixed for a certain period, whereas the SDE subsidy (a premium tariff) during the fifteen year period is adjusted for fluctuations in the gas and electricity price. The SDE subsidy is either granted based on the "first come, first served" principle or based on (cost-effective) ranking. The latter is also referred as tender procedure. The difference between SDE and SDE+ is that all renewable energy technologies need to compete for one (limited) budget, whereas in the SDE each technology got its own (limited) budget.

This implies that in the new situation offshore wind has to compete with lower cost renewable energy technologies.

The Prinses Amalia Wind Farm and the Egmond Wind Farm receive subsidy from the old MEP regulation. The three additional wind farms that are about to be constructed, have been granted €5.3 bln subsidy under the SDE regulation. After a tendering procedure early 2010, around €4.5 bln has been granted to the German company Bard for developing two projects (Zeeenergie and Buitengaats) in the North of the Netherlands (0.6GWe total) whereas the remaining budget has been granted to Eneco in November 2011 for realizing the Q10 project near Katwijk. In the ranking process a correction for the distance-to-shore was made in order to realize a level playing field for tendering projects. Note that both the subsidy for the Eneco project and the two Bard projects was the budget for offshore wind earmarked by the Balkenende IV government for the period 2008-2011. To make sure that the offshore wind energy projects will actually be realised, selected parties are obliged to sign an execution agreement including a EUR 20 million bank guarantee. The offshore wind parks should be taken into operation within five years after the subsidy decision has become final.

The decision of the Mark Rutte government to redesign the SDE to SDE+ puts a hold on new offshore wind projects in the Netherlands as offshore wind is not able to compete with cheaper renewable options such as biogas.

The investment deduction scheme EIA is another instrument that has been used to support the investment in offshore wind farms. With the EIA, companies can deduct 41.5% of the investment costs from their fiscal profit, which resembles an investment subsidy of around 10%. For 2012 the total EIA budget is set at €151 million (standing for around 1.5 billion euro of energy investments). The maximum investment sum which can be deducted in one year is 116 million euro. Only in case the project has not started up in that year, the part of the investment above 116 million euro can be taken to the next year.

4.3.3. Permits

In the Netherlands, companies that want to develop an offshore wind project need to be in possession of permit prior to applying for SDE+ subsidy. This means that currently a number of locations in the North Sea permits have been granted for companies that tendered for part of the €5.3 billion budget. In a relatively short time, the permits will not be valid anymore as the construction of the wind farms has not been started yet (due to a lack of new subsidies granted). It is important to realize that the companies involved spent a significant amount of money for getting these permits. This is different from other countries where locations for offshore wind parks are preset by the government, reducing a lot of pre-financing uncertainty for companies willing to develop an offshore wind park in competition. The Balkenende IV government recognized this and envisaged introducing concessions instead of the permitting system. However, with the fall of the government, these plans have been abandoned.

4.3.4. Green Deal offshore wind

On 3 October 2011 the Ministry of Economic Affairs, Agriculture an Innovation and the Netherlands Wind Energy Association (NWEA), on behalf of the wind sector (almost 50 companies), signed the Green

Deal Offshore Wind. In this Green Deal the main concerns are concrete initiatives and a better public-private cooperation. Key concepts in this Green Deal include a substantial cost reduction through innovation and policy changes, further experimental and shaping legislation. The goal is a strategic growth of the offshore wind market from the Netherlands, a strong home market and achieving climate goals (NWEA interview). The government will also have to clarify the issues around renovation of the grid in a way that it is able to accept new type of energy, clarify how the connection takes place and who is responsible for it (AgentschapNL, 2012[47]).

The government will also have to clarify the issues around renovation of the grid in a way that it is able to accept new type of energy (now mainly ACE, needed ACDC and grid stability), clarify how the connection takes place and who is responsible for it. How the Green Deal will develop is highly uncertain. Currently the TSOs – the Transmission System Operators are not obliged by law to make this connection which gives difficulties to project developers and causes serious delays.

4.3.5. Infrastructural policies

Institutional aspects of grid connection in the Netherlands are not fully regulated. The current division of tasks with regards to offshore wind discharge to the grid is very unclear. Similarly, the transmission connection is not regulated by law. Contrary to Denmark and Germany where national Transmission System Operator (TSO) is responsible for connecting farms to the grid, in the Netherlands TSO's are not obliged to connect to the grid. It is up to the project developers and companies to arrange and pay for the connection

There is no homogeneous regulatory framework on electricity trade and coordination of grid development across Europe.

4.4. Infrastructure

4.4.1. Knowledge infrastructure

Each TIS has a knowledge and a technological base, and key links and complementarities among products, knowledge and technologies, which greatly affect the creation, production and use of innovative products and services. Technological knowledge encompasses both tacit and codified elements, and is closely related to the problem solving activities of firms. Knowledge does not diffuse automatically and freely among firms, but it has to be absorbed by firms through their differential abilities accumulated over time.

Patent classifications can provide a good overview of the classes of technologies (and their trajectories) that are relevant for the analysed TIS, however, the Dutch are not a dominating player in that respect. Scientific publications are the second good indicator of knowledge infrastructure.

[47] http://www.agentschapnl.nl/programmas-regelingen/policy-offshore-wind-energy accessed 9 January 2012

The number of publications on offshore wind energy shows a steady increase in recent years. Before 1994 hardly any publications dealt with this theme (see Figure 9).

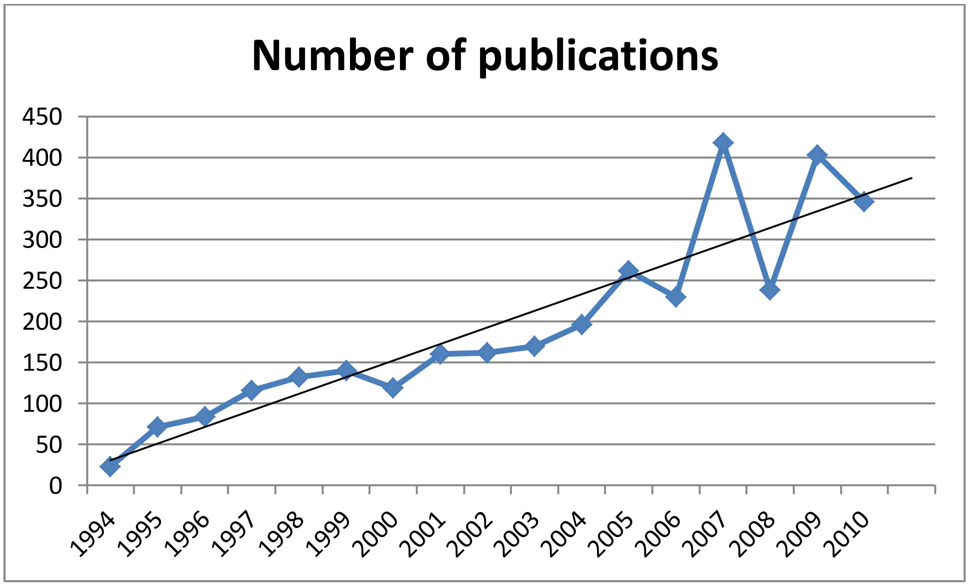

Figure 9. A number of publications on offshore wind energy worldwide.

Also the number of countries participating in knowledge production in the area of offshore wind energy shows a steady increase from a few in 1994 to well over 40 in 2010/11 and a number of journals involved in offshore wind energy is expanding rapidly from 23 in 1994 to 346 in 2010. Most knowledge production, however, is concentrated in Northwest-Europe and the USA. In the rest of the world, offshore wind knowledge production takes place predominantly in coastal regions. Table 5 below shows the most prolific countries in off shore wind knowledge production. The Netherlands ranks number 12 worldwide in terms of publications in the field of offshore wind.

According to experts engineering knowledge on substation and vessels is fully available, for turbines only academic knowledge. Experts also claim that the Dutch offshore wind knowledge is in very high international regard but in fact it does not translate to production capacity (de Vries, 2012.)

Table 5. Most important countries in an offshore wind knowledge production

COUNTRY	1994	1995	1996	1997	1998	1999	2000	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010	Grand Total
USA	28	54	76	81	107	81	80	132	134	145	147	182	140	159	104	189	145	**1984**
GERMANY	2	1	2	7	6	4	6	11	12	18	24	42	22	104	31	77	57	**426**
UK	0	6	8	11	17	27	24	18	25	15	13	24	56	69	21	60	57	**451**
CHINA		2			3	6	2	2	6	10	12	13	24	29	25	42	51	**227**
JAPAN		2	3	6	5	10	6	19	11	12	30	18	15	21	19	31	31	**239**
DENMARK		1	5	1	4	7	5	9	11	11	11	23	18	37	24	31	38	**236**
AUSTRALIA	3	7	3	11	3	15	9	8	8	8	19	9	24	20	8	37	12	**204**
CANADA		13	9	23	5	4	11	13	9	15	9	10	8	22	14	18	15	**198**
FRANCE		3	4	11	10	4	19	3	8	26	8	13	19	21	9	26	10	**194**
SPAIN		5	2	2	1	9	4	10	6	3	3	21	16	14	7	25	16	**144**
ITALY	1	5	4	3	2	8	3	6	6	9	9	11	11	12	7	20	25	**142**
NETHERLANDS		4	3	3	6	7	7	5	7	6	6	12	12	18	7	20	17	**140**
INDIA		2	8	5	3	2	5	2	4	3	2	7	12	4	14	13	15	**101**
NORWAY		3	1	2	2	4	2	3	2	2	6	9	7	8	5	17	20	**93**
SWEDEN	2		3	1	1	1	2	3	7	3	6	6	6	11	1	12	9	**74**
Chile					1		3	5	13	2	14	6	4	9		4	6	**67**
TAIWAN			1		2	1	2	3	2	6	3	4		7	3	7	9	**50**
PORTUGAL			3	3	1			2	8	10	6	2	2	5	3	13	4	**62**
SOUTH KOREA				1					4	1	6		5	14	2	8	12	**53**
BRAZIL		2	1	1		4	1	2	2	1	5	7	4	3	8	3	6	**50**
NEW ZEALAND		4		1	2	5	5	5	2	4	4	6	1	4	2	1	7	**53**
RUSSIA			2	1	3	6	3	1	1	2	3			10	4	13	3	**52**
SOUTH AFRICA		1		1	6	1	5	1	5	2	3	6	2	2	1	8	4	**48**
MEXICO	1	1			1					5	4	7		9	1	3	6	**38**
ARGENTINA				3							7	8		3	5		8	**34**
GREECE			1		1	3	6	2		2			2			5	1	**23**
IRELAND		1	2		2			3	1		2	1	2	2	2	3	3	**24**
Grand Total	**40**	**126**	**148**	**189**	**200**	**218**	**216**	**281**	**300**	**333**	**382**	**474**	**419**	**637**	**352**	**746**	**620**	**5681**

Table 6 further shows that knowledge production is fairly concentrated in a small number of organisations. Research is not immediately connected to industry with very few companies involved in publications. That may suggest that the sources of technological opportunities in offshore wind energy are not related to major scientific breakthroughs at universities but may come from R&D carried out by companies. Reversely, no significant patenting activity comes from universities.

Table 6. Ranking of most prominent organisations worldwide publishing on offshore wind energy

Number of publications	Organization	COUNTRY
110	NOAA	USA
104	Oregon State Univ	USA
91	Woods Hole Oceanog Inst	USA
88	USN	USA
70	Univ Washington	USA
68	Riso Natl Lab	Denmark
60	Univ Calif San Diego	USA
57	Chinese Acad Sci	Peoples R China
57	Univ Miami	USA
44	Delft Univ Technol	Netherlands
43	Texas A&M Univ	USA
41	Univ Delaware	USA
38	Univ Concepcion	Chile
38	US Geol Survey	USA
38	Rutgers State Univ	USA
37	Louisiana State Univ	USA
37	Univ Hawaii Manoa	USA
34	Indian Inst Technol	India
33	Univ Aalborg	Denmark
32	Tech Univ Denmark	Denmark
30	N Carolina State Univ	USA
29	Fisheries & Oceans Canada	Canada
28	Univ Bremen	Germany

4.4.2. Physical infrastructure

The presence and sufficient capacity of physical infrastructure is very important for the development and functioning of every innovation system. Its lack or malfunctioning may have serious consequences for the functioning of the TIS. In this subsection we identify and analyse the Dutch wind turbines, wind farms, grid, harbours, vessels and foundations.

Wind turbines

As much as wind turbine technology is well developed for onshore applications, offshore technology is still a young industry and by many companies seen as risky. Currently works are being carried out by many companies abroad (Bard, Vestas, Siemens) on the development of over 5 MW wind turbines which are adjusted to offshore climatic conditions. The Dutch market has so far been served by these international establishments but there are two innovative start ups: Xemc-Darwind and 2-Be in the Netherlands that also try their chances in the field.

Wind parks

In 2011 there are four operational offshore wind parks in the Netherlands (see Table 7). Princes Amalia is 11th and Egmond aan Zee is 13th biggest in the world in terms of capacity.

Table. 7. Operational wind farms in the Netherlands in 2011

Wind farm	Capacity [MW]	Turbines	Location	Built year	Capital costs	Depth range	Distance to shore	Owner
Princess Amalia	120	60 × Vestas, V80-2MW	52°59′N 4°22′E	2008	€350m	19-24m	26km	Eneco
Egmond aan Zee (OWEZ)	108	36 × Vestas, V90-3MW	52°36′22″N 4°25′8″E	2008	€200m	15-18m	13km	Nuon, Shell
Irene Vorrink	17	28x Nordtank NTK600/43	52°35′53″N 5°35′20″E	1996	£19m	2-3m	1km	Nuon
Lely	2	4x Nedwind 500kW/41	52°47′49″N 5°7′8″E	1994	£4.4m	3-4m	0.8km	Nuon

In 2012 two Bard parks with 120 windmills of total capacity of 600MW are planned in the North Sea. In 2012/13 Eneco plans construction of a wind farm of around 120 MW capacity in block Q10 near Katwijk. The Q10 farm will also demonstrate new technologies to stimulate innovative building techniques (AgentschapNL, 2012[48].)

Harbours

Harbours are of vital importance for the offshore wind industry but they need to be specifically adopted (deep water quays, large storage facilitates, space for manoeuvre) to be able to serve offshore wind industry. The Dutch harbours, due to their direct access to North Sea as well as their experience and infrastructure developed for operating offshore gas and oil industry are particularly suitable for large logistical operations related with installation of wind parks. The Netherlands itself located among most important offshore wind countries: Denmark, Germany and the UK, is a top location for the offshore wind business.

The current situation with the Dutch harbour infrastructure is following: Eemshaven is important and presently used for German projects (Bard included) due to its specialised facilities and large deep access. Vlissingen – for the UK projects, Den Helder with experience and infrastructure already in place (for oil and gas) has the ambition to become the main harbour for maintenance of the offshore wind farms and logistics while Amsterdam and Rotterdam oppose projects close to their harbours. Figure 10 shows the Dutch harbours serving the offshore operations.

[48] http://www.agentschapnl.nl/programmas-regelingen/policy-offshore-wind-energy accessed 9 January 2012

Figure 10. Dutch harbours serving offshore operations

Grid

Europe's electricity grids were originally built to handle large centralized power plants rather than great amounts of distributed renewable generation such as that produced by offshore wind farms. The grid therefore (stability and capacity wise) is not ready for accepting bigger amounts of offshore wind energy. Compared to Germany, the Netherlands, except for Noord Holland province has a good grid infrastructure. Germany builds farms where the population density is low so there is also little grid development. In UK the grid is very poor so both countries have bigger problem than the Netherlands. In the Netherlands the issue is therefore down to the connection of the turbine to the grid. So within the countries there is a need for reinforcement and between the countries for much more interconnectors, otherwise the European grid is obsolete to accept the bigger amounts of energy from renewables.

The Dutch national Transmission System Operator is TenneT BV. It is also Europe's first cross-border electricity transmission operator. A significant section of TenneT's high-voltage grid borders on the North Sea in both the Netherlands and Germany. Two connections for offshore wind farms have already been completed in the German section of the North Sea and work is underway on three more wind farms. In addition, the Dutch electricity grid is linked to Norway by means of an undersea cable link (NorNed) and to the United Kingdom (BritNed cable). There are also plans for new undersea cables to Norway (NorNed2 and NORD.LINK) and Denmark (COBRA cable). These interconnections will play an important part in the further development and integration of wind energy and the promotion of market integration.

At the end of 2011, the European Commission has made an innovation grant of €3 mln towards the development of a program to warrant European grid security in the future. Together with a number of TSOs and universities involved, TenneT is responsible for this project. The program is aimed at integrating the growing share of sustainable electricity into the grid and at managing the increasing cross-border electricity flows (Tennet, 2011[49]).

Vessels and foundations

Despite a good number of vessel companies and foundation manufacturers in the Netherlands, the availability of foundation adjusted to deep waters and specialised vessels that can work far-offshore could become a major constraint in the Netherlands in case new government decides to reach the earlier formulated ambitions. Bigger companies such as Van Oord purchase new vessels to increase their competitiveness, smaller firms such as SFV subcontract other firms who own vessels or they borrow specific type of vessels to accomplish their contracts. Hiring of vessels however is not always cost effective so many contracts are refused due to too high costs. Due to quality issues and despite high costs, European contractors tend to order vessels in Europe (Van Oord, 2011).

4.4.3. Financial infrastructure

Availability of financial infrastructure is another element important for the development of every innovation system. The funds are needed for R&D activities and for investment.

Investment funds

So far in the Netherlands the existing wind parks have been financed at the level of:

1. €350 mln for Princess Amalia
2. €200 mln for Egmond aan Zee (OWEZ)
3. £19 mln for Irene Vorrink and
4. £4.4 mln Lely (see also Table 6 above)[50].

The Prinses Amalia Wind Farm and the Egmond Wind Farm receive subsidy from the old MEP regulation.

The three additional wind farms that are about to be constructed, have been granted a €5.3bln subsidy under the SDE regulation (see earlier section on institutions). A major share of the funds (€4.5 bln) has been allocated for the two Bard initiatives (120 windmills, amount to a total of 600 MW). The remaining has been granted to Eneco for the development of a wind farm of around 120 MW capacity in block Q10 near Katwijk. (AgentschapNL, 2012[51].)

[49] www.tennet.org, accessed 30 dec 2011
[50] http://en.wikipedia.org/wiki/OWEZ accessed 30 dec 2011
[51] http://www.agentschapnl.nl/programmas-regelingen/policy-offshore-wind-energy accessed 9 jan 2012

Big portion of funds for realisation of the existing offshore wind projects came from the owners of the farms: Nuon, Shell and Eneco and from banks such as Rabobank, Dexia (now closed down) or Fortis. The banks have dedicated renewable energy investment funds through which they co-funded the parks.

A note needs to be made that in the Netherlands much of the financial resources is being spent on various types of evaluations and impact assessment before the farm gets a permit. These expenditures are not included in the capital costs per wind park above. Given that 4/5th of the applications are turned down, the funds used for permits and evaluations are lost. For comparison, in UK the evaluations are done after permits are granted, which results in a greater number of realised projects (see Figure 11).

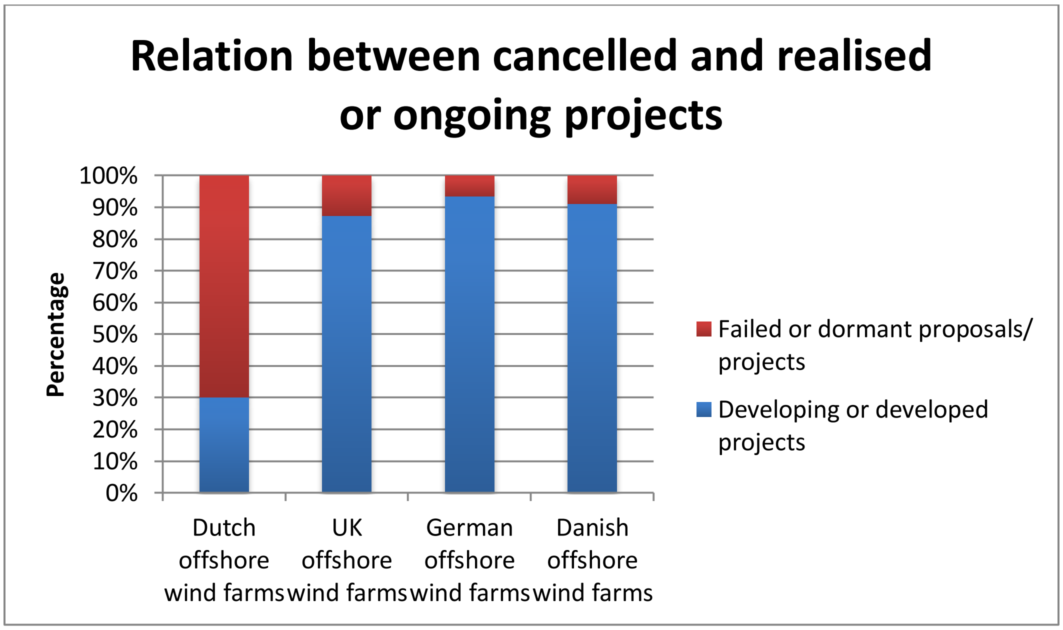

Figure 11. Relation between cancelled and realised or ongoing projects in the Netherlands compared with German, UK and Denmark

R&D funds

The largest R&D investment in 2010/11 was an awarded of €23.5 mln subsidy to the innovation project Far and Large Offshore Wind (FLOW). This grant was still the decision of the earlier government.

In 2011 after the Green Deal was signed €1.4 mln is planned as a contribution to the Knowledge Center Offshore Wind in Den Helder.

At the European level as shown in Section 2.2 (Networks) the Dutch knowledge institutes and companies are among 4 most important collaborators on R&D projects. Examples of such projects include: Seanergy 2020, Twenties or Top Wind (EWEA, 2012[52]). They are mostly funded by the 7th Framework Program (FPU) of EU at the level of several mln € each.

[52] http://www.ewea.org/?id=12 accessed 9 January 2012

In the situation of current national budgetary cuts on the offshore wind activities, 7th FPU will be the major source of funds for the Dutch research activities.

5. Functional analysis

In this section a set of seven system functions is used to evaluate the dynamics of the Dutch offshore wind TIS at the end of 2011. Over 30 stakeholders' interviews served as a main source of evaluation information (see Appendix A). The actors were asked to evaluate specific functions by means of scale between 1-5 (very weak-very strong) and following a set of diagnostic questions (Appendix B).

5.1. Functional dynamics in 2010-2011

Overall, although the period of 2010-2011 was not very stimulating for the Dutch offshore wind industry, there have been many activities and the field has been quite dynamic in the Netherlands. Next to positive developments, there are also several negative ones. The positive developments are in the field of knowledge development (F2), entrepreneurial activities (F1) and lobbying (F7). The negative ones are related with the negative guidance of the search (F4) caused by unfavourable political and financial conditions, in particular change of the government and the political direction in 2010; as well as poor home market (F5).

Figure 12 gives an overview of system function fulfilment as judged by the interviewees. The high level of entrepreneurial activities (F1) can be explained by the recent developments in the area of harbour infrastructure, in construction business (vessels, foundations) and contribution of Dutch companies to projects abroad. In the Netherlands itself no new parks are being constructed. There are three wind parks expected in 2012/13 (two of Bard and Q10 by Eneco) but they were the decision of the earlier cabinet. The uncertainty and indecisiveness of the current government provides a rather strong negative guidance of the search (F4), which makes many of the Dutch companies move abroad with their activities. The financial crisis makes it further worse because the governments 'concerns are now more with the budgetary savings. Some knowledge creation and diffusion (F2 and F3) can be observed over time (with two major offshore wind conferences in both years). The new knowledge is developed in the construction field and often relates to cost saving measures. Market formation (F5) is stimulated mainly by the developments in Europe (mainly the UK, Belgian and German projects), in which the Dutch companies were involved. There is a rather poor market formation in the country itself. Poor are also financial resources (F6). Despite these unfavourable conditions, however, the functional analysis in 2010/11 shows very strong and growing lobby activities (F7). Particularly the Green Deal closed between 50 companies and the government in October 2011 gives actors hope that one day the Dutch offshore wind market will get a green light. In the following subsections we discuss each of the functions in more detail.

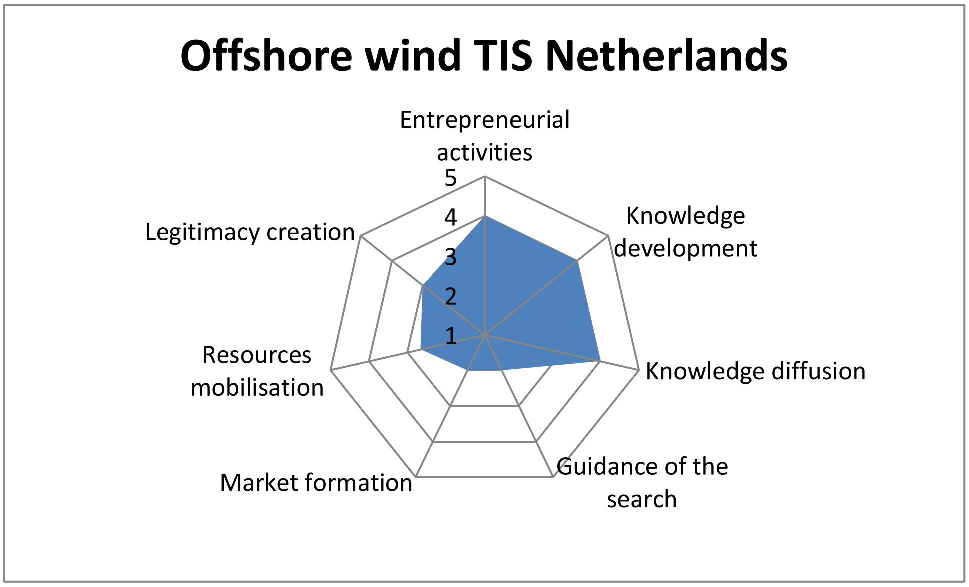

Figure 12. Overview of system function fulfilment in 2011

5.2. Entrepreneurial experimentation (F1)

No innovation system can exist without entrepreneurs. Their role is to turn knowledge into concrete action that generates new business opportunities and value to their societies. Entrepreneurs can be new entrants seeking business opportunities or incumbent companies diversifying their activities to realise new business prospects. To evaluate the entrepreneurial experimentation in the Dutch offshore wind TIS a number and the type of actors involved in experimentation (incumbent vs. start ups) was studied as well as the number and type of activities of these actors, such as involvement in national versus international projects, specialization along the value chain or focus on large scale production.

The structural analysis shows that larger incumbent companies such as Sif, Smulders, Ballast Nedam, Mamoet Van Oord, Jumbo, etc. dominate the value chain (Figures 2-4). Analysis of their entrepreneurial activity (see Box 1 for selected examples) further shows that the incumbents are major contributors to the entrepreneurial experimentation. These established offshore construction firms diversified their activities to offshore wind and are leading entrepreneurs on a European scale. This type of companies accelerate the system development, are less vulnerable to changing political winds in the country, and are more stable financially. They also have the capacity to exercise a larger impact on the wind power lobby and, for instance, contribute to the mobilization of complementary resources for, among others, grid improvements. There are few new entrants in the Dutch value chain: one of them is Hareema.

Analysis of the technological character of the entrepreneurial activities reveals dominance of the Dutch companies in the construction business (in particular vessels, foundation and rising of wind farms) (see Box 1 for selected examples. 2012). These activities build on the extensive Dutch competences related to offshore activities. Very limited activity is taking place in the manufacturing of turbines, even though some start ups are present in the Netherlands (Ecofys, NWEA, 2011). However 2/3rd of the total national investments in the field goes to the construction work and $1/3^{rd}$ to placing of the foundations (so to business other than turbines) (VSF, 2011).

Analysis of entrepreneurial activities of the Dutch companies also demonstrates that the lion share of their business is based on developments outside of the Netherlands. They strongly relay on availability of markets and projects abroad (Ecofys, VSF, Van Oord, 2011). At the national level entrepreneurial activities suffer from the lack of political support. The changing renewable policy of consecutive cabinets results in unstable regulatory regimes and ineffective support programmes that fail to assist in achieving the ambitious goals (Ecofys, VSF, Rabobank, 2011) and that hinder the development of domestic market. Lack of domestic market further hampers involvement of particularly smaller companies who do not have access to international projects and does not allow to balance the dominance of strong incumbent firms in the value chain.

In the situation where countries, the UK in particular, decide to protect their national markets and increase the number of domestic actors in the national value chain – for the Netherlands this would imply a loss of an important market and a source of revenue. On the other hand, such a decision could put a substantial pressure on the Dutch government to consider development of the domestic market that could help avoid erosion of its own offshore wind industry that currently earns its bread abroad.

The function F1 entrepreneurial activities is therefore evaluated at the level of 4 (strong) mainly to acknowledge the Dutch entrepreneurial activities abroad in the absence of strong domestic market (see Figure 12).

Box 1. Selected examples of the Dutch entrepreneurial activities in 2011

- Consortium of Strukton and Hollandia worked on foundation of German Dan Tysk offshore wind project
- Van Oord invested in new vessel for installing offshore wind turbines
- The Dutch foundation manufacturer Smulders reached the level of 60% of all offshore wind foundations currently constructed in the North Sea
- Royal Doeksen invested €4mln in two maintenance vessels while Abis shipping built new vessels for transporting turbines
- Royal Haskoning, IHC Merwede, Ballast Nedam and Van Oord focused on the prospective French market but Smit Marine contracting resigned from investment in new vessels for cables because of uncertainty of governmental policies

5.3. Knowledge development (F2)

New knowledge and mechanisms of learning are prerequisites of every innovation system. There are different types of knowledge (codified/scientific, tacit/engineering) and various sources of new knowledge (R&D, learning by doing, learning by searching, etc.). To evaluate this function the number and the type of actors involved in the knowledge development (knowledge institutes vs. industrial parties), as well as the type of knowledge developed (number of patents, publications, specialization along the value chain, alignment of produced knowledge with needs, etc) were studied.

As structural analysis suggests, scientific knowledge production in the Netherlands is very strong and concentrated in a small number of institutes. With regards to the competencies of the organisations, as judged by their track record of published articles, the Dutch TU Delft ranks highest in terms of number of journal publications (44 publications) and is followed by ECN (16 publications) (see also Table 1). The Dutch knowledge institutes are known worldwide for their scientific expertise on offshore wind energy. They also rank high internationally (next to the Danish) in terms of the number of publications on offshore wind. TU Delft is 10th in the world (Web of Science, Thompson Scientific) and follows 6th Danish Risø (see also Table 4). The major focus of the Dutch knowledge institutes is wind turbine aerodynamics.

However, as shown elsewhere (Wieczorek et al., 2013), sources of technological innovations in offshore wind are not directly related with scientific breakthroughs at university. The real opportunities to innovate in offshore wind actually come from advancements in R&D equipment, infrastructure and operation of the wind farms. The Dutch knowledge institutes collaborate with national and international industry but this work does not translate into a factual manufacturing capacity in the country. There are no major wind turbine manufacturers. The Dutch industry rather specialises in construction of wind farms but it does not patent (VSF, Kema, 2011). This implies that the codified knowledge on offshore wind is not very well aligned with the actual industrial needs.

Furthermore, there are rather unfavourable R&D conditions caused by limited governmental commitment and resulting poor domestic offshore wind market. The poor market may lead the academic knowledge production to lose its competitive edge, as a consequence of hindered interaction with, and insufficient feedback from, commercial innovation activities.

Selected events confirming the dynamics of this function in the Netherlands are presented in Box 2. Based on this analysis the function F2 - knowledge development is evaluated at the level of strong (4) in the Netherlands (to acknowledge very strong academic position of the country) (see Figure 12).

Box 2. Selected examples of the Dutch knowledge development activities in 2011

- Measurement tower for experimental wind farm was placed at Callantsoog
- Offshore Ship Designers launched a new offshore wind farm maintenance vessel concept
- XEMC (former Darwind) begins testing of 5MW offshore turbine
- 14 PhD students at TU Delft financed (in 50%) by the government begin work on a large far offshore wind project (FLOW)
- Dutch institute finds a solution for monopile failures at offshore wind farms
- A two-year study at Dutch offshore wind farm Egmond aan Zee has revealed that marine life can benefit from the presence of offshore wind turbines

5.4. Knowledge diffusion (F3)

Knowledge exchange is essential for innovation and for the build-up of innovation systems. It takes place in the process of interaction. In emerging systems the interaction takes the form of bi- and tri-lateral collaborations. In more mature innovation systems like offshore wind, networks emerge and they play a key role in diffusion of knowledge in the system. To asses if there is enough knowledge exchanged between different actors' groups e.g. science and industry, or users and industry, and across geo borders in the Netherlands; we looked at the number and type of networks and tried to assess the general accessibility of knowledge. We complemented our findings on tacit knowledge diffusion with insights from qualitative research based on interviewing actors.

The analysis of different types of networks (section 4.2) demonstrates that knowledge networks based on collaboration on journal articles are not very extensive with most co-authorship within the country (TU Delft collaborating mostly with ECN) and poor involvement of industry. The engineering type of knowledge that motivates the offshore wind TIS is difficult to disseminate (VSF, Van Oord, RWE,Siemens, MPI, Kema, 2011). Companies, in fear of losing their competitive advantage, are not very eager to share their know-how (in e.g. scientific publications) (VSF, Dong DK, Dong UK, Rabobank, A2Sea, MPI, 2011; Eize de Vries, 2012). The collaborations on European research projects are more frequent than on journal articles and with a more substantial involvement by industry. The Netherlands emerge as most active collaborator on Europe research projects and has a strong national research network (such as Flow). The transfer of university knowledge to a specific context of application is particularly challenging in the Netherlands because of a strong academic culture and lack of domestic market which would allow for a more substantial and immediate application of this knowledge.

Given strong industrial collaborations at foreign wind farms, actors feel that when necessary, parties can easily find each other and gain access to foreign knowledge (MPI, JDR, RenewableUK, 4COffshore, KBR, PMSS, Typhoon Offshore, 2011). Informal sharing of knowledge is therefore more popular. A great number of international workshops and meetings provide only opportunities for the first contact, which then lead to tight market cooperation and effective knowledge transfer.

Universities in the Netherlands are valued for the number of specialised offshore courses, and they also provide industry with an easy access to good students who are then trained in-house and provided with hands-on experience. The courses however do not cover the demand for human resources. Box 3 presents selected knowledge diffusion activities in the Netherlands in 2011.

In view of this discussion, and taking into account the opinion of the interviewees, we conclude that there is a good offshore wind network that crosses national borders, even though connections with universities are mainly local. We assess the function F3 - knowledge diffusion as strong in the Netherlands (4) (see Figure 12).

Box 3. Selected examples of the Dutch knowledge diffusion events in 2011

- Professional training programme on offshore wind started in Den Helder (with TU Delft and ECN)
- Den Helder municipality expressed an ambition to develop a knowledge centre on offshore wind
- An EWEA 2011 conference on offshore wind took place in the Netherlands
- Powercluster project was funded by EU with the goal to learn from experiences of oil and gas industry
- Windpower Monthly created a special report examining European careers options in offshore wind sector, featuring exclusive research, individual case studies, courses and employer information
- Windpower Monthly launched Windpower Offshore, a free weekly email bulletin covering the latest news from the global offshore wind sector

5.5. Guidance of the search (F4)

Guidance of (or providing direction to) the search is a function that relates to all activities within innovation systems that can influence the visibility and clarity of the specific 'wants' among the users of technology. It can be fulfilled by industrial or governmental actors and provides a broad direction to the way in which financial resources are allocated. Assessment of the guidance of the search included evaluation of: the type of actors involved in offshore wind and their activities; impact of soft institutions (the level of governmental commitment, presence and reliability of policy goals and vision, expressed expectations) and influence of hard institutions (presence and quality of regulatory regimes, policy instruments and permitting procedure) were analysed.

Offshore wind is young and expensive technology compared to oil-based sources. Its commercial operation, therefore, strongly depends on political support (Rabobank, GL, Kema, EWEA, 2011) and national policies (Prassler and Schaechtele, 2012). Governmental commitment, its policy goals and visions about growth and technology design are important informal, soft types of institutions that have major impact on the guidance of the search. The national governments, however, are not always stable in their commitments (JDR, 2011). Particularly in the Netherlands, guidance of the search is very negatively evaluated by the interviewees (Ecofys, NWEA, Rabobank, Alstom, RWE, 2011; Verdong and Wetzels, 2012) while critics even point at the lost prime mover position of the Netherlands. Due to changing governmental renewable energy preferences and inconsistent stop-go support policy, the Netherlands is not an attractive offshore wind market (RWE, NWEA, 2011). The government is criticised for having no vision, no strategy and no stable framework (permitting) for any renewable activities in the country.

The analysis confirms that especially the current resources and renewable programs such as SDE regulation are neither sufficient to reach the CO_2 reduction targets nor the MW targets (with current crisis the price per MW makes the offshore wind power extremely expensive even compared to other renewables). The SDE scheme is based on a tendering procedure and it implies that offshore wind needs to compete with lower cost renewable technologies. This makes it unlikely that new offshore wind farms will be developed (except for the ones which were approved in previous tender rounds). Other regulations that are creating obstacles to development of offshore wind are non-harmonised rules on piling all across Europe (in the Netherlands they are shorter than anywhere else situating); upfront payment for all permits before acquiring consent to construct; bank guarantee needed to get SDE subsidy and decommissioning fee needed at the level of some €50 mln as a reserve for the decommissioning of the farm. The decommissioning fee is considered a true absurd for two reasons. Firstly, the other (coal or nuclear) plants are not obliged to pay it. Secondly, given the novelty of the technology, it is difficult to evaluate whether after 20 years of operation the wind farms will need to be broken down. Perhaps they can still operate after maintenance operations. These regulations makes offshore wind additionally expensive(Van Oord, 2012; FLOW, 2012; Vries,2012; Nuon/Vattenfall, 2012; Out-Smart, 2012).

Furthermore, the industrial, innovation and environmental policies are badly linked in the Netherlands. SDI and policy is directed towards technology that is cheapest and allows meeting 14% target and not the one that will help develop Dutch industry or will be environmentally beneficial in the long run. Introduction of offshore wind innovations in the Netherlands is very difficult because of the contracting procedure which costs time and is not flexible enough to include novelties that mostly need further adjustments. The reason is that such adjustments require modification of regulations and variation to original plans. These are, firstly, seen as too expensive and secondly only possible when there is a consortium of people who trust each other and manage to get out of the procedural hassle. This further requires confidence in the market and that is currently is missing (Van Oord, 2012; FLOW, 2012; Vries,2012; Nuon/Vattenfall, 2012; Out-Smart, 2012).

There is also in the Netherlands an idealistic approach to skipping stages of technological development and designing ultime turbine e.g. 20MW. Some therefore think that the best approach for the Netherlands would be to keep developing the prototypes and trading them. This approach makes the Netherlands lie much above the learning curve but does not translate to innovative products that are applied in the market. Industry holds back and uses smaller 7-8 MW turbines, which according to them are sufficient (Van Oord, 2012; FLOW, 2012; Vries,2012; Nuon/Vattenfall, 2012; Out-Smart, 2012) .

What makes the situation even more complicated is the presence of gas for another 26 years. There is, therefore, a lack of urgency on the part of the government to promote other energy sources. It would be the task for renewable lobby to convince the government. For the time being the country has moved its focus from electricity production to heat production, which makes it even more difficult to meet the 14%target because all subsidies went to geothermic projects and gas.

The lack of clarity about which parts of the North Sea will be allocated for wind farms further negatively influences the guidance of the search causing that not only Dutch companies are hindered to work domestically but also the international organisations cannot invest in the Dutch projects.

Among the signs that positively influence the direction of search are: the expectation of large markets and huge employment possibilities; observable increasing returns to scale (although scarcity of materials and transportation costs to far off shore still make it very expensive); the Green Deal; and the signing of the memorandum of understanding (MOU) by the ministers from 10 European countries (incl. the Netherlands) about the development of a European offshore grid. Also the industry, through its persistency and activities provides a strong guidance. The involvement of large offshore incumbents who diversify their business to offshore wind and a great number of SMEs ready to work in the offshore wind, drive the system development. The companies are also determined to wait for a new government and for a new stable subsidy scheme (Van Oord interview) because the system is yet too immature to function independently (Rabobank, KEM, 2011).

It can be concluded, therefore, that while the European goals provide a strong guidance for the offshore wind system development and there is a strong commitment on the part of Dutch industry, the direction given by the government, however, is non-existent. This function, guidance of the search (F4) is, therefore, evaluated as weak (2) (see Figure 12). Box 4 presents selected events influencing the Dutch guidance of the search

Box 4. Selected examples of the Dutch events influencing guidance of the search in 2011

- The industry (>50 companies) and the Dutch Wind Energy Association (NWEA) convinced the Dutch government to sign the Green Deal Offshore Wind Energy
- 5.2 GW ambition formulated in NREAP considered no longer objective for the Dutch government
- Dutch government was criticised for putting more emphasis on the operating support needed for the wind farms than on the benefits (employment) for industry/the country
- Dutch government considered a quota system for after 2015 but uncertainties arose as to whether the system would be designed in such a way (as the UK did) that offshore wind would get a chance
- Innovation Platform expressed an opinion that the Netherlands should focus on offshore wind (and biomass options and domestic heat conversion)
- Essent (RWE) moved away from offshore wind
- Industry urged government to join projects and support infrastructure to develop home market

5.6. Market formation (F5)

New technologies, sustainable in particular, need protected space to develop because they are often far from optimised and frequently have to compete with very efficient matured and cheaper incumbents solutions. Formation of a niche market with a set of supporting incentives is one of the possibilities. On the other hand, the formation of a market around such emerging technologies and systems is a sign that they are developing and acquire increased legitimacy. To evaluate market formation in the Netherlands, the size of the market (installed capacity, wind farms consented and planned) and the impact of supporting incentives were analysed.

The Dutch market is currently seen as too limited with no new farms under construction in 2011. Three large-capacity projects for a total 1.8 GW (Bard 1 and 2 and Q10), are consented and planned for 2012/13 but they were a decision of the previous government. The current government does not have any concrete plans after 2012. This is the main reason why many firms do projects abroad (Alstom; Van Oord, 2011). Other reasons include high costs, low reliability of technology (Rabobank, 2011), un-clarity with regards to regulatory framework and lack of consistent and continuous governmental support. In 2010/11 there were no new farms constructed and the current installed capacity in the Netherlands (around 250MW) is considered very little compared to the other European countries such as Denmark (850MW) (EWEA, 2011[53]). Deficiencies in physical infrastructure (like grid capacity, cabling or vessels and foundations availability) do not hinder the current market formation but, if not addressed, may become serious obstacles to its future expansion.

In Europe, however, offshore wind is considered a booming, billion euro business able to provide many jobs. The rationale to invest in offshore is because of limited onshore capacity (KEMA, 2011). Many believe that with good political support and certainty from national polices the market is able to grow 5x (NWEA, 2011) and become independent from the governmental subsidies (ALSTOM, 2011).

Box 5 presents selected market formation events in the Netherlands. One of few positive market activities that caught media attention in 2010/11 is the huge German Bard investment (subsidised by

[53] http://www.ewea.org/fileadmin/ewea_documents/documents/publications/reports/23420_Offshore_report_web.pdf

Dutch and which stakes were bought by SHV and Typhoon Capital) to build two parks with total of 120 windmills of high capacity. This initiative is hoped to provide employment for Dutch workers and contracts for smaller Dutch firms onshore. Furthermore the Dutch network manager Tennet closed a deal with Germans about the delivery of electricity cables and the Foundation Energy Valley is involved in discussing the plan to place cables in the North Sea that would connect other European wind projects into a pan European grid. The grid, that 10 European countries agreed to develop, is expected to give a significant boost to the Dutch market.

Based on these considerations it can be concluded that the Netherlands, without further steps, are in a danger of losing market shares and position at a European level. Strong, open and competitive domestic market could help the Netherlands regain its leading position and reduce their dependency and vulnerability to decisions of the UK. It is also important to support domestic industry, now busy abroad, and the involvement of a great number of SME's. Given poor university-industry interaction, greater home market would allow researchers better test their academic work in practice. The function market formation (F5) is therefore evaluated at the level of weak (2) (see Figure 12).

Box 5. Selected examples of the Dutch events influencing market formation in 2011

- Government subsidy was granted for two operational projects (NUON/Shell, Eneco)
- €4.9 billion government subsidy (operational support for 20 years) became available for 3 projects to be developed: 2 from Bard (since August 2011: Typhoon Capital and utility HVC), one from Eneco, Q10
- Permits have been granted for three other locations, but no subsidy made available

5.7. Resource mobilization (F6)

Resources in all forms: financial, human and physical are necessary as basic input to all activities of the innovation system. Without these resources systems are unable to function. The function resource mobilisation was assessed based on the study of: availability of financial resources; availability of competencies and expertise and availability of physical infrastructure.

Financial: The data for years 2010-2011 show a number of small financial successes. First is the subsidy provided to the German consortium Bard in the amount of €4.5 bln Euro for two wind parks (120 windmills) and second is the subsidy granted to Eneco in the amount of €0.9 bln for Q10 park near Katwijk. Third is the grant to FLOW project in the amount of €23,5 mln. However, the availability of financial resources in the Netherlands is considered by actors in the field as the largest barrier (Alstom, KEMA, NWEA, 2011) to the extent that when the subsidy was granted for the German BARD consortium, it served for high disappointment in the Netherlands. The Dutch industry first fought for being part of the consortium and managed to include Van Oord to do the construction works. Then the industrial actors negotiated allocation of total of 30-40% of the construction process to the Dutch companies. Later on, in 2011 Typhoon Capital and the Dutch utility SHV bought stakes in the investment, which made this largest renewable project fully owned by Dutch shareholders and cooled down the heated debate.

These financial resources, however, are the outcomes of the earlier government decisions. The current government is willing to invest in offshore wind energy, but argues that the prices must first come down considerably before any large-scale investments can be supported again. For the time being therefore, the government has stopped the subsidies for offshore wind power generation but did nothing about decommissioning fee or bank guarantees. The perception of the technology as being very expensive, compared to natural gas, create a lack of urgency and a significant slowdown of resource mobilisation from other sources. Particularly the banks are hesitant to invest as they perceive offshore wind as an uncertain and risky terrain. The risk is so high that many projects are either not bankable (Van Oord, 2011) or a great number of banks (10-15) and insurers need to be involved in one project to share the risks (Rabobank, Van Oord, 2011; KPMG, 2010). This lack of finances is an implication of the crisis and the governmental lack of commitment to the field and renewables in general (Ecofys, 2011).

At the European level the number of wind farms is growing steadily and according to EWEA (2011c) there are more banks that are willing to finance offshore wind farms. Globally, where there is little interest in investing in the offshore wind compared to other RES technologies (KPMG, 2010[54]), Europe is being prised for the diversity of energy subsidies (particularly the UK and Belgium) and longer term commitments such as in the UK or Germany. Some EU subsidies, at the level of €32 mln were allocated to the development of the European electricity system. Still, increased levels of investments will be necessary for new wind farms and incentives for technology development (through R&D and demonstration), grid improvements and integration, harbours adjustments and development of clusters around the ports. The Dutch companies will need to wait for a new government and a new subsidy scheme (Van Oord, 2011) while constructing foreign farms (VSF, 2011).

Human: Lack of human resources is not yet the biggest barrier but it may become one. In unfavourable market conditions and lack of governmental vision on offshore wind, young people are hesitant to undertake education in the area which, later, would not pay their bills. In some 5 years from now, however, it is expected that many current offshore wind specialists will retire and will have to be replaced by new ones (Alstom, Ecofys, 2011). This is next to the already urgent need for qualified workforce, mostly electrical engineers (Alstom, 2011) and technicians. It is difficult to find them at universities; they need to be trained on the job. This serves for a dynamic mobility of experts among the various companies (KEMA, VSF, 2011). In 2010/11 a number of professional educational programs have been set up on offshore wind to fill in this gap and in expectation that the field would grow. Many companies, however, train people in-house and give them hands on experience not available at universities (VSE, KEMA, 2011), Van Oord Academy serving as an example. Overall, academic education of actors in the Netherlands is very high regarded in Europe and translates to the production of prototypes but because of a lack of application context and a lack of industrial culture, it leads to few real products on the market (Van Oord, 2012; FLOW, 2012; Vries,2012; Nuon/Vattenfall, 2012; Out-Smart, 2012).

---

54 http://www.kpmg.com/UK/en/IssuesAndInsights/ArticlesPublications/Documents/PDF/Market%20Sector/Power_and_Utilities/KPMG_Offshore_Wind_in_Europe_eng_FINAL.pdf

At the European level there is an intensifying collaboration on education, which is a sign of the need to harmonise and coordinate the system. However, the courses and programmes are quite recent and very few compared to the needs (all interviewees; INTPOW, 2011, Jacobsson and Karltorp, 2012a). Europe-wide funding cuts for the higher education sector pose an additional threat. It may become a Europe wide problem when the offshore wind system develops to meet the European renewables targets.

Physical: Availability of physical infrastructure in the Netherlands is evaluated as quite problematic. Three elements are repetitively dominating the discussion in this area: underdevelopment and cost of technology (Rabobank, 2011), underdevelopment of grid and issues around connection to the grid (especially lack of interconnectors binding wind farms with the grid) (Rabobank, NWEA, Ecofys, Alstom, 2011; Van Oord, 2012; FLOW, 2012; Vries,2012; Nuon/Vattenfall, 2012; Out-Smart, 2012) as well as availability of vessels (VSF, van Oord, 2012). In the future (2015) cabling may become an additional supply constraint.

Even though the Netherlands, who actively serves the oil and gas industry, has good harbour infrastructure, it does need to be adjusted to be able to assist the offshore wind operations. Some harbours such as Rotterdam, face societal opposition because their adjustment to meet offshore wind standards would imply territorial extension and intensification of activities and what that entails – noise, transport and pollution.

In view of this discussion function F6: resource mobilisation is assessed in the following way: financial resources at the level of weak (2), Human resources we rate at the level of moderate (3) and physical resources as moderate (3) (see Figure 12). Box 6 presents selected examples of Dutch resource mobilisation events in 2011.

Box 6. Selected examples of the Dutch resources mobilisation events in 2011

- Possibly extra €84 million will be made available from EU for new Eneco project (needs €400-450 million for investment)
- Meewind invested €150 million in Bard projects
- Limited capital available for grid extensions (Tennet)
- Professional training program on offshore wind started in Den Helder (with TU Delft and ECN)
- Van Oord started its own training program. With underdeveloped home market, training seems to be essential to supply the international offshore wind market.
- Opinion: with current low ambitions there are no constraints regarding vessels (construction, maintenance, logistics). Vessels could become a major constraint in the case of a new government trying to catch up with earlier formulated ambitions
- Opinion: global growth of offshore wind could potentially but not necessarily lead to scarcity of rare earth materials esp. neodymium en dysprosium, of which large quantities are required for direct drive permanent magnet generators used in several new turbine models
- Opinion: cabling could become a supply constraint as of 2015
- Den Helder uttered ambition to become main harbour for offshore wind farms maintenance and logistics
- German offshore wind electricity got partly lost due to grid problems (Dutch Tennet needs funds to strengthen German grid)

5.8. Creation of legitimacy (F7)

For a new technology to be economically successful it needs to become a part of the incumbent regime or even overthrow it. This causes that the emerging technologies are often perceived by the incumbent actors as a serious threat. Incumbents therefore tend to oppose and resist the novelties. To overcome their resistance, advocacy coalitions are needed that would put the new technology on the political agenda, lobby for favourable conditions and resources and by doing so, create legitimacy for a new technological trajectory. To evaluate if there is enough creation of legitimacy, the degree of resistance to technology, the perceived level of competition between technologies and the extent to which the hard and soft institutions increase legitimacy were analysed.

According to the interviewees there is no big societal opposition to offshore as long as the windmills are not visible onshore (Alstom, Van Oord, Kema, 2011). Municipalities worry about societal resistance only when farms are planned in the vicinity of 20 km from shore (NWEA, 2011). Also activities of NWEA who actively promotes the utilization of wind power in the country is positively influencing the public acceptance of the technology.

Experts think, however, that in the Netherlands there is a very strong oil and gas lobby, which is rather interested in keeping the status quo. They are also considered better organised, with many professionals and therefore stronger in lobbying and more effective in convincing the government to their rights than the renewables lobby. In the result they get stronger financial support than all renewables together (CE Delft and Ecofys, 2011). In these conditions the renewable lobby has particularly difficult task of convincing the government that because renewables need time, action is needed as soon as possible. NWEA is expected to lobby stronger for the offshore wind (Van Oord, 2012; FLOW, 2012; Vries,2012; Nuon/Vattenfall, 2012; Out-Smart, 2012).

Regarding institutions, 14% binding RES target is still there, but the (crucial) role offshore wind is officially not recognized by the government even though there are many positive opinions that offshore wind is a good alternative to onshore, that it may lead to creation of many jobs and is necessary for the development of competencies of national industry. Many companies such as Ballast Nedam and Volker Wessels called upon Minister Rutte to give them certainty that their wind energy will be discharged to the grid. Also NWEA lobbied with Minister Rutte to create a better level playing field for the Dutch entrepreneurs (see Box 7 for more lobby events in the Netherlands). Still the financial instruments in support of renewables are designed in a way that the various renewable technologies not only need to compete with the strong oil and gas lobby but also with each other.

In view of this discussion and accounting for interviewed experts' opinion the function F7: creation of legitimacy is rated at the level of moderate (3) in the Netherlands (see Figure 12).

Box 7. Selected examples of the Dutch legitimacy creation activities in 2011

- Limited interest at a global level in investing in offshore wind compared to other RES technologies
- Opinion: 14% binding RES target still there, but (crucial) role offshore wind not recognized
- Opinion: offshore wind leads to creation of jobs
- Opinion: offshore wind as an alternative for onshore wind (NIMBY)
- Opinion: offshore wind not being an alternative for onshore wind (too expensive)
- Opinion: coal power plants become less efficient with more offshore wind, on a net base more CO_2
- Permits for two farms not granted because of harbour interests and disruption for birds

6. Identification of systemic weaknesses

6.1. Functional pattern

Based on the analysis of the structure of the Dutch offshore wind innovation system (Section 4) and its dynamics (Section 5) it can be concluded that poor legitimacy of offshore wind (F7) in the Netherlands and the related lack of guidance of the search (F4) are the critical factors in the formation of the Dutch offshore wind innovation system. Both have strong impact on the other innovation system processes, in particular the market formation (F5) and resources mobilisation (F6). Even though the entrepreneurial activities (F1) as well as knowledge creation and diffusion (F2 and F3) are currently strong in the Netherlands, in the long run, they may get negatively affected by poor market formation (F5) and deficiency of resources (F6). Addressing of the legitimacy (F7) as well as the guidance of the search (F4) problems and simultaneously constructing home market (F5) are key to improving the performance of the remaining system processes due to the feedback loops that exists between the functions. In practice, improvement of the two processes implies tackling of structure related problems. They are identified and discussed in the following section.

6.2. Structural causes of functional weaknesses

Table 8 summarises the evaluation of the seven system functions as discussed in Section 3 (Functional analysis) and the reasons why they are strong or weak (inducement and blocking mechanisms respectively). The blocking factors are later on attributed to structural components of the system that are responsible for the weakness of the function and which need to be altered to improve the performance of the analysed system. Alteration of the structural elements can be done by either stimulation of its occurrence (presence) or by improving its capacity, capability or intensity.

Table 8. Results of the coupled structural-functional analysis and identification of systemic problems

Function	Functions evaluation	Inducement mechanisms	Blocking mechanisms
F1 Entrepreneurial activities	4 strong	- Large number of strong incumbent firms - Experience and competence of construction companies - Availability of market abroad	- Lack of vision and goals for environmental, industrial and innovation policies - Unstable regulatory regime, long contracting procedure - Lack of innovative subsidy schemes, ineffective support programmes (SDE, bank guarantees, decommissioning fee)
F2 Knowled ge develop	4 strong	- Strong and concentrated scientific knowledge - Good international reputation of knowledge institutes (TU Delft, ECN)	- Poor overlap in knowledge base of industry and knowledge institutes - Insufficient dedicated R&D funds
F3 Knowledge diffusion	4 strong	- Good collaboration on European research projects (both knowledge inst. and industry) - Strong international industrial collaboration - Many venues to exchange knowledge and to network - A number of specialised courses	- Poor international collaboration on scientific knowledge - Problematic transfer of university knowledge to specific context of application - Poor diffusion of engineering knowledge - Lack of immediate application context
F4 Guidance of the search	2 weak	- Expectation of large market and employment - Observable increasing returns to scale - Green Deal - MoU on EU grid extension - Strong, competent and experienced industry	- Cost and reliability of technology - Lack of vision and goals for environmental, industrial and innovation policies - Unstable regulatory regime, long contracting procedure - Lack of innovative subsidy schemes, ineffective support programmes (SDE, bank guarantees, decommissioning fee) - Non-harmonised rules on piling in Europe - Lack of spatial policy on North Sea
F5 Market formation	2 weak	- Big projects of the earlier government - Activities around grid extension and renovation	- Lack of increase in installed capacity - Cost and reliability of technology - Unstable regulatory regime, long contracting procedure - Lack of vision and goals for environmental, industrial and innovation policies - Lack of innovative subsidy schemes, ineffective support programmes (SDE, bank guarantees, decommissioning fee)
F6 Resources mobilisation	2+ weak	- Availability of funds for earlier decided projects - Increase in educational programs - Highly regarded education in the Netherlands - Good harbour infrastructure and geo positioning of the country	- Cost and reliability of technology - Lack of financial resources for new projects - Unstable regulatory regime, long contracting procedure - Lack of vision and goals for environmental, industrial and innovation policies - Lack of innovative subsidy schemes, ineffective support programmes (SDE, bank guarantees, decommissioning fee) - Lack of human resources - Unavailability of grid interconnectors
F7 Legitima cy creation	3 moderate	- Limited societal resistance - Expectation of large market and employment	- Insufficient renewable lobby - Lack of level playing field

Based on this summary, four types of problems can be identified:

1. Actors problem
    - Lack of human resources
2. Interaction problems
    - Poor overlap in knowledge base of industry and knowledge institutes
    - Poor international collaboration on scientific knowledge
    - Poor diffusion of engineering knowledge
    - Problematic transfer of university knowledge to specific context of application
3. Institutional problems:
    - Lack of vision and goals for environmental, industrial and innovation policies
    - Lack of spatial policy on North Sea
    - Unstable regulatory regime, long contracting procedure
    - Lack of innovative subsidy schemes, ineffective support programmes (SDE, bank guarantees, decommissioning fee)
    - Non-harmonised rules on piling in Europe
    - Lack of level playing field
    - Cost of technology
4. Infrastructural problems:
    - Lack of financial resources for new projects
    - Insufficient dedicated R&D funds
    - Unavailability of grid interconnectors
    - Reliability and availability of technology
    - Grid access and capacity

The Dutch offshore wind innovation system comprises of many competent and motivated actors, especially internationally recognised knowledge institutes and industry that is ready and willing to invest. There are good knowledge development and entrepreneurial activities even in unfavourable domestic market conditions mainly because of availability of market abroad. That suggests that the Netherlands is well embedded in European activities but there is a lack of domestic market. The actor problem refers to the future availability of personnel, mainly engineers, should the governmental decide to develop offshore wind farms and expand domestic market.

The Dutch industry is very well connected with each other, Green Deal serving as a proof where 50 companies mobilised themselves in a very short time and convinced the government to sign the deal. Second great research-focused consortium is the FLOW program. The interaction problems that need to be addressed in the Netherlands refers to the collaboration between industry and knowledge institutes on the development of common knowledge and training of suitable work force that can meet the expectations of the industry. There is a very strong need for a network that would bring all the various parties together. The Netherlands also needs to decide whether they want to continue focusing on academic innovation and creation of novelties or will they develop home market where some attention will be given to their application and testing.

Institutional problems within this system are strongly related with the poor guidance from the Dutch government. The specific institutional problems refer mainly to the capacity of existing regulations and subsidy programs. They are insufficient for the needs and for meeting the goals. Furthermore, the government is too much focused on the CO_2 reduction target using cheapest technology. This target should be better linked to the objective of industry development and longer term environmental considerations. In conditions of the missing level playing field any renewable energy sources stand chances with incumbent gas and oil regime. The Dutch industry also suffers from non-harmonised rules on piling in Europe

Main infrastructural problems in the Dutch offshore wind innovation system relate to the poor public financial resources for investment as well as R&D. This problem mostly affects function knowledge development. There are also knowledge infrastructure problems. The specificity of knowledge namely the fact that it is very much technology embedded causes its poor transferability from university to industry causing poor knowledge diffusion in the system. The physical infrastructure is currently not a serious obstacle to the development of the Dutch offshore wind innovation systems. The problems with physical infrastructure such as grid interconnectors, cabling, vessels and foundations are only potential when the government decides to achieve the earlier goals and targets.

All these problems negatively impact almost all Dutch offshore wind innovation system processes (as indicated in Table 8) and effectively block the build-up of the system.

7. Policy challenges

7.1. National vs. spatially extended context

Dutch policy and strategy in support of the system based on this national delimitation would therefore need to focus on the development of home market, national lobby and framing as well as on investments in domestic programme to support university-industry collaboration. This systemic perspective leads to a much better informed layout of policies that the more traditional output oriented view. However, as much as the nation states are important to facilitating transition processes, organising policy purely at national level can overlook impact of context on national TIS. For example, while scientific knowledge is produced locally or nationally; engineering knowledge is created by international companies and therefore diffused via European market interaction, a wider than national context. Further extension of the policy analysis by taking into account the impact of external forces, therefore, additionally extends the recommendations.

Major context development that played an important role in the formation of the Dutch offshore wind innovation system until 2011 include landscape type of developments: EU commitment to offshore wind, good global position and clear renewable and climate targets coupled with the availability of European R&D funds as well as financial crisis of 2008. Finally, not without importance was the impact of offshore wind TISs in other neighbouring countries such as the UK, Germany or Denmark. The three countries have had largest installed capacity in Europe in 2011. The UK is young but large and promising market that the Dutch companies already use. Denmark and Germany excel in turbine manufacturing and both have strong engineering knowledge production (Wieczorek and Hekkert, 2014). Taking these aspects into consideration may reveal that many Dutch national weaknesses can be addressed by using strength of other countries or regions in the process of collaboration.

For example, from the Dutch national perspective stimulating domestic market has a number of advantages. It might help the Netherlands to reduce its dependency and vulnerability to decisions of the UK, motivate domestic entrepreneurial activities of smaller companies or support the reduction of costs through demand creation. A functional Dutch market is also necessary for the formation of a strong European offshore wind innovation system and reaching of the European climate targets. However, national market formation requires a strong political support, stable renewable policy of consecutive cabinets, encouraging regulatory regime and effective support programmes. These, however, are either of great deficiency in that country or they continue to fail in achieving the ambitious goals (Ecofys, VSF, Rabobank, 2011). In these conditions tapping on other markets and relying on higher legitimacy for offshore wind in e.g. Germany and the UK would be a viable short-term strategy for the Netherlands (see Table 9). The increased mobility of the companies that this process would stimulate contribute to the European transmission of engineering knowledge via market interaction and would help address the problem of poor university-industry interactions in the Netherlands. It would also provide the Dutch firms with access to wider (physical, human and financial) resources abroad. The Netherlands may therefore want to pursue domestic policies to support offshore wind, however, they are better off when joining forces because of a common supranational set of challenges and opportunities (Wieczorek et al., 2013). From an innovation perspective decentralisation and cooperation are also more stimulating for innovative activity than independency and self-sufficiency (Saxenian, 1994)

Table 9. Implications of the interaction of the Dutch offshore wind TIS with the context on framing of selected problems and policy (source: Wieczorek and Hekkert, 2014)

Problem	National solution	Interaction effect	Implications for problems and policy
lack of home market	domestic market formation	market in the UK & DE	market formation less of a problem if access to neighbouring markets is possible
lack of legitimacy	national lobby and framing	higher legitimacy in DE & the UK	potential spill-over's when coordinated
lack of knowledge exchange	programme to support university-industry collaboration	international knowledge exchange	no serious problem due to mobility of multinationals
grid in need of renovation	national action for grid improvement	same problem everywhere	need to cooperate on supra grid development
lack of trained personnel	investment in national training programmes	same problem everywhere	need to cooperate to have access to wider set of resources

7.2. Systemic instrument

Policy design is not a practice of research but of the governmental organisations. It is always about making choices from the possibilities offered by the given historical situation and cultural context (Howlett, 2011). Without pretending to be in a position to suggest the best design of policy that would tackle the above identified problems and not trying to be complete in the suggestion, based on the analysis a number of elements can be proposed for national policy makers who deal with the offshore wind system obstacles. The elements are shortly described below.

Institutional settings (formal and informal)are critical measures because they have impact on actors guiding strategies regarding generation, application and diffusion of innovation (Martin, 2000). Formal institutions are a precondition for market formation, informal have impact on perceptions of new technology. Follwoing institutional improvements are proposed:

- Green Deal 2.0 – focused on specifying the Green Deal 1.0 agreements, stimulating the change of discourse and attitude, stimulating better alignment of industrial, environmental and innovation policy away from purely meeting the targets towards also the development of collaboration policies on industry, innovation and environment.

- Utilisation of academic culture of the Netherlands and making trading of novelties easier by creating law that would oblige utilities to have part of their projects tested and demonstrated and wind farms to have a demo part.

- Decision regarding how to meet the 14% target with alternative technologies and stick to it.

- IPR as a form of institutional regulation is not always the best decision of innovators immediately following the discovery. Still, the common view is that it is the best way to protect the inventors property. Tools to commercialise public research results – clusters, incubators, science parks etc. (Rigby and Ramlogan, 2012, Nesta).

National R&D and Demo Programme

The main objectives of the R&D and Demo programme is the development of low-cost technologies, in particular turbines, specialised vessels, cables, foundations and substations and optimisation of the entire value chain. Second focus is the economics of offshore wind: setting of the green value of kWh, the most efficient manner to trade it within Europe as well as the evaluation of the effectiveness of the various support schemes (FIT, subsidies) and the strategies for their potential timely phase out. The programme would particularly encourage university-industry collaboration and would have two modules. By default it would support projects that are *feasible*. However, it would also have substantial budget available to making projects *profitable*. Proponents of the latter type of projects, to be eligible for funds, would need to demonstrate the outcomes of their work in the Innovation Zones (described below).

National R&D tax incentive

This incentive would stimulate private R&D and move away from academic mentality but on condition that the companies feed in data into a database. The R&D should be targeted at innovative activities; and only incremental tax incentive for the amount of R&D that exceeds certain baseline (Rigby, 2012, Nesta Compendium).

National learning scheme

Already used in the Netherlands – useful to support offshore wind training activities of companies. In the context of such a scheme, companies cover part of their educational costs through subsidy. Learning in this scheme can be targeted e.g. at SMEs.

FLOW/TKI

Continuous support to TKI follower of FLOW with the purpose to create confidence, network and facilitate knowledge flows

Monitoring evaluation program

Concerns the policy of the country to enforce data reporting. Such a model would collate information on all experiments in the country. Similar program to the German monitoring programme from 80s-90s enforce every wind farm owner and technology owner to produce technological monitoring data. Given that society contributes 1/3 of costs of the wind farm, it has the right to the results of these farms to make further technological progress possible. The aim of the database would be to facilitate better informed decisions on second generation projects. Although seemingly controversial, making information accessible is proved to improve operation and maintenance practices, the likelihood of reducing the costs of wind energy and increasing safety. The use of semantic technologies[55] to facilitate data exchange and improve operation and maintenance is a well known practice in the oil and gas industry (Nguyen et al., 2013).Expectedly, this would double the innovation rates.

Innovation Zones

Innovation Zones are test fields: dedicated spaces at sea or parts of existing wind farms that expedite first generation of projects and technologies before their commercial scale-up. Innovation Zones should be coupled with an obligation to add test any new turbines in these Zones – good for training people and reduction of costs. Given the tendency of the wind farms to go further offshore and towards harsher conditions, areas in which such tests are required include: turbines, foundations, grid connection, installation techniques, management and logistics, farm maintenance, transport etc. The data and experiences (including failures) gathered in the Innovation Zones would be brought together in a monitoring evaluation programme.

Expert Mobility Programme

Expert Mobility Programme is also part of the above mentioned R&D and Demo Programme and aims to support offshore wind researchers who wish to gain practical experience by spending 1-2 years in the industry or in Innovation Zones. Such a programme would facilitate skills development, knowledge diffusion and reduction of training costs. It would also encourage greater collaboration between business and academia and support the process of trust building and network expansion. Labour legislation and international migration policies can provide incentives for further, international spatial

[55] Such as ISO standards, RESTful webservices, Semantic Web etc

mobility of high skill labour. Such a mobility program would bridge the gap between contractors, knowledge institutes and industry but requires personnel trained now.

7.3. Technology-specific vs. technology-neutral policy

This type of policy suggestion is a clear plea for technology-specific policies at European level while there is in Europe an increasing interest in moving towards more technology-neutral policies[56]. In line with Azar and Sanden (2011) however, even though technology-neutral policy helps avoid picking winners and ensures a good set of competitive technologies, if left to the market, it will always chose the one that is first in line in terms of cost, and not the one that is currently more expensive but has greater potential to solve the problem in the longer term. Offshore wind is such an immature technology, of which it is expected to help respond to the emerging challenges of climate change, energy security and access[57]. Technology-neutral policy will not help offshore wind avoid the *valley of the death* and compete with other more advanced technologies on equal terms. Offshore wind does require targeted innovation policy to move out of the early stage of development. This policy, however, to be effective, needs to be well aligned with broader (renewable) energy development goals and properly integrated into existing macro-level policy.

8. Conclusions

The Netherlands need to decide about the extent to which offshore wind plays a role in their national energy mixes (security, diversity issues) and whether it is any serious trajectory through which national renewables targets can be achieved. These choices are important because they have implications for the strategies with regards to stimulating innovativeness and what relates with this – the development of national offshore wind TIS's.

Undoubtedly, before leaving it up to the market, which Dutch like to do, much needs to be done in terms of priority setting, risk sharing, permitting, environmental impact assessment and framework development to help stimulate innovation in the field. The companies, however, are determined to wait for a new government and a new stable subsidy scheme because the system is yet too immature to function independently from political support and substantial subsidies.

Theoretically speaking while in aquatic biomass the transnational linkages were missing but the system was under strong impact of developments in a broader system context, this case shows system that harnessed the power of these forces to own advantage: actors developed cooperation with foreigners to complement domestic value chain gaps, missing skills and resources.

[56] http://www.endseurope.com/32700/energy-groups-outline-positions-on-rd-rule-update?DCMP=TEMAIL24713 accessed July 2013
[57] E.g. http://epp.eurostat.ec.europa.eu/statistics_explained/index.php/Renewable_energy_statistics accessed July 2012

References

Azar C, Sandén BA, 2011, The elusive quest for technology-neutral policies. Environmental Innovation and Societal Transitions, 1(1):135–9

Bergek A., Jacobsson S., Carlsson B., Lindmark S., Rickne A. 2008. Analyzing the functional dynamics of technological innovation systems: A scheme of analysis. Research Policy, 37:407-29

Berkhout F., Wieczorek, A.J., Raven, R., 2011. Avoiding environmental convergence: a possible role for sustainability experiments in latecomer countries? International Journal of Institutions and Economies, 3(2):367-385

Binz C, Truffer B., L. Li, Y. Shi, Y. Lu, 2012. Conceptualizing leapfrogging with spatially coupled innovation systems: The case of onsite wastewater treatment in China, Technological Forecasting and Social Change, 79:155–71

BWEA, 2011. UK Offshore Wind: Charting the Right Course. Scenarios for offshore capital costs for the next five years

Capros P., Mantzos, L., DeVita, N. Tasios, A., Kouvaritakis, N., 2010. Trends to 2030-update 009,European Commission-Directorate General for Energy in collaboration with Climate Action DG and Mobility and Transport DG. Office for official publications of the European Communities, Luxembourg, ISBN 978-92-79-16191-9

CE Delft and Ecofys, 2011. Overheidsingrepen in de energiemarkt: onderzoek naar de Nederlandse speelveld voor fossiele brandstoffen, hernieuwbare bronen, kernenergie en energiebesparing

Chaminade C. and Edquist, C., 2010. Rationales for public policy intervention in the innovation process: A systems of innovation approach. In: Smits, R., Kuhlmann, S. and Shapira, P. (eds) The Theory And Practice of Innovation Policy, an International Research Handbook, Cheltenham: Edward Elgar, 95–114

Coenen L, Benneworth, P., Truffer, B., 2012. Towards a spatial perspective on sustainability transitions. Research Policy, 41:968–79

Coenen L, Raven, R, Verbong, G, 2010. Local niche experimentation in energy transitions: A theoretical and empirical exploration of proximity advantages and disadvantages. Technology in Society, 32:295-302

Coenen L, Truffer, B., 2012. Places and spaces of sustainability transitions: geographical contributions to an emerging research and policy field'. European Planning Studies, 20(3):367–74

Crawford, S. Ostrom, E. 1995. A grammar of institutions. *American Political Science Review,* 98(3),582-600.

De Vries, E., 2012. Rotation Consultancy, WindpowerMonthly, Personal communication, April

Department of Energy and Climate Change, 2011. The UK Renewable energy Roadmap

EU, 2008a. 20-20 by 2020 Europe's Climate Change Opportunity. COM (2008) 30 23.1.2008. Brussels, EU

EU, 2008b. Communication on offshore wind energy

EU, 2011. European Union roadmap for moving to a competitive low carbon economy in 2050, COM (2011) 112, Brussels, EU

EWEA, 2011a. Wind in our sails - The coming of Europe's offshore wind energy industry. The European Wind Energy Association. 11/2011

EWEA, 2011b. Pure Power, Wind energy targets for 2020 and 2030.

EWEA, 2011c. Offshore Grid: Offshore Electricity Infrastructure in Europe. A techno-economic assessment, October

EWEA, 2012. Creating internal energy market in Europe, September

Dewald, U., Truffer, B. 2011. Market Formation in Technological Innovation Systems—Diffusion of Photovoltaic Applications in Germany. Industry and Innovation, (18)3:285–300

Garud R, Karnøe P, 2003. Bricolage versus breakthrough: distributed and embedded agency in technology entrepreneurship, Research Policy, 32(2):277-300

Guillet J., 2011. Banking offshore wind. Chapter 03 in pfi intelligence briefing. http://www.green-giraffe.eu/uploads/0911%20PFI%20Financing%20Offshore%20Wind%20%20%28JG%29.pdf

Hekkert M, Suurs R, S Negro, S Kuhlmann, R Smits, 2007. Functions of innovation systems: A new approach for analysing technological change, Technological Forecasting and Social Change, 74: 413-32.

Hillman K, Suurs R., M. Hekkert, B. Sanden, 2008. Cumulative causation in biofuels development: a critical comparison of the Netherlands and Sweden, Technological Analysis and Strategic Management, 20:592–612

Howlett M., 2011. Designing Public Policies: Principles and Instruments (Routledge Textbooks in Policy Studies)

INTPOW, 2011. Offshore Wind Germany Market Study 2011, Norwegian Renewable Energy Partners, 2011

Jacobsson S, 2012. Chalmers University, Sweden. Personal communication. May

Jacobsson S, Bergek, A., 2011. Innovation systems analyses and sustainability transitions: Contributions and suggestions for research. Environmental Innovations and Societal Transitions 1:41-57

Jacobsson, S, Karltorp, K., 2012a. Formation of competencies to realize the potential of offshore wind power in the European Union. Energy Policy, 44

Jacobsson, S, Karltorp, K., 2012b. Mechanisms blocking the dynamics of the European offshore wind energy innovation system - challenges for policy intervention, Draft, Gothenburg University

Jacobsson, S, V. Lauber, 2006. The politics and policy of energy system transformation – explaining the German diffusion of renewable energy technology, Energy Policy, 34:256–76

Klein-Woolthuis, R, M Lankhuizen, V Gilsing, 2005. A system failure framework for innovation policy design, Technovation, 25:609-619

KPMG, 2010. Offshore wind in Europe. 2010 Market Report

Makridis, C, 2013. Offshore wind power resource availability and prospects: A global approach, Environmental Science and Policy, 33: 28-40

Markard J, Petersen, 2010. Tailwind for large investors – Analyzing ownership structures in offshore wind power. In: Modern Energy Review 2(1)

Markard J, Raven R, Truffer, B., 2012. Sustainability transitions: an emerging field of research and its prospects*. Research Policy*, *41*(6):955-67

Martin, R., 2000. Institutional approaches in economic geography. In: Sheppard, E., Barnes, T.J. (Eds.), A Companion to Economic Geography. Blackwell Publishing Ltd., Oxford, UK

Metcalfe J., 1995. The economic foundations of technology policy: equilibrium and evolutionary perspectives, in P. Stoneman (Ed.) Handbook of Economics and Innovation and Technology Change

Mierlo van B, Leeuwis C, R Smits, R Klein-Woolthuis, 2010. Learning towards system innovation: Evaluating a systemic instrument, Technological Forecasting and Social Change, 77: 318-34

Negro S, Alkemade, F., Hekkert, M.P, 2012. Why does renewable energy diffuse so slowly? A review of innovation system problems Renewable and Sustainable Energy Reviews, 16 (6), pp. 3836-46

Negro S, M. Hekkert, 2008. Explaining the success of emerging technologies by innovation system functioning: the case of biomass digestion in Germany, Technological Analysis and Strategic Management, 20: 465–82

Negro S, M. Hekkert, R. Smits, 2007. Explaining the failure of the Dutch innovation system for biomass digestion – a functional analysis. Energy Policy, 35:925–38

Nguyen T, Prinz A, Friisø T, Nossum R, Tyapin I, 2013. A framework for data integration of offshore wind farms, Renewable Energy, 60:150-161

OECD, 2012. Statistical annex to the 2012 OECD STI Outlook Country Profiles, in OECD Science, Technology and Industry Outlook 2012, OECD Publishing

Prassler, T., Schaechtele, J., 2012. Comparison of the financial attractiveness among prospective offshore wind parks in selected European countries, Energy Policy, 45:86–101

Raven R., Schot, J., Berkhout, F., 2012. Space and scale in socio-technical transitions. Environmental Innovation and Societal Transitions 10(4):63-78

RenewableUK, 2011a. Working for a Green Britain: vol 2. Future Employment and Skills in the UK Wind and Marine Industries, July

Saxenian, AL, 1994. Regional advantage : culture and competition in Silicon Valley and Route 128. HUP, Cambridge, MA

Smits R, Kuhlmann, S, 2004. The rise of systemic instruments in innovation policy. The International Journal of Foresight and Innovation Policy, 1(1/2):4-32

Späth, P, Rohracher H, 2012. Local Demonstrations for Global Transitions—Dynamics across Governance Levels Fostering Socio-Technical Regime Change Towards Sustainability. European Planning Studies, 20(3):461-79

The Crown Estate, 2011. UK Offshore wind report 2011

Truffer B, Coenen L, 2012. Environmental Innovation and Sustainability Transitions in Regional Studies, Regional Studies, 46(1):1-21

WBGU, 2013. World in transition. Governing the Marine Heritage. German Advisory Council on Global Change. Berlin

Weber M., Rohracher H, 2012. Legitimizing research, technology and innovation policies for transformative change, Research Policy, 41:1037–47

Wieczorek AJ, Negro SO., Harmsen R., Heimeriks GJ., Hekkert MP., 2013. A Review of the Western European Offshore Wind Innovation System. Renewable and Sustainable Energy Reviews, 26:294–306

Wieczorek AJ., Hekkert,. M., 2012. Systemic instruments for systemic innovation problems: A framework for policy makers and innovation scholars. Science and Public Policy, 39:74–87

Wieczorek, A.J., Hekkert, M.P., Coenen, L., Harmsen, R., 2014. Broadening a national focus in technological innovation system analysis: the case of offshore wind. Environmental Innovations and Societal Transitions, accepted for publication

Wieczorek, A.J., Hekkert, M.P., Negro S.O., Heimeriks, G.J., submitted. Analysis of a nascent renewable energy innovation system: aquatic biomass in the Netherlands. Science and Public Policy, 2014

Wind directions, 2012. Building Bridges for our Electricity, February, 31(1)

Windpower Monthly, 2011. Special Report: Rising to the challenge. UK prepares for the next round of offshore growth, from foundations to turbine technology

Woolley, O. 2013. Governing a North Sea grid development: The need for a regional framework treaty. Competition and Regulation in Network Industries, 14(1): 73-97

Appendix A

Personal communications (ca 1h) during EWEA Conference, 29 November-1 December, 2011, Amsterdam, The Netherlands with representatives of:

Alstom, The Netherlands, Country Sales Director, Grid
Ecofys, Wind Energy, The Netherlands, Unit Manager
Kema, Arnhem, The Netherlands, Consultant Wind Energy
Rabobank, The Netherlands, Senior Associate
Van Oord Offshore Wind Projects BV, The Netherlands, Regional Manager
Volker Staal en Funderingen (VSF), The Netherlands, Director
Volker Staal en Funderingen (VSF), The Netherlands, Project Engineer
Netherlands Wind Energy Association (NWEA), The Netherlands, Senior Advisor

These experts have been asked to evaluate the Dutch TIS in European context using 5-tier scale of absent -weak-medium-strong-excellent. Their responses have been coded and used for graphical presentation.

Personal communications (ca 1h) during EWEA Conference, 29 November-1 December, 2011, Amsterdam, The Netherlands with representatives of:

4C Offshore, UK, Director Product Development
A2Sea, Denmark, Business Developer
DONG Energy, Denmark (Dong DK), Senior Manager Operations and O&M Management
DONG Renewable Energy, UK (Dong, UK), Offshore wind Project Development Manager
Esbjerg Business Development Center, Denmark, Business Consultant
EWEA, Brussels, Research officer
EWEA, Brussels, Policy lobbyist
Germanischer Lloyd Renewable Certification (GL), Germany, Head of Group Project Management
JDR Cable Systems LTD, UK, Sales Director
Jutlandia, Denmark, HSEQ Manager
KBR Power, UK, Senior Business Developer
KBR Power, UK, Technical Professional
MPI Workboats, UK, Operations Manager
Offshore Center Denmark (OCD), Renewables Manager
PMSS, UK, Director
RenewableUK, UK, Offshore wind Development Manager
RWE; Germany, Executive Support Manager
Seas NVE, Denmark, Project Engineer
Seas NVE, Denmark, Project Manager
Siemens Wind Power A/S, Denmark, Strategic Recruiting Specialist
Siemens Wind Power A/S Germany, Senior Sales and Marketing Manager
Typhoon Offshore, UK, Head of UK Operations

These experts have been asked to evaluate their home TIS in European context using same 5-tier scale. Their assessment was also a useful source of information about the Dutch offshore wind TIS.

Personal communications (ca 8h) during a working session on Systemic policy for offshore wind in the Netherlands and Europe, 21 June 2012, Utrecht, The Netherlands with:

Van Oord, ECN, NWEA Manager Business Development
FLOW, Director
Offshore Monthly, Rotation Consultancy, Expert
Ampelmann TU Delft, Project manager, CEO,
Nuon/Vattenfall, Manager Offshore New Developments
Out-Smart, Founder and CEO

Appendix B

Diagnostic questions to determine the functioning of innovation systems

Key process	Diagnostic question
Entrepreneurial activities	- Are there sufficient[58] and suitable types of actors contributing to entrepreneurial experimentation and upscaling? - Are the amount and type of experiments of the actors sufficient? - How much technological up scaling takes place?
Knowledge development	- Are there enough actors involved in knowledge development and are they competent? - Is the knowledge sufficiently developed and aligned with needs of actors in the innovation system?
Knowledge exchange	- Are there sufficient network connections between actors through which knowledge is exchanged?
Guidance of the search	- Do actors and institutions provide a sufficiently clear direction for the future development of the technology?
Market formation	- Is the size of the market sufficient to sustain innovation and entrepreneurial experimentation?
Resource mobilisation	- Is the availability of financial resources sufficient? - Are there sufficient competent actors / well trained employees? - Is the physical infrastructure sufficient?
Creation of legitimacy	- Do actors, formal and informal institutions sufficiently contribute to legitimacy? - How much resistance is present towards the technology, project set up or permit procedure?

[58] Since innovation does not recognise an optimum, it is impossible to judge whether there is *enough* of it. Our discussion on the *sufficiency* of innovative activity in the areas defined by the system functions is, therefore, based on the qualitative evaluation of the capacity of the four analysed systems to grow and accelerate. At the same time we refrain from any quantitative assessment in the context of reaching the European and national targets.

Chapter V

A Review of the European Offshore Wind Innovation System[59]

Abstract

Offshore wind has the potential of becoming an important pillar of the future European energy system. It can contribute to policy objectives on climate change, energy security, green growth and social progress. However, the large potential of offshore wind does not automatically lead to a large share in future energy systems; neither does the emergent stage of development of the technology. Recent insights in innovation studies suggest that the success chances of technological innovations are, to a large extent, determined by how the surrounding system - the innovation system - is built up and how it functions. In this paper we assess the offshore wind innovation systems of four countries: Denmark, the UK, the Netherlands and Germany with the objective to provide recommendations for strengthening the overall European offshore wind innovation system. We use the Technological Innovation System (TIS) approach to analyse the system in 2011. Based on the analysis we identify a number of challenges that the European offshore wind sector faces. Some of them include: a serious deficiency of engineers; fragmented policies and poor alignment of national regulatory frameworks; cost of the technology and limited grid infrastructure. Since the problems hinder the entire system development we call for a systemic policy instrument that would support the innovation system around this technology and contribute to its wider diffusion in Europe.

Key words: Offshore wind, technological innovation system, systemic problems, systems functions, systemic instruments

1. Introduction

The development and diffusion of offshore wind energy technology is important for European energy policy [1,2]. Firstly, there is a large amount of potential: the European Wind Energy Association (EWEA) expects 150 GW of offshore wind capacity to be realised in 2030, which would supply 14% of Europe's electricity demand [3]. The technical potential of offshore wind in Europe is estimated at 5800 GW [4] and allows for even further expansion after 2030. Offshore wind has thus the possibility of becoming an important pillar of the future European energy system, contributing to policy objectives on climate change, energy security and affordable energy[5] . Secondly, the technology is in the early stages of technological development and, therefore, many business opportunities can be reaped in this emerging sector and thereby contributing to green economic growth. However, a large potential does not automatically lead to a large share in future energy systems; neither does an emergent stage of

[59] This chapter has been published as Wieczorek, A.J., Negro, S.O., Harmsen, R., Heimeriks, G.J., Hekkert, M.P., 2013. A Review of the Western European Offshore Wind Innovation System. Renewable and Sustainable Energy Reviews, 26: 294–306

technological development automatically lead to success for companies and the related economic growth and growth in employment. Innovation and technological change are by definition very uncertain processes. The outcomes are strongly determined by processes of chance and by external events that can hardly be influenced. Nevertheless, the scientific community that studies innovation has shown that a conscious and intelligent management of innovation processes strongly increases the success chances of innovation [6,7,9].

The most important insight that has dominated the field of innovation studies in the recent decades is the fact that innovation is a collective activity and takes place within the context of an *innovation system*. The success chances of innovations are, therefore to a large extent, determined by how the innovation system is built up (defined as *structure* of the innovation system) and how it *functions*. Many innovation systems are characterised by flaws that hamper the development and diffusion of innovations. These flaws are often labelled as system failures [6]; or system problems [7]. Intelligent innovation policy therefore evaluates how innovation systems are functioning, tries to create insight into the system problems and develops policies accordingly.

This paper assesses the offshore wind innovation system of four countries: Denmark, the UK, the Netherlands and Germany with the objective to provide recommendations for strengthening the overall European offshore wind innovation system. We chose the countries mainly because of their largest installed capacity in 2011 (the UK – 1586 MW, Denmark – 854 MW, the Netherlands – 247 MW and Germany – 195 MW [3]). The second reason is the potential high contributions of these countries to European offshore wind. We use the Technological Innovation System (TIS) approach to analyse the state of the system in 2011. We also identify the weaknesses that may hinder its further development.

The paper is structured as follows: Sections 2 and 3 describe the theory and methodology applied in this paper. In Sections 4 we look into the *structure* and *functioning* of the innovation systems in the UK, Denmark, the Netherlands and Germany. The paper closes with concluding remarks in Section 5 on challenges of the European offshore wind innovation system.

2. Innovation system theory

Innovation systems highlight the interaction between actors who are needed to turn an idea into a successful process, product or service in the marketplace. A Technological Innovation System (TIS) can be defined as the set of actors and rules that influence the speed and direction of technological change in a specific technological area [8-10]. The purpose of analysing a TIS is to evaluate the development of a particular technological field in terms of the structures and processes that support or hamper it. The identified obstacles in structure and processes may then be easier addressed by a policy. By this, the TIS analysis forms an analytical building block of a systemic policy framework that helps identify and address the obstacles in a systematic and coherent way [7].

The structure of the innovation system consists of four types of components: (i) actors, (ii) institutions and (iii) interactions, operating within (iv) specific infrastructure (for a more elaborate description of the components see [7]:

1. Actors involve organisations contributing to a technology such as a developer or adopter, or indirectly as a regulator, financer, etc. It is the actors of a TIS that, through choices and actions, generate, diffuse and utilise technologies.

2. Institutions encompass common habits, routines and shared concepts used by humans in repetitive situations [11]. By this they are different from organisations (such as firms, universities, state bodies, etc.) [12,13]. *Formal* institutions encompass: policy goals, rules, laws, regulations, instructions. *Informal* institutions encompass: visions, customs, common habits, routines, established practices, traditions, ways of conduct, norms, and expectations. Institutions constrain and enable actors in the innovation system to undertake actions related to innovation.

3. Interactions take place between actors through networks. These interactions are essential for e.g. knowledge exchange, learning, innovation, and shared vision building.

4. Infrastructure consists of: physical, financial and knowledge infrastructure. Physical infrastructure encompasses: artefacts, instruments, machines, roads, buildings, telecom networks, bridges, harbours. Knowledge infrastructure includes: knowledge, expertise, know-how, strategic information. Financial infrastructure includes: subsidies, financial programmes, grants, venture capital, etc.

The structural analysis of systems is based on mapping its elements and evaluating their capacity to stimulate innovation. The structural elements, their presence or absence as well as their capacities are critical to the functioning of the innovation systems [7].

However, even though different innovation systems may have similar components, they may function in an entirely different way. Therefore, measuring how innovation systems are functioning is considered a big breakthrough in innovation systems research. Table 1 presents criteria that have been proposed in the literature [8] to evaluate how innovation systems are functioning. These assessment criteria are labelled in the literature as *key processes of innovation systems* or *system functions*. In order to empirically evaluate the key processes a set of diagnostic questions are used (Table 1).

The structure and key processes complement each other. While key processes are more evaluative in character and allow to assess the performance of an innovation system; the structure is what needs to be adjusted to allow for better system functioning. In other words: the key processes, if badly fulfilled, signal problems in the structure. By identifying where the problems are within the system they can easier be addressed by policy. For example, weakness of the function knowledge development may be caused by the lack of knowledge institutes providing appropriate courses and educating people that can work with the new technology.

Table 1. Description of the seven key processes of innovation systems

Key process	Description	Diagnostic question
Experimentation by entrepreneurs	Entrepreneurs are essential for a well functioning innovation system. Their role is to turn the potential of new knowledge, networks, and markets into concrete actions to generate – and take advantage of – new business opportunities.	Are there sufficient[60] and suitable types of actors contributing to entrepreneurial experimentation and up-scaling? Are the amount and type of experiments of the actors sufficient? How much technological up scaling takes place?
Knowledge development	Mechanisms of learning are at the heart of any innovation process, where knowledge is a fundamental resource. Therefore, knowledge development is a crucial part of innovation systems.	Are there enough actors involved in knowledge development and are they competent? Is the knowledge sufficiently developed and aligned with needs of actors in the innovation system?
Knowledge exchange	To learn relevant knowledge needs to be exchanged between actors in the system.	Are there sufficient networks or connection between actors through which knowledge is exchanged?
Guidance of the search	This system function refers to those processes that lead to a clear development goal for the new technology based on technological expectations, articulated user demand and societal discourse. This process enables selection, which guides the distribution of resources.	Do actors and institutions provide a sufficiently clear direction for the future development of the technology?
Market formation	This process refers to the creation of markets for the new technology. In early phases of developments these can be small niche markets but later a larger market is needed to facilitate cost reduction and incentives for entrepreneurs to move in.	Is the size of the market sufficient to sustain innovation and entrepreneurial experimentation?
Resource mobilisation	The financial, human and physical resources are necessary basic inputs for all activities in the innovation system. Without these resources, other processes are hampered.	Is the availability of financial resources sufficient? Are there sufficient competent actors / well trained employees? Is the physical infrastructure sufficient?
Creation of legitimacy	Innovation is by definition uncertain. A certain level of legitimacy is required for actors to commit to the new technology with investment, adoption decisions, etc.	Do actors, formal and informal institutions sufficiently contribute to legitimacy? How much resistance is present towards the technology, project set up or permit procedure?

3. Methodology

The analysis focuses on the UK, Denmark, the Netherlands and Germany, - because of their largest installed capacity in 2011 and potential contribution to European offshore wind industry. We analyse how the innovation systems function based on qualitative and quantitative information from several sources: scientific and industrial literature, patent analyses, European project collaboration, 4C Offshore Wind Database (version October 2010), over 30 stakeholders' interviews (see reference list; due to confidentiality reasons not all names and functions can be published). During the interviews, experts and stakeholders from the UK, Denmark, the Netherlands and Germany were asked to express their views on the functioning of the national TISs following the diagnostic questions presented in Table 1.

We then compare the functioning of the national TISs and draw, wherever possible, general conclusions for the European offshore wind TIS. Based on the data we score each system functions for all four

[60] Since innovation does not recognize an optimum, it is impossible to judge whether there is *enough* of it. Our discussion on the *sufficiency* of innovative activity in the areas defined by the system functions is, therefore, based on the qualitative evaluation of the capacity of the four analysed systems to grow and accelerate. At the same time we refrain from any quantitative assessment in the context of reaching the European and national targets.

innovation systems using a 5-tier scale of absent (1)-weak (2)-moderate (3)-strong (4)-excellent (5). This is graphically presented in Fig.7.

The analysis has been reviewed by 10 offshore wind experts, which provided additional information about the systems. Based on the coupled structural-functional analysis we identify the system *weaknesses* that block the functioning of the four analysed TISs.

4. Analysis of innovation system functioning

4.1. Experimentation by entrepreneurs (F1)

To evaluate entrepreneurial experimentation in the four analysed countries we studied the number and the type of actors involved in the offshore wind sector (incumbents[61] vs. start-ups), the number and type of experimental projects of these actors, actors' involvement in national versus international projects and specialisation along the value chain.

Fig. 1 and 2 present the value chain for offshore wind in the Netherlands and the UK. The value chains for Germany and Denmark are not provided due to space limitations. Analysing the value chains leads to the following observations.

1. Both figures show that despite the technology is still in an infant stage, a wide range of actors are present in the value chain. Interestingly, both incumbent actors from other fields and many new entrants are present. Important incumbents are the utilities (e.g., RWE (DE) and (DK)), oil and gas companies (Shell (UK, NL)), engineering firms (Siemens (DE)), offshore companies (van Oord (NL) and Mammoet (NL)) and financial firms (Typhoon Capital (NL)). Established firms that are diversifying into offshore wind bring the necessary capabilities to this emerging sector. From an innovation perspective, involvement of such (incumbents) companies effectively serves the purpose of knowledge cross-fertilisation, investor confidence and eventually the expansion of the offshore wind market.

2. The development, operation and management of wind farms are predominantly carried out by national companies and so is the ownership of the projects. Large utilities such as E-on (DE), Centrica (UK), RWE (DE), Nuon (NL), Dong Energy (DK) and Eneco (NL) dominate as owners, developers and operators of the farms. This dominance is observable mostly in the UK and least in Germany where only 39% of approved offshore wind projects are owned by large utilities. The remaining shares in German wind farms are held by a great number of developers, financial investors and municipal utilities [14]. As such, Germany can be characterised by a more dispersed wind park ownership structure compared to the UK, Denmark and the Netherlands.

3. The Dutch actors are very internationally oriented and specialise in offshore construction [15-17]. There are more Dutch companies, especially offshore construction firms e.g. Ballast Nedam, Van Oord, Mammoet present in the foreign value chains (see Fig. 1) than the English firms (see

[61] The term *incumbent* in innovation studies denotes an existing usually large company that has a stable position on the market.

Fig. 2). Moreover, contrary to the UK, a greater number of Dutch companies are involved in international rather than domestic projects. This implies that the Netherlands has got a very well developed construction industry (foundations, substations, and wind farm installation) for which the national market is too small. The involvement of Danish and German companies in national and international projects is relatively equally spread.

Figure 1. Dutch actors involved in the Dutch and foreign projects along the value chain in 2011[62]

4. The UK innovation system seems most open to foreign actors and misses a strong industrial base. Fig. 2 depicts the UK offshore wind value chain and discerns UK actors (bottom) from actors from abroad (top)[63]. There are more non-UK than UK companies all along the UK value chain. This is not surprising. The UK, unlike Germany and Denmark, does not have a single manufacturer of the required 3–7 MW+ wind turbines. Also, the value chain for local components is small and not very complete [19], while in 2010/2011 the UK had the highest installed capacity and more offshore wind farms than any other European country. This indicates that the UK has got a developed market (demand) but a small national industry (supply) [20].

[62] The value chain figures show only the main actors and are therefore purely indicative. We do not strive to be exhaustive here but in the analysis we fully acknowledge the dynamics in the field. For example one of the missing Dutch companies in the 4C database and in this figure is Econcern/Evelop. The company developed projects in UK (1), Belgium (1) and Germany (4) and was an important player in the Dutch value chain but went bankrupt and does not exist anymore [18]

[63] Note the difference with Fig. 1 that depicts the value chain for Dutch actors, not the value chain in the Netherlands.

Figure 2. The UK and international actors involved in UK offshore wind projects along the value chain

5. Two wind turbine manufacturers: Siemens (DE) and Vestas (DK) dominate in Europe, having supplied respectively 51% and 39% of installations in 2011. These two companies are followed by REpower (DE/IN[64]) (3%), Areva (FR/DE)(<1%) and Bard (DE)(1%) [58]. EWEA [58] lists also a number of new entrants to the offshore wind turbine manufacturing business, such as Bard (DE) and Nordex (DE), both developing large 6 MW+ wind turbines. Other newcomers from outside of the four analysed countries but important for the entire European offshore wind innovation system include: Alstom (FR), AMSC (US), Condor (UK/IT), DSME (KR), Envision (CN), Gamesa (SP), GE (US), Goldwind (CN), Northern Power Systems (US), Samsung (KR), Ming Yang (CN), Sinovel (CN), Hyundai (KR) and XEMC–Darwind (CN/NL) [18,19].

6. Similarly, the substructure supply is dominated by established companies such as BiFAB (UK), Bladt (DK) and Sif (NL) and Smulders (NL); with a few new entrants such as Heerema (NL) and EEW (DE), Strabag (DE) and Weserwind (DE) [3]. The presence of new entrants in the system is important so that the levels of competition and technology price stabilisation are increased. Their emergence also indicates that the value chains are quite dynamic.

---

[64] With major shares of Shuzlon (India)

7. The range of subsea high voltage cable suppliers however is limited and none of the established suppliers are located in the analysed countries: ABB (SE/CH), Nexans (FR) and Prysmian (IT). NKT (DE) and General Cable (US) are the only new entrants to high voltage cable market.

8. The leading suppliers of vessels in Europe are A2Sea (DK) and Ballast Nedam (NL), Seaway Heavy Lifting (NL) and Jumbo (UK). According to EWEA [3] there are hardly any new entrants in this field and none from any of the four analysed countries. Some sources [21] expect a number of new vessels to start operating at several European offshore wind farms in 2012. However, if the new vessels do not start operating and the field develops further, the current cable and vessels suppliers may face manufacturing capacity limits [3].

9. We observe large specialisation differences along the value chain per country. Where Denmark and Germany dominate in terms of wind turbine manufacturing and related capabilities, the Dutch heavily specialise in offshore construction. The UK does not have such a strong national industry and is very dependent on foreign actors to fulfil their national ambitions. From the European offshore wind TIS perspective this specialisation along the value chain is not problematic, because the four countries seem to complement each other. Similarly, the limited number of the UK actors in the UK value chain is not problematic either as long as foreign companies do the job. However, these dependencies between nations could turn out to be problematic. In the UK a too strong dependence on foreign actors may result in a loss of legitimacy and political support at the national level, as national incentives for offshore wind primarily lead to the building up of an offshore wind industry abroad. This situation would then have serious impacts on entrepreneurial activity in all countries. Because of a lack of a strong home market, especially in the Netherlands and Denmark, the offshore wind industry in these countries (and the UK) would be most affected. German entrepreneurial activity would probably be less affected. The rather complete European offshore wind TIS may then turn out to be unsustainable due to too strong interdependencies.

In that view we evaluate the function F1 Entrepreneurial experimentation at the level of: moderate (3) in the UK, excellent (5) in Germany; and (conditionally) strong (4) in the Netherlands[65] and in Denmark. Even though these are high scores, we suggest that there are more entrepreneurial experiments needed in all four countries to reduce risks and increase experience in the field.

4.2. Knowledge development (F2)

To evaluate the knowledge developed in the four analysed countries we studied the number and the type of actors involved in the knowledge development (knowledge institutes vs. industrial parties), as well as the type of knowledge developed (tacit or codified). The data is based on academic publications, patent data and interviews with experts of the field.

[65] This score is to acknowledge the Dutch entrepreneurial activities abroad in the absence of strong domestic market. The function Market formation is assessed in the later part of this report.

The main knowledge institutes that perform research on offshore wind in the four analysed countries are listed in the Table 2. It provides an overview of: (i) the total number of knowledge institutes per country, (ii) the total number of publications on offshore wind per analysed country, and (iii) the top three organisations publishing in the field per country including the number of publications per institute and the national percentage.

Table 2. Number of knowledge institutes and scientific publications on offshore wind by the UK, Danish, Dutch and German actors (1994-2010)[66]

Country	Total no of organisations	Total no of publications	Most important organisations (incl. number of publications and national percentage)
UK	170	451	Univ Durham (21, 5 %) Univ Strathclyde Scotland (18, 4%) Univ Oxford (16, 4%)
Denmark	66	236	Risø Natl Lab (68, 29%) Univ Aalborg (33, 14%) Tech Univ Denmark (32, 14%)
Netherlands	43	140	Delft Univ Technol (44, 31%) Univ Utrecht (13,9%) ECN (13, 9%)
Germany	194	426	Univ Bremen (28, 7%) Leibniz Univ Hannover (23, 5%) Alfred Wegener Inst Polar & Marine Res (22, 5%)

The total number of knowledge institutes involved in publishing in both Denmark (66) and the Netherlands (43) is much lower than in Germany (194) and the UK (170). However, the Danish and the Dutch knowledge institutes rank highest internationally in terms of the number of publications on offshore wind. In particular, the Danish Risø National Lab for Sustainable Energy and the Dutch Delft University of Technology (TU Delft) excel in their number of journal articles per institute (68 and 44 respectively).

To study the type of actors involved in the knowledge development a list of educational organisations giving courses dedicated to renewable energy, and wind in particular is shown in Table 6 (in Section 4.6). The list is long and growing in both educational categories: vocational and academic. However, only a small number of programmes specialise in the particular needs of the offshore wind sector (these are marked with a *). This overview does not include organisations that offer individually arranged courses (such as PhDs).

To study the knowledge infrastructure in offshore wind we also identified patents by the keywords *offshore wind*. Table 3, presents an overview of the most important patent classes in offshore wind.

66 In multi-organization papers a joint paper by two research organizations from the same country is computed once in the country profile and once for each of the author organizations.

Table 3. Most important patent classes relevant to offshore wind

Patent code	Description
F03D	WIND MOTORS
B63B	SHIPS OR OTHER WATERBORNE VESSELS; EQUIPMENT FOR SHIPPING
B01D	SEPARATION
H02K	DYNAMO ELECTRIC MACHINES
F03B	MACHINE OR ENGINES FOR LIQUIDS
E21B	EARTH OR ROCK DRILLING
E02B	HYDRAULIC ENGINEERING
F16L	PIPES; JOINTS OR FITTINGS FOR PIPES
B29C	SHAPING OR JOINING OF PLASTICS

Most patents are classified in the area F03D (wind motors) and the large majority of these patents were filed after 2002. For illustration, Fig. 3 shows the amount of wind motor patents from Vestas over time.

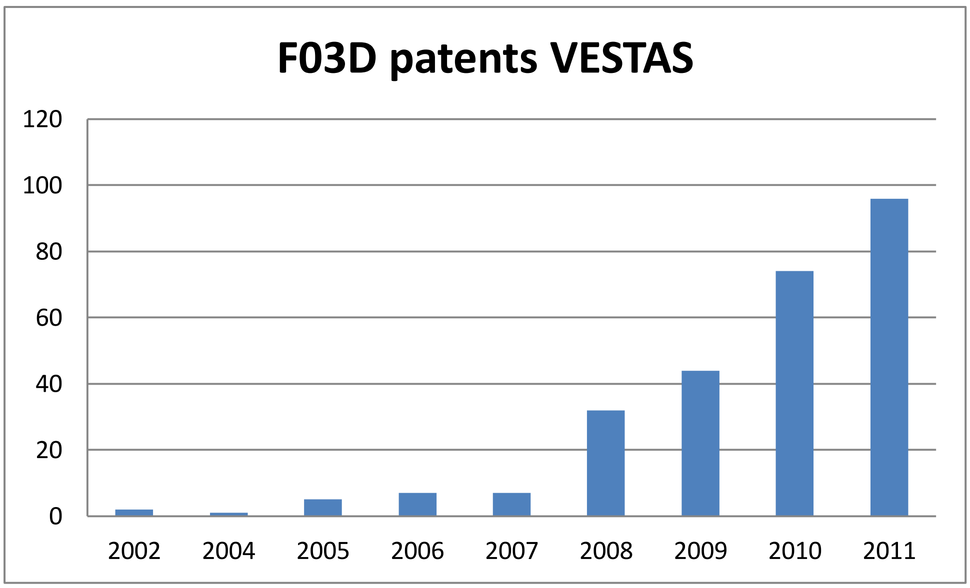

Fig. 3. Overview of wind motor patents from Vestas over time. x-axis: year, y-axis: no of patents

In the patent class F03D, the main companies involved in manufacturing wind turbines according to the EPO patent analysis are General Electric (US) with 453 patents, Vestas (DK) with 344 patents and Siemens (DE) with 193 patents but there are also many new entrants in these areas who experiment with new designs and in doing so make the field very dynamic. The UK and Dutch organisations are not dominant players in this respect and no significant patenting activity comes from universities in any of the four countries under study.

Interviews with various offshore wind actors revealed that it is the engineering knowledge that drives the offshore wind innovation system. This knowledge is produced by companies and is not patented nor published[16,17], [22-25], [19]. For example, many German firms are world leaders in dedicated R&D, ground-breaking wind turbine and other wind technology development, and implementation of advanced offshore wind technology. Germany was the first country in the world to install an offshore

4.5 MW wind turbine in 2002: the Enercon E-112. Enercon later decided not to enter the offshore market. Another two offshore dedicated wind turbines were installed in 2004: the REpower 5M and Multibrid M5000. In 2005 Aerodyn Energiesysteme developed a third 5 MW wind turbine for BARD within a record nine-month period, of which two prototypes were installed in 2007. Also innovative foundations were developed by REpower and Weserwind (jacket), and BARD (tripile) [19]. Because of the tacit character of this knowledge, and for reasons of not losing their competitive advantage, companies do not codify nor eagerly share this knowledge [16,19], [26-28], which makes its analysis very difficult.

The above data shows that there are enough competent actors that can develop both codified as well as tacit types of knowledge in all four analysed countries. From the perspective of national TISs, however, there are two points of attention. Firstly, the differences in concentration of codified knowledge production may imply for the UK and Germany the possible risk of insufficient focus and critical mass because of the distribution of resources in knowledge development. In Denmark and the Netherlands the likelihood of insufficient diversity and variety in scientific knowledge development might exist. As much as the dispersed model is useful for the training of future engineers all over the country, it may not be sufficient for the provision of advanced education that is closely linked with research [29]. A concentrated model may lead knowledge development in the field more efficiently, and make it more visible and accessible to companies who want to cooperate. A minimal amount of focus and critical mass is also necessary to contribute to and compete in the international knowledge development.

In the opinion of the interviewed stakeholders the level of knowledge developed in Europe on offshore wind is sufficient [22,23], [30-35]. They also agree that the research focus should now shift to making the technology cost effective, particularly in relation to wind turbines and cables. The interviewees also emphasised that although companies do not eagerly share their know-how, there is good access to the European pool of knowledge on offshore wind.

Based on this analysis we evaluate the function F2 - knowledge development at the level of excellent (5) in Denmark, strong (4) in the Netherlands (to acknowledge publications) and in Germany (to acknowledge patents) and moderate (3) in the UK.

4.3. Knowledge diffusion (F3)

To asses if there is enough knowledge exchanged between different actors' groups e.g. science and industry, or users and industry, and across geo borders in the four analysed countries, we looked at the number and type of networks and tried to assess the general accessibility of knowledge. We complement our findings on tacit knowledge diffusion with insights from actors' surveys.

The structural analysis of different types of networks demonstrated that knowledge networks based on collaboration on journal articles are not very extensive. Based on an analysis of the Cordis database, Fig. 4 shows that the UK, Denmark, the Netherlands and Germany are most active collaborators on research projects in Europe. All four countries have strong national research networks (such as the UK Crown

Estate's Offshore Wind Accelerator [36], Renewables Innovation Network [37], Dutch Far and Large Offshore Wind (FLOW) project [38]), the German Center for Wind Energy Research Forwind [39]).

Fig. 4 presents a European collaboration network of organisations aggregated on country level. Its form emphasises the centrality of the different nodes/actors in the network and shows that the UK, Denmark, the Netherlands and Germany are clear leading collaborators in the field in Europe (the four largest circles in the figure).

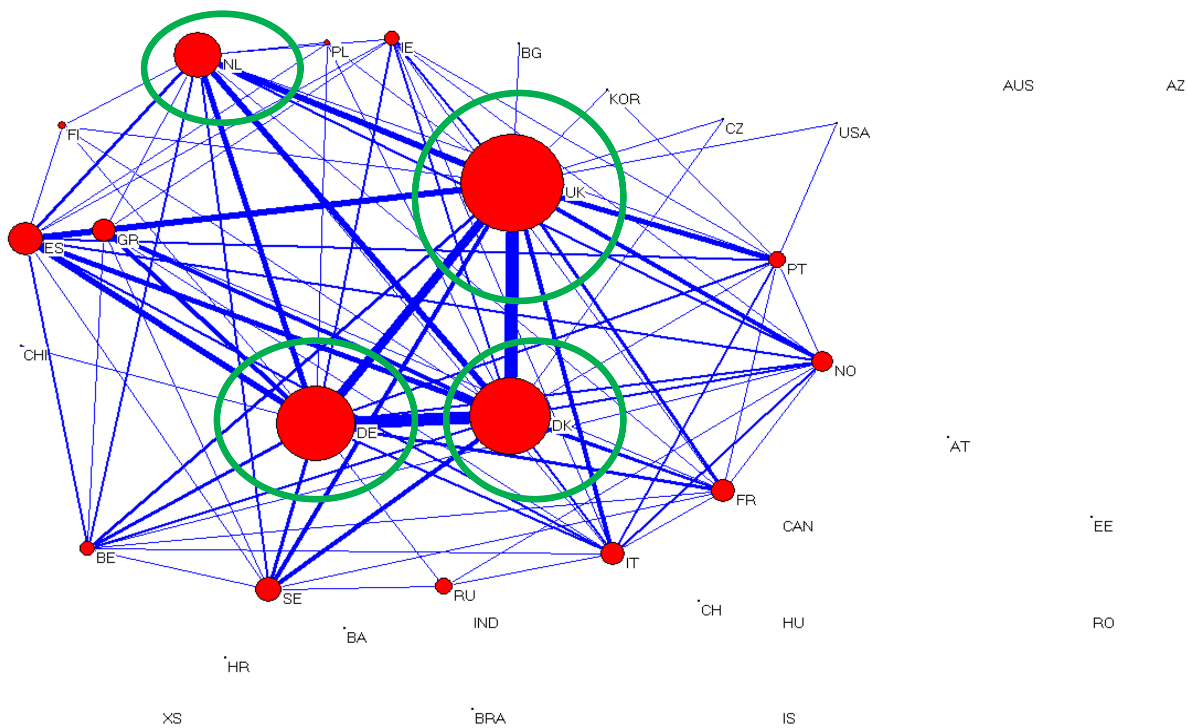

Figure 4. European collaboration network of organisations aggregated on country level. Size adjusted for occurrence in projects, lines lower than 10 removed. The four largest collaborators: the UK, Denmark, the Netherlands and Germany circled

Fig. 5 further specifies organisations that collaborate mostly on European projects (Risø (DK), ECN (NL), TU Delft (NL), Aalborg University (DK), Vestas (DK), University Oldenburg (DE), University Edinburgh (UK)). The project collaborations show, in addition to the main organisations involved in journal publications, also a large number of companies and research organisations that do not publish but do collaborate in projects (Vestas (DK), Dong (DK), Lloyd (DE), Garrad Hassan and Partners (DE), etc).

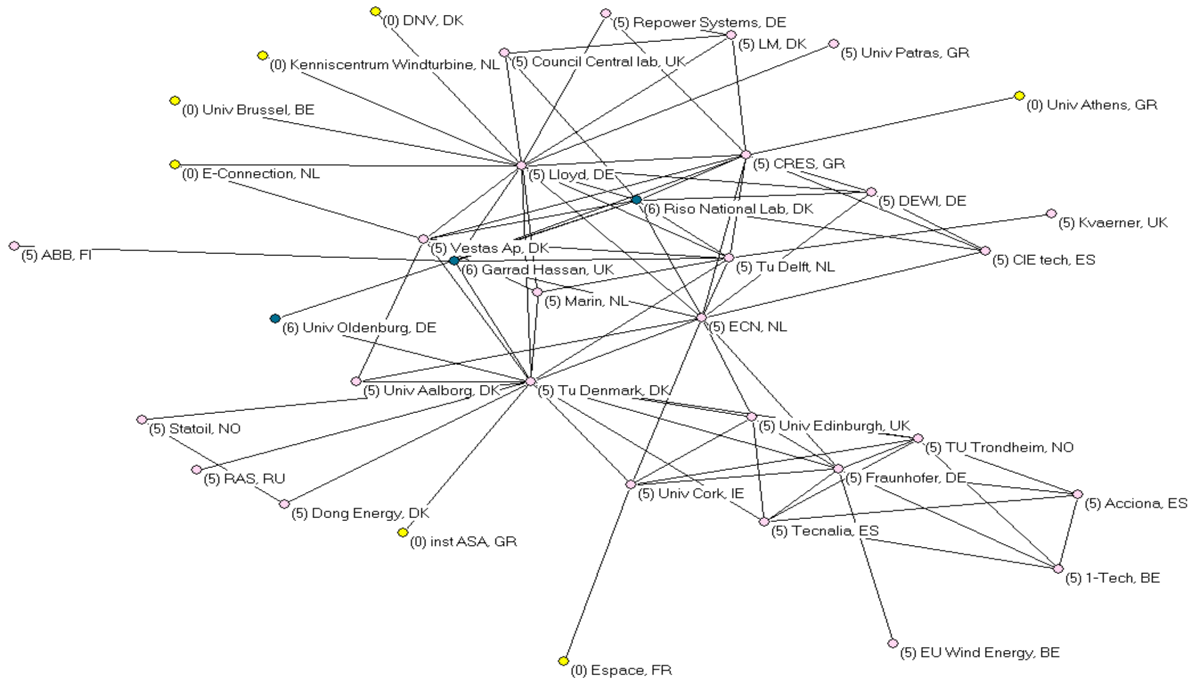

Figure 5. The core of the CORDIS collaboration network (values lower than 3 removed, unconnected nodes are not shown)

In all analysed countries there are very strong lobby and industrial networks [31]. A good network is seen as critical for making the new project bankable and finding a sufficient number of partners[28]. In general there is, therefore a sense of a relatively good level of knowledge diffusion in the offshore wind sector. Parties know each other and, if necessary, through partnerships and common projects they have the possibility to gain access to each other's knowledge[67] [24], [40-45]. In Denmark the Offshore Centre Denmark (OCD) plays a particularly important role in the process of bringing incumbents and start-ups together at common events and pre-arranged meetings [33]. However, as mentioned before, the sharing of technological knowledge is not fully public and freely accessible because companies are wary of losing their competitive advantage. This is reflected by increasing efforts to protect innovations by patents.

We assess the function F3 - knowledge diffusion in Denmark and Germany as excellent (5), strong in the Netherlands (4) and moderate in the UK (3).

4.4. Guidance of the search (F4)

To assess guidance of the search we have analysed the type of actors and their activities that influence guidance of the search; impact of informal institutions on the direction of the search (the level of governmental commitment, presence and reliability of policy goals and vision, expressed expectations);

[67] See for example [61]

and formal institutions (presence and quality of regulatory regimes, policy instruments and permitting procedure).

Table 4 presents an overview of national renewable energy targets per country.

Table 4. Renewable energy targets per country

Country	2020 Renewable energy target (Dir. 2009/28/EC)	2020 National renewable electricity target	2020 Projected offshore wind capacity acc. to NREAP	2020 Projected share of offshore wind in total renew. Electricity (based on NREAP data)
Netherlands	14%	35% (under consid.)	5.2 GW	38%
UK	15%	30%	13 GW	38%
Germany	18%	30%	10 GW	14%
Denmark	30%		1.3 GW	26%
EU27	20%		44 GW	

The 5.2 GW offshore wind capacity in the Dutch National Renewable Energy Action Plan (NREAP) will most likely not be realised since in 2011 the government moved its focus from relatively expensive electricity options such as offshore wind to cheaper renewable options (at least per kWh of final energy produced) such as biogas and geothermal heat.

In the German NREAP, the German government is expecting to achieve a share of 19.6% renewable energy in total energy consumption. The overachievement of 1.6% is an expectation based on current developments but is not considered a national target. As part of the overall renewable target, Germany's federal goal [46] is to achieve 30% of its *electric* power generation from renewable energy sources by 2020. According to the German NREAP renewable electricity as the percentage of total electricity production grows from 10.2% in 2005 to 38.6% in 2020, an overachievement of 8.6%.

The German government has currently the most clear and relatively consistent commitment to offshore wind among the four countries. In particular its decision to phase out nuclear power in the next 20 years[68] serves the large-scale renewable market well, in which offshore wind has a significant share [47]. This commitment provides entrepreneurs with great security with respect to planning and investing [22]. It also makes German firms such as Siemens, Hochtief, OWT, PNE international market leaders [22,23,48]. Denmark has a new government (started autumn 2011) [67], which wants to set the goal to 50% of energy from wind and other alternative energy sources[69]. This raises hopes among the offshore wind industry for better times [26,30,31,33] and high taxes on coal and gas [35]. In the UK, offshore wind is a crucial element of the government's plans to reduce the carbon intensity of the power sector, increase energy security and provide affordable energy to consumers [27,43,44], [49-51]. In the Netherlands the current government, is not seen by stakeholders, as one that has vision or strategy, nor

[68] The plan concerns 17 of its nuclear power plants — which have met around 20% of its electrical power.

[69] At the moment of finalizing this paper the New Danish Energy Agreement outlined the framework for the Danish climate and energy policy until 2020 and the direction until 2050. According to this agreement CO_2 emissions in 2020 will be 34 % less than they were in 1990. Energy consumption will decrease by 12 % in 2020 compared to 2006. Around 35 % of the country's energy will come from renewable sources and almost 50 % of electricity will come from wind. It has also been decided to build a total of 3300 MW new wind power. A part of it is two new large offshore wind farms at Kriegers Flak between Denmark and Germany (600 MW) and at Horns Reef off the west coast of Jutland (400 MW) [68].

does it provide a stable framework for any renewable activities [15,34,52,53]. The guidance of the search provided by the government on the development of the domestic market for renewables is almost absent [54]. Still Dutch constructors do belong to the group of international market leaders but, contrary to the German firms, they are not backed by the national government and a strong home market. This holds considerable future risks forthe Dutch, in case Germany and the UK continue to support national industry.

The national policy goals expressed in the NREAPs and driven by the common EU goals on climate change differ per country. Even though some of our interviewees doubt whether the goals will be realised[70]. Still, from the guidance perspective the goals do constitute relatively stable drivers for the development of the offshore wind system in the four analysed countries and Europe as a whole. They also provide space for industrial activities, as an outcome of which there emerge common expectations of a large market and huge potential.

What the goals do not do is provision of any guidance with regard to grid improvements [15,30], [32-35], [41,42,55]. There are different circumstances regarding grid integration in the four analysed countries. The national governments lack a consistent and coordinated (at the European level) vision on how improvements in reliability and integration of the grid should be carried out [15]. At the same time, there is a strong need to develop a pan-European grid and a cross-Europe regulatory framework and trade policies [2]. Stakeholders believe that a coordinated effort in this respect will strongly drive the development of a European offshore wind. Currently the EU took some preliminary steps towards harmonised grid integration measures. The first being a memorandum of understanding that was signed by ministers from 10 EU countries to develop an offshore grid that would serve entire Northern Europe.

Overall, we conclude that the European goals provide a strong guidance for the offshore wind system development. At the national level, Germany, due to the commitment of the government and a feed-in tariff that functions well, has the strongest (5) guidance of the search (function 4). The UK is evaluated at the level of: strong (4), Denmark: moderate (3) while the Netherlands as weak (2) due to a non-existent guidance by government but a strong one by the industry.

4.5. Market formation (F5)

To evaluate market formation in the four analysed countries we have looked into the size of the market (installed capacity, wind parks consented and planned) and the supporting incentives.

As can be seen from Fig. 6, the UK with 1586 MW has the most grid connected wind capacity next to another 4308 MW under construction [3]). UK is also considered the largest global market for offshore wind [27,43,44,49]. In Germany offshore wind is developing into an extremely attractive market. Although the amount of grid connected projects is still modest (195 MW at the end of 2011), the summed capacity of consented projects is by far the greatest of all four countries analysed. Markets in both countries constitute the most profitable offshore wind development areas in the financial attractiveness ranking [56].

[70] The interviewees do not believe in the power of non-compliance mechanisms (e.g. [32], [40]).

At the end of 2011, Denmark has the second largest grid connected offshore wind capacity (854 MW). In 2012 the 400 MW Anholt wind farm operated by Dong is added. The next step will be the erection of 6 demonstration wind turbines in Fredericshavn in 2013. Compared to the UK and Germany, Denmark, however, does not have detailed long-term plans for developing Danish offshore wind capacity beyond 2013. The Dutch market is also very limited with no new farms in the pipeline. Still, three large capacity wind parks of total 1.8 GW (Bard 1 and 2 and Q10) were already consented and their construction is planned for 2012/2013. Feed-in budget for these farms, however, were already decided upon by the government that fell in February 2010. The likelihood that other consented Dutch projects will finally be built is therefore very small.

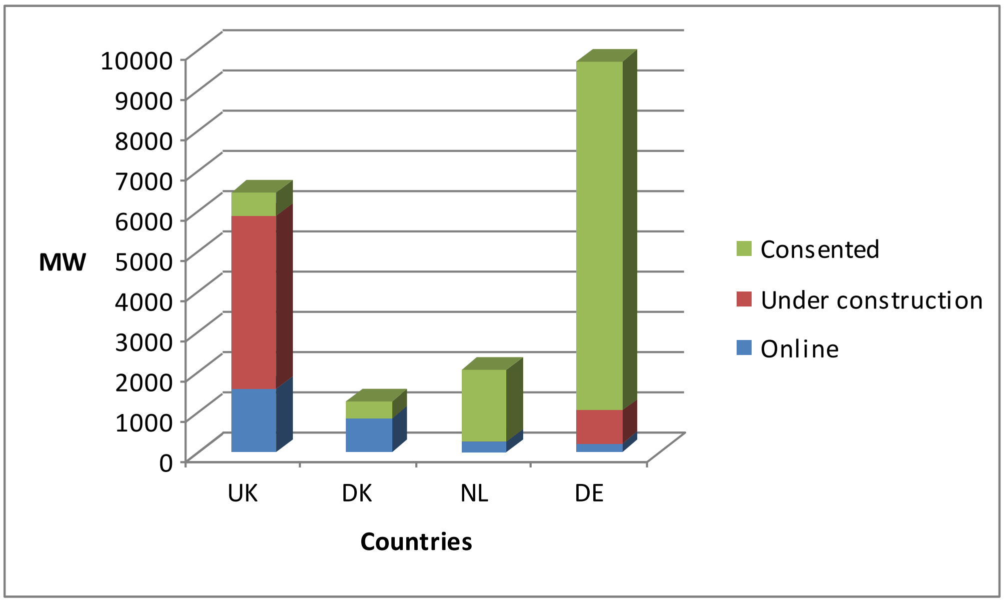

Figure 6. Overview of MW installed (online), consented and under construction per country [3]

There is a great diversity in financial incentives and policy instruments applied in various countries (see Table 5). Many interviewers consider this diversity a serious barrier [22,23,25,41,42,53].

Table 5. Offshore wind policy instruments in the four analysed countries

Country	**Main policy instrument**	**Other financial incentives**	**Current support [€/MWh] KPMG (2010)**
Netherlands	Feed-in premium	Fiscal investment deduction scheme	Tender outcome (if any)
UK	Renewable Obligation Certificate(ROC)		122.2 €/MWh certificate price for 2ROCs 57.9 €/MWh market price for electricity incl. LEC=180.1 €/MWh
Germany	Feed-in tariff	soft loans via KfW (state owned bank) funding programmes	35€/MWh basic tariff 130 €/MWh initial tariff 20 €/MWh sprinter bonus (start up until 1 Jan 2016)
Denmark	Feed-in tariff		Tender outcome (if any)

The UK development of offshore wind is being driven by the Renewable Obligation Certificates (ROCs) regulation. Within the scheme energy companies are obliged to provide defined amounts of renewable energy. Failure incurs a fine, which is transferred as revenue to others who do meet the requirements. That means that there is no fixed price per ROC. There is, furthermore, hardly any manufacturing in the UK and the risk for the UK is that Germany may very soon take over the leadership with regards to the size of the market.

The amount of compensation in the German feed-in tariff follows the principle of cost-covering compensation and is based on the specific electricity production costs. The plant operator receives the feed-in tariff from the grid operator. Compensation payments are distributed equally to all operators and passed on to the electricity consumers (i.e. the feed-in tariff is not paid from the state budget). The feed-in tariff is granted for 20 years and there is no annual cap.

The Dutch feed-in premium (Stimuleringsregeling Duurzame Energie +, SDE+) is the follow up regulation of the SDE. The “old” SDE for offshore wind was based on (cost-effective) ranking of competing offshore wind projects (given a limited subsidy budget for offshore wind). In the new SDE+ all renewable energy technologies together need to compete for one (limited) budget. This implies that in the new situation offshore wind has to compete with lower cost renewable energy technologies.

The most important incentive to promote offshore wind in Denmark is fixed feed-in tariff available for wind parks established via a governmental tender process, where the required tariff is a part of the bidding from the various operators. Currently there are no open tenders for offshore wind in Denmark.

Based on these considerations we conclude that the Netherlands and Denmark, without further steps, are in a danger of losing market shares at a European level. Denmark, due to low increase in installed capacity and consented projects and no detailed long-term vision of the government; The Netherlands, due to lack of projects being in the pipeline and a lack of level playing field for offshore wind developments compared to cheaper renewable energy technologies. We evaluate the function F5 market formation: in Germany at the level of excellent (5), in the UK as strong (4), while in Denmark and in the Netherlands as weak (2).

4.6. Resource mobilisation (F6)

To assess the function resource mobilisation we have studied the availability of financial resources, of competencies and expertise, and of physical infrastructure.

Financial resources

Until now the availability of financial resources (capital costs) has not been very problematic. However, availability of funds (capital costs and R&D funds) does create a significant barrier [15]; [17,22,23,27,28,31,32,35,44,45]. Due to the economic crisis in 2007 banks have decreased their loans which makes many projects financially unviable. This implies that increased numbers of banks and (international) financial organisations need to be involved in the financing of one project and a number of insurers to take the risk on board [14,17,28,57,58]. This has particular implications for the great number of consented and planned wind farm projects (as depicted in Fig. 6). Also the funding for non-nuclear energy R&D proposed in the EC's 2014-2020 budget is very small and considered insufficient to achieve the EU's 20202 renewable and climate targets [58].

Germany and the UK seem to have the most certain financial situation of all four countries. The financial certainty in the UK is assured until 2014, with an average of €2,3bn p/a (GBP 2bn p/a). In expectation of a big market and following the ambition of the UK government to make offshore wind a part of the UK renewable energy mix – work started on identifying additional sources of capital that would allow for funding the Round 3 projects (2017-2022) [69]. The UK also allocated significant investments to the development of harbour infrastructure. It is a similar situation in Germany. Amongst the reforms the government confirmed that the state-backed KfW infrastructure bank will provide up to €5bn of financing to 10 offshore wind farms, and also announced that the planned reduction in subsidies for offshore wind developers will be delayed from 2015 to 2018 [70].

In Denmark there are many pension funds who invest a great deal in wind (financial and industrial investments) [71]. They see a long-term profit from such investment because wind turbines are considered very reliable and wind is generally perceived as a safe business. By comparison, in the UK there is not enough confidence in technology (wind turbines are expensive so low-risk wind turbines are preferred) which causes many pension funds to be locked-in, financing traditional big infrastructural projects [45]. These projects are seen by the pension funds as more reliable than the renewable offshore projects, so the UK Prime Minister needs to call on investment, pension and sovereign wealth funds to back offshore wind projects [72].

In the Netherlands two large offshore wind farms are going to be constructed in 2012/2013, but the perception remains that offshore wind is a very expensive option in the near future. Despite large subsidies from the Dutch government, wind power provides merely four percent of Dutch electricity. The Dutch government is willing to invest in innovation to bring down the costs of offshore wind energy, but prices must come down considerably before large scale investments can again be supported. For the time being therefore, the government has stopped the subsidies for offshore wind power generation.

Overall, to meet their national renewable targets all four countries will face financial challenges. Increased levels of investments will be necessary for new wind farms and incentives for technology development (through R&D and demonstration), grid improvements and integration, harbours adjustments and development of clusters around the ports.

Human resources

Currently, offshore wind is an attractive, well-paid field in Germany and Denmark [23,26,30,33] but in the Netherlands young people are sceptical[15]. Also in the UK it still pays better to work for oil and gas than for the offshore wind sector [40]. This has very serious consequences for the UK who has a rapidly growing market but a quite underdeveloped domestic value chain. The UK faces a serious shortage of personnel with all types of offshore wind skills and experience: electrical, structural design, power engineers, construction and commercial managers and environmental specialists [59]. In the remaining three countries the situation is better, still various types of expertise are missing [25,27,40], [41-43], [48,53,60,61,66].Denmark additionally expects a generation gap when current professionals will have to retire, and there will be either too few new experts, or they will have little practical experience [33,53] Shortage of skilled labour makes companies educate personnel internally [16,17,23,24] or attract them from other companies. This serves for a relatively high level of mobility of offshore wind experts in Europe [22,35].All four countries make attempts to address this problem by designing an increasing number of offshore wind educational programmes and courses (see Table 6). Denmark and the Netherlands are frontrunners in academic and polytechnic training. programme

Table 6. Organisations offering renewable energy courses relevant for offshore wind field[71]

Country	Vocational courses	Academic/ Polytechnic BSC level	Academic/ Polytechnic MSc level	Academic/ Polytechnic PhD
UK	Nat Ren Energy Centre (NAREC) Northumberland College Lowesift College* Falk Nutec* East Coast Training Services* Siemens*	Univ of Exeter Univ of Cumbria* Univ of Birmingham Univ of Nottingham Univ of Dundee*	Cranfield University* Loughborough Univ Swansea Univ Univ of Birmingham Univ of Centr Lancashire Univ of Dundee* Univ of Edinburgh* Univ of Exeter* Univ of Leeds Univ of Nottingham	UK Energy Research Center* Univ of Dundee* Univ of Central Lancashire* University of Strathclyde*
Denmark	Danish Univ Wind Energy Training (DUWET)* Offshore Center Denmark* Survival Training Center* AMU-Vest* Falck Nutec* Maersk Training Centre A/S* EUC Vest* Danish Wind Power Academy*	Business Academy South-West*	Aalborg Univ* Techn Univ Denmark*	Risø * Techn Univ Denmark*
Nether-lands	Hoogeschool van Arnhem and Nijmegen (HAN)* Maritime Campus NL* NHL* ROC Kop Noord Holland* DUWIND* DHTC* Ascent Safety* Van Oord Academy* Hogeschool Den Bosch	Delft Univ of Techn* (HAN)* Outsmart*	Delft Univ of Techn*	Delft Univ of Techn*
Germany	Education Centre for Renewable Energies (BZEE)* Ren Agency RENAC Deutsches Wind Energy Institute ForWind* Edwin Academy Univ of Kassel Deutsche WindGuard* Falck Nutec* Moog		Aachen Univ of Applied Sciences Univ of Applied Sciences Bremerhaven Univ of Flensburg Univ of Hanover Univ of Kiel Univ of Oldenburg Univ of Applied Sciences Hamburg Univ of Applied Sciences	Oldenburg Univ Univ Stuttgart* Vestas (professorship)* Schleswig Holstein (professorship)* Univ of Applied Sciences Hamburg

[71] Based on [62] and websites of the organizations accessed on 2 Feb 2012

			Saarbrücken	
European/ Internatio nal	GL Garrad Hassan* World Wide Energy Institute		European wind energy Master (EWEM) (4 techn Univ in North Europe)* EUREC & 8 Univ Siemens* European Academy of Wind Energy EAWE*	

(*) Denotes that the organisation gives a dedicated offshore wind module, specialisation or introduction within their educational programmes portfolio

There is also intensifying European collaboration on education, which is a sign of the need to harmonise and coordinate the system at the European level. The European Academy of Wind Energy (EAWE) provides many courses on offshore wind. EAWE is a registered body of research institutes and universities in Europe (the UK, Denmark, the Netherlands and Germany included) working on wind energy research and development [73]. The training and educational programmes are thus quite recent and sill insufficient to the needs. Europe-wide cuts on funding for the higher education sector pose additional threats [58].

Physical resources

With respect to physical resources, three issues repeatedly dominate the discussion in all four analysed countries: the reliability and cost of technology, availability of cables, deficiency of the grid infrastructure and problems related to grid connection [63].

Especially, grid stability and capacity is an enormous issue in all of Europe[15,22,23], [26-28], [30]; [32-35], [41,42,53,55,80]. The European grid requires modification and renovation to be able to accept larger amounts of renewable energy [58]. There are also difficulties with securing grid access with financial implications relating to where the connection takes place. Trends suggest, for example, that linking wind parks into hubs before connecting them to the grid is less expensive than connecting them individually but no common grid strategy is as yet developed [64]. All four countries have works underway to improve their part of the grid. However, the indecisiveness of many national governments with regards to the future energy mix, and in particular the renewable share, makes any common action rather difficult [55,74,75].

Regarding cables' availability, there are issues with fluctuating copper prices and a general lack of, especially the high-voltage export cables [23,41,76,77]. Cable companies complain that cable orders for offshore wind farms come too late for them to timely and economically deliver the order. This often makes the costs of wind farm project suddenly higher than anticipated [40].

Scarcity of vessels is not found to be very problematic at the moment of analysis. However, many interviewees emphasised that innovations are needed to adjust the vessels for operation in deep waters (>50m), and for performance of different tasks [16,17,24,27,40,41]. Presently around 50-60 different types of dedicated vessels are needed for one farm installation. In the future, if the offshore wind system develops, the scarcity of specialised, deep water vessels may therefore become a serious constraint [78].

Finally, all countries also have a good harbour capacity, particularly the Netherlands, the UK and Denmark serving the oil and gas industry. However, almost all harbours need to be adjusted to be able to serve the offshore wind operations [3]. Some, such as Rotterdam, face societal opposition because their adjustment to meet offshore wind standards would imply territorial extension into the city and intensification of activities, entailing increased noise, transport and pollution.

We assess function F6: resource mobilisation in the following way: financial resources in the Netherlands as weak (2), in Denmark moderate (3), in Germany and the UK strong (4). We rate human resources as strong (4) in Germany and Denmark, moderate (3) in the Netherlands, weak (2) in the UK. Physical resources: weak (2) in the UK and moderate (3) in the three remaining countries.

4.7. Legitimacy creation (F7)

To evaluate if there is enough creation of legitimacy we have analysed the level of resistance to technology, the perceived level of competition between technologies and the extent to which the formal and informal institutions increase legitimacy.

In terms of legitimacy in specific countries, much depends on the extent to which offshore wind is needed to meet the national renewables target. A second factor is the extent to which the national governments see offshore wind as a means to develop national industry and create jobs. In Germany and the UK, for example, the national visions, the support programmes and measures are the most developed. They are therefore considered by the interviewees as contributing most to increasing the legitimacy of offshore wind. Also Denmark (with the new greener government) sees offshore wind as a major future contributor to the national energy production [26]; [30,31,33,35]. In the Netherlands: the lack of vision, absence of any consistent programme and poor subsidy scheme, are the factors most limiting the legitimacy of this renewable energy technology [15,34].

The informal institutions, especially the expectations regarding the robustness and availability of technology and markets, are in our view very optimistic. However, the technology will not have proven itself for another several years. If it does not, the failed expectations may create tensions. Risk perception is another issue that is of great importance for this very capital intensive sector. The increased levels of risk are due to lack of confidence in technology [42]. Banks are often risk-avoiding and therefore unwilling to finance wind farms comprising new wind technology without track record [17,25,27,53]. At the time of the financial crisis many banks lowered their offshore wind energy project funds making it difficult to install a wind farm without involvement of more financial organisations [28]. Furthermore, uncertainties about the grid connection and overall lack of alignment of the vision on grid improvements, additionally hinder the legitimacy creation.

None of the analysed countries reveal any significant societal opposition to offshore wind farms as long as the wind turbines are not visible from the shore and there is no huge impact of construction on the local public [16,17,22], [24-26], [30,31,33,34,40,48,53, 65]. We therefore rate function F7: creation of legitimacy at the level of weak (2) in the Netherlands and strong (4) in the UK, Germany and Denmark.

4.8. Comparison of overall system functioning

Comparison of the functional pattern of the four offshore wind innovation systems (Fig. 7) reveals that entrepreneurial activities are relatively strong in all four countries but are strongest in Germany. In Denmark knowledge creation excels while the UK scores relatively low. Knowledge diffusion is strongest in Germany and Denmark but low in the UK. Market formation processes are by far the best in Germany, good in the UK but very weak, almost non-existent in the Netherlands and Denmark. Resources mobilisation is equally weak in all four analysed TISs, while legitimacy creation scores on average slightly higher. Still it is equally low in all four countries.

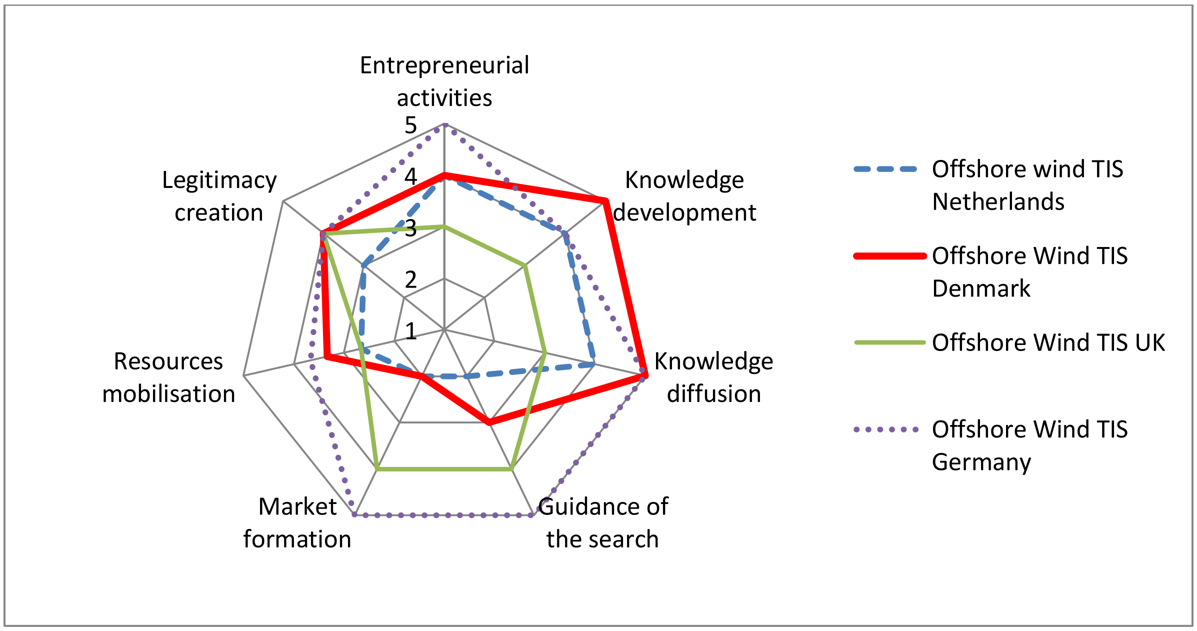

Figure 7. Comparison of system function fulfilment in four analysed countries

Based on this analysis we can conclude that there is not only a strong need for, but in fact already an emergence of, a European offshore wind innovation system. Fig. 7 shows the extent to which the national TISs contribute to the European innovation system. A strong indicator of European system emergence is the visible complementary specialisation of the four countries in entrepreneurial experimentation and knowledge creation. While in the national context this specialisation may have rather negative implications such as loss of national legitimacy or leakage of financial resources, from the European perspective it works to the advantage of the sector.

5. Conclusions and challenges for the European Offshore Wind TIS

Offshore wind technology holds the potential for tackling major energy issues, climate change problems and creating jobs and economic growth. However, to develop further, three innovation system's processes require particular policy attention. These processes include: resource mobilisation (as described by function F6), market formation (function F5) and legitimacy creation (function F7). The processes are hindered by either the absence or by the malfunctioning of the specific structural elements of the innovation systems. Based on our analysis we suggest that to support the formation of the European offshore wind innovation system, the following issues require prompt policy attention:

First, is has become evident that national policies, instruments and regulatory frameworks differ strongly and are not aligned. Similarly, a uniform European grid strategy and electricity trade code is still lacking. A more European perspective on this industry, instead of individual national perspectives, would be beneficial for the offshore wind sector.

Second, this emerging sector is experiencing shortages of skilled labour. This is most likely one of the most serious problems in the near future as the sector expands The development of adequate training programmes proves to be a time consuming process and needs to commence now.

Third, the costs need to be reduced and the reliability of offshore wind farms must increase. This will logically be the result of increased market size and cumulative learning experiences. However, due to the high capital costs and reduced liquidity of financial markets there is a clear trend towards avoiding experimentation with new designs and new construction methods as it may increase risks. We observe that this technological field is too immature to avoid investing in innovative procedures and technologies.

Fourthly, the grid infrastructure requires renewal with respect to better access and expansion to accommodate growing amount of renewable energy. Because of the lack of common European vision and coherent electricity market, grid issue is not only a technical obstacle but also an institutional barrier requiring a stable regulatory framework at the European level.

We recommend that an orchestrated policy effort is applied, built around the above challenges, in order to strengthen the development and functioning of the European offshore wind innovation system. This would be essential for the diffusion of offshore wind technology in Europe and, in the long run to the achievement of the European 2050 vision of moving to a competitive low carbon economy [1].

References

[1] EC. A roadmap for moving to a competitive low carbon economy in 2050. 2011

[2] EC. Energy 2020. A strategy for competitive, sustainable and secure energy. 2011.

[3] EWEA. Wind in our sails - The coming of Europe's offshore wind energy industry. The European Wind Energy Association. 2011;11

[4] EEA. European Environmental Agency Technical report 6/2009: Europe's onshore and offshore wind energy potential. An assessment of environmental and economic constraints. 2009

[5] EC. Innovation Union http://ec.europa.eu/research/innovation-union/index_en.cfm accessed 04/2012

[6] Negro SO, Alkemade F, Hekkert MP. Why does renewable energy diffuse so slowly? A review of innovation system problems. Ren Sust Energy Review 2012;16: 3836-46

[7] Wieczorek AJ, Hekkert MP. Systemic instruments for systemic innovation problems: A framework for policy makers and innovation scholars. Sci and Publ Policy, 2012;39:74-87

[8] Hekkert MP, Suurs R, Negro SO, Kuhlmann S, Smits REHM. Functions of innovation systems: A new approach for analyzing technological change. Techn Forec and Soc Change, 2007;74:413-32

[9] Bergek A., Jacobsson S., Carlsson B., Lindmark S., Rickne A. Analyzing the functional dynamics of technological innovation systems: A scheme of analysis. Res Pol, 2008;37:407-29

[10]. Markard J, Truffer B. Technological innovation systems and the multi-level perspective: towards an integrated framework. Res Pol, 2008;37:596–615

[11] Crawford S. Ostrom E. A grammar of institutions, Amer Polit Sci Review, 1995;98;582–600

[12] Lipsey R, Carlaw KI, Bekar CT. Economic Transformations. General Purpose Technologies and Long Term Economic Growth. Oxford: OUP, 2005

[13] Edquist C. (ed.) Systems of Innovation: Technologies, Institutions and Organizations. London: Pinter, 1997

[14] KPMG. Offshore wind in Europe. (2010) Market Report. 2010

[15] Ecofys, Wind Energy, The Netherlands. Pers comm with a repres. EWEA Conf, 29/11-1/12/2011, Amsterdam, The Netherlands

[16] Volker Staal en Funderingen (VSF), The Netherlands. Pers comm with 2 repres. EWEA Conf, 29/11-1/12/2011, Amsterdam, The Netherlands

[17] Van Oord Offshore Wind Projects BV, The Netherlands. Pers comm with a repres. EWEA Conf, 29/11-1/12/2011, Amsterdam, The Netherlands

[18] Van Zuilen E, FLOW. Pers comm, April 2012, Amsterdam

[19] De Vries E, Wind Power Monthly, Rotation Company. Pers comm, April, 2012 Amsterdam

[20] Westwood D. Offshore Wind: Building an Industry. Analysis and scenarios for industrial development, 2010

[21] Bloomberg New Energy Finance. Offshore Wind Market Outlook, 13.01.12, http://www.docin.com/p-194017138.html accessed 04/2012

[22] RWE; Germany. Pers comm with a repres. EWEA Conf, 29/11-1/12/2011, Amsterdam, NL

[23] Siemens Wind Power A/S, Denmark and Germany. Pers comm with 2 repres. EWEA Conf, 29/11-1/12/2011, Amsterdam, NL

[24] MPI Workboats, UK, Pers comm with a repres. EWEA Conf, 29/11-1/12/2011, Amsterdam, NL

[25] Kema, Arnhem, The Netherlands. Pers comm with a repres. EWEA Conf, 29/11-1/12/2011, Amsterdam, NL

[26] DONG Energy, Denmark. Pers comm with a repres. EWEA Conf, 29/11-1/12/2011, Amsterdam, NL

[27] DONG Renewable Energy, UK. Pers comm with a repres. EWEA Conf, 29/11-1/12/2011, Amsterdam, NL

[28] Rabobank, The Netherlands. Pers comm with a repres. EWEA Conf, 29/11-1/12/2011, Amsterdam, NL

[29] Jacobsson S. Goteborg University. Pers comm, March 2012, Amsterdam

[30] Seas NVE, Denmark. Pers comm with 2 repres. EWEA Conf, 29/11-1/12/2011, Amsterdam, NL

[31] Jutlandia, Denmark. Pers comm with a repres. EWEA Conf, 29/11-1/12/2011, Amsterdam, NL

[32] Esbjerg Business Development Center, Denmark.Pers comm with 2 repres. EWEA Conf, 29/11-1/12/2011, Amsterdam, NL

[33] Offshore Center Denmark (OCD). Pers comm with a repres. EWEA Conf, 29/11-1/12/2011, Amsterdam, NL

[34] Netherlands Wind Energy Association (NWEA). Pers comm with 2 repres. EWEA Conf, 29/11-1/12/2011, Amsterdam, NL

[35] A2Sea, Denmark. Pers comm with a repres. EWEA Conf, 29/11-1/12/2011, Amsterdam, NL

[36] http://www.carbontrust.com/our-clients/o/offshore-wind-accelerator accessed 04/2012

[37] http://www.renewables-innovation.co.uk accessed 02/2012

[38] http://flow-offshore.nl/images/2011-08/flow_samenvatting.pdf accessed 02/2012

[39] www.forwind.de accessed 02/2012

[40] JDR Cable Systems LTD, UK. Pers comm with a repres. EWEA Conf, 29/11-1/12/2011, Amsterdam, NL

[41] RenewableUK, UK. Pers comm with a repres. EWEA Conf, 29/11-1/12/2011, Amsterdam, NL

[42] 4C Offshore, UK. Pers comm with a repres. EWEA Conf, 29/11-1/12/2011, Amsterdam, NL

[43] KBR, UK. Pers comm with 2 repres. EWEA Conf, 29/11-1/12/2011, Amsterdam, NL

[44] PMSS, UK. Pers comm with a repres. EWEA Conf, 29/11-1/12/2011, Amsterdam, NL

[45] Typhoon Offshore, UK. Pers comm with a repres. EWEA Conf, 29/11-1/12/2011, Amsterdam, NL

[46] EEG. German Renewable Energy Act, 2009

[47] Schultz S. Will Nuke Phase-Out Make Offshore Farms Attractive? *Spiegel Online*, 23/03/2011

[48] Germanischer Lloyd Renewable Certification (GL), Germany. Pers comm with a repres. EWEA Conf, 29/11-1/12/2011, Amsterdam, NL

[49] BWEA. UK Offshore Wind: Charting the Right Course. Scenarios for offshore capital costs for the next five years. 2011

[50]The Crown Estate. UK Offshore wind report 2011, 2011

[51] Department of Energy and Climate Change: The UK Renewable energy Roadmap, 2011

[52] Rabobank. An outlook for renewable energy in the Netherlands. Rabobank Industry note #320, June 2012

[53] Alstom, The Netherlands. Pers comm with a repres. EWEA Conf, 29/11-1/12/2011, Amsterdam, NL

[54] Verdonk M, Wetzels W. Referentieraming Energie en Emissies: Actualisatie 2012 Energie en emissies in de jaren 2012, 2020 en2030, ECN, 2012

[55] EWEA.. Pers comm with 2 repres. EWEA Conf, 29/11-1/12/2011, Amsterdam, NL

[56] Prässler T, Schaechtele J. Comparison of the financial attractiveness among prospective offshore wind parks in selected European countries ,Energy Pol, 2012;45; 86-101

[57] Guillet J. Banking offshore wind. Chapter 03 in pfi intelligence briefing. 2011.http://www.green-giraffe.eu/uploads/0911%20PFI%20Financing%20Offshore%20Wind%20%20%28JG%29.pdf

[58] EWEA. Wind directions. Bridging the gaps, Feb, 2012;31:1

[59] RenewableUK. Working for a Green Britain: vol 2. Future Employment and Skills in the UK Wind and Marine Industries, 07/2011

[60] INTPOW. Offshore Wind Germany Market Study 2011, Norwegian Renewable Energy Partners, 2011

[61] http://www.offshorewind.biz/2012/08/07/shared-knowledge-could-enhance-offshore-wind-industry-for-germany-uk/ accessed 08/2012

[62] Wind Power Monthly. Wind Power offshore Career's Guide: Jobs survey. Career profiles, Courses, Employers' Zone 2012, 2012

[63] Edwards, I. Overcoming Challenges for the Offshore Wind Industry and Learning from the Oil and Gas Industry, Natural Power, 2011

[64] OffshoreGrid. Offshore Electricity Grid Infrastructure in Europe. A Techno-Economic Assessment, 2011.

[65] Jones CR, Eiser JR. Understanding 'local' opposition to wind development in the UK: How big is a backyard? Energy Policy 2010;38:3106-17

[66] Jacobsson S, Karltorp K. Formation of competencies to realize the potential of offshore wind power in the European Union. Energy Policy, 2012;44:374-384

[67] http://www.denmark.dk/en/menu/About-Denmark/Government-Politics/ accessed 04/2012

[68] http://www.offshorewind.biz/2012/04/16/new-danish-energy-agreement-makes-denmark-safe-investment/ accessed 04/2012

[69] http://www.thecrownestate.co.uk/media/229356/owdf_04_01_finance_group_paper.pdf accessed 04/2012

[70] http://www.businessgreen.com/bg/news/2100019/germany-enjoys-surge-offshore-wind-investment accessed 04/2012

[71] http://www.ft.com/intl/cms/s/0/7740d04c-5c9c-11e0-ab7c-00144feab49a.html#axzz282JQwcp6, accessed 04/2012

[72] http://www.energyefficiencynews.com/articles/i/4677/, accessed 04/2012

[73] www.eawe.eu accessed 02/2012

74] http://www.offshorewind.biz/2012/10/12/uk-european-offshore-wind-development-shaken-by-political-uncertainty/ accessed 05/2012

[75] http://www.smartenergyjournal.com/2012/09/29/political-uncertainty-damages-investors-confidence-in-green-energy/ accessed 09/2012

[76] http://www.supplymanagement.com/2012/wind-farm-cables-face-global-deficit/, accessed 09/2012

[77] http://www.powerengineeringint.com/articles/print/volume-20/issue-5/features/going-the-distance.html, accessed 09/2012

[78] http://www.offshore-technology.com/features/featureoperation-maintenance-offshore-wind-oil-gas-hydrocarbons-installed-capacity-wind-farm-specialised-resources-ship-boat-vessel-installation/, accessed 09/2012

[79] Wieczorek AJ, Negro SO, Harmsen R, Heimeriks GJ, Hekkert MP. A systemic assessment of the European offshore wind innovation system based on insights from the UK, Denmark, the Netherlands and Germany, JRC, Petten, 2012

[80] O'Keeffe A, Haggett C. An investigation into the potential barriers facing the development of offshorewind energy in Scotland: Case study – Firth of Forth offshore wind farm, Ren and Sust Energy Reviews, 2012;16(6):3711–21

[81] Jacobsson S. and Karltorp K, 2013. Mechanisms blocking the dynamics of the European offshore wind energy innovation system - challenges for policy intervention. Draft. Gothenburg University

Chapter VI

Broadening the national focus in technological innovation system analysis: the case of offshore wind[72]

Abstract

This paper empirically explores if and how the spatial dimensions of Technological Innovation System matter using the case of offshore wind in North-Western Europe. In particular, it demonstrates the territory-specific institutional embeddedness and transnational linkages effects between four national offshore wind innovation systems. The paper discusses the consequences of taking these spatial dimensions into account in the analysis of the domestic TIS performance and argues that their acknowledgement contributes to better understanding of the systems' dynamics and leads to policy advice that is in sync with recent internationalization developments in the development and diffusion of the offshore wind industry.

Key words

Systemic problems, systemic policy, technological innovation system, offshore wind, transnational linkages, institutional embeddedness, territorial embeddedness

1. Introduction

The Technological Innovation System (TIS) perspective has become a popular analytical tool to explain the success and failure of the development and diffusion of renewable technologies and their contribution to sustainability transitions. The core of the TIS perspective comprises the analysis of the emergent structural configuration of the innovation system (actors, networks, technology, institutions) and major processes (also labelled as system functions) that support the formation and development of radically new technological fields (Hekkert et al., 2007; Bergek et al., 2008). Analyses based on the TIS perspective create insight in the weaknesses of the innovation system and suggest ways in which the development and diffusion of technology can successfully be improved (Wieczorek and Hekkert, 2012). The specific focus on analysing emergent technological fields distinguishes TIS from related frameworks (Coenen and Diaz Lopez, 2010) like the sectoral (Malerba, 2002) and regional innovation systems (Cooke, 2001).

Technological Innovation Systems are essentially global systems. Initial conceptualizations of TIS have emphasized that technology development and diffusion are processes that cut across spatial boundaries (Carlsson and Stankiewicz, 1991; Carlsson, 1997). Hence, the most appropriate way to understand the

[72] This chapter is based on a paper accepted for publication as: Wieczorek, A.J., Hekkert, M.P., Coenen, L., Harmsen, R., 2014. Broadening the national focus in technological innovation system analysis: the case of offshore wind. Environmental Innovations and Societal Transitions.

emergence of new technology would be to study the TIS as a global system (Binz et al., 2014).However, many empirical TIS studies delineate their analysis to a single country, see e.g. Jacobsson and Lauber, 2006; Negro and Hekkert, 2008; Hekkert et al., 2007; Negro et al., 2007; Bergek et al., 2008 or Hillman et al., 2008. The choice for a *national* focus is often justified by the importance of national institutions for technology development and diffusion and by the aim to inform domestic technology and innovation policy. The international aspects that influence such nationally delineated technological fields are predominantly discussed under a broad term of *exogenous forces* without a clear explanation of their impact on the analysed TIS (Coenen and Truffer, 2012; Markard et al., 2012). By treating these influences as merely exogenous or contextual, there is a risk of overlooking the TIS' interconnectedness with other innovation systems, on national, regional or sectoral levels as pointed out in a recent reflection paper on TIS by Jacobsson and Bergek (2011). This weakness is further substantiated by recent observations made in sustainability transition literature concerning the spatial distribution and variation of structural configurations of the systems (Berkhout et al., 2011; Dewald and Truffer, 2011; Späth and Rohracher, 2012; Coenen et al., 2010, 2012; Truffer and Coenen, 2012; Binz et al., 2012; Raven et al., 2012). Without spatial sensitivity, it is argued, TIS studies overlook how national policies and resources may be conditioned by broader international networks, markets and institutional configurations and thus influence the impact of these policies and resources in considerable ways. A narrowly defined national focus may, for example, underestimate the importance of other countries in technology development and therefore overestimate the role of a national government in R&D stimulation. To avoid containerized TIS studies (Binz and Truffer, 2012) more attention to the spatial dimensions of TIS is therefore called for (Coenen et al., 2012).

In this paper we concentrate on empirically exploring if and how the spatial dimensions of TIS matter using the case of offshore wind in North-Western Europe. Offshore wind is an emerging renewable energy technology with considerable potential and for this technology Europe is the leading continent in terms of installed capacity, key industrial players and profitability potentials (Makridis, 2013). Using insights from an earlier TIS analysis of offshore wind in Germany, the Netherlands, the UK and Denmark respectively (Wieczorek et al., 2013), we aim to demonstrate the implications of moving beyond a national TIS focus by highlighting the territory-specific institutional embeddedness and transnational linkages effects between the four national offshore wind innovation systems. In particular, we discuss the consequences of taking these spatial dimensions into account in the analysis of systemic problems. Due to our focus on four countries we acknowledge that we do not create a full picture of the global TIS for offshore wind and its implications for national development. However, the chosen scope does make it possible to analytically show what a spatially sensitive view adds to an (implicitly) nationally focused TIS analysis.

For our analysis we draw on the TIS framework complemented by insights from economic geography on territory-specific institutional embeddedness and transnational linkages, explained in Section 2. In Section 3 we describe the methodology. In Section 4 having presented basic facts about offshore wind in Europe we discuss structural configuration and functional performance of four nationally delimited TISs: Germany, the Netherlands, the UK, and Denmark. We identify systemic problems of each system and sketch the required national policy response. In Section 5 we focus on the transnational linkages effects between the four TISs and the impact of broadening the analytical scale and in particular, the explicit inclusion of the linkages on the definition of systemic problems and policy in the studied countries. We conclude in Section 6.

2. Theoretical framework

The TIS perspective emerged in the early nineties from a quickly expanding innovation system literature, which is rooted in evolutionary economics and industrial dynamics (Freeman, 1987; Lundvall, 1992; Nelson, 1993). A Technological Innovation System is defined as ‘a dynamic network of agents interacting in a specific economic/industrial area under a particular institutional infrastructure and involved in the generation, diffusion, and utilisation of technology’ (Carlsson and Stankiewicz, 1991, p. 93). These actors, networks, institutions and technology constitute the structural components of the TIS following the more general systems of innovation framework (Edquist, 1997). A novel and quintessential aspect of the TIS perspective concerns its attention for the functional performance of the innovation system’s components, conceptualized through a set of functions, as defined in two programmatic papers by Bergek et al. (2008) and Hekkert et al. (2007).This set of functions refers to: (1) *Entrepreneurial activities*: exploring and exploiting business opportunities on the basis of new technologies and applications. The applications create opportunities to learn about the functioning of new products, processes or services after exposure to market dynamics. (2) *Knowledge development*: The creation of knowledge lies at the heart of any innovation process. While science-based research and development are important key processes to generate new knowledge, these are not the only ones. Various other types of knowledge can also serve as input for innovation, including experience-based knowledge development through doing, using and interacting (Jensen et al., 2007). (3) *Knowledge exchange*: For the development of new or improved products, processes or services, the diffusion of knowledge can be as important as the actual generation. Successful innovators are often those firms that know how to make commercial use of ideas and knowledge generated by others (Chesbrough, 2003). (4) *Guidance of the search* is necessary for the selection or rejection of a particular direction of technological development. The formulation of expectations and visions, priority setting in R&D strategies and foresight studies contribute to such selection processes. Also user-producer interaction provides an important feedback mechanism in this context. (5) *Market formation*: Innovation is by default couched in uncertainty as it often disrupts the status quo on existing markets. The more radical an innovation is the higher its disruptiveness. This means that incremental innovation, building forth on existing products, processes or services, is more likely to be accepted by existing users and markets while markets for completely new innovations often still need to be formed. (6) *Resource mobilization* refers to the mobilization and allocation of resources that are necessary to make the various processes in the innovation system, as described above, possible. Primarily they refer to the collective efforts to secure financial capital (seed and venture capital, policy support programs) and human capital (through education, training and competence development). (7) *Creation of legitimacy* is required to overcome the liability of newness (Zimmerman and Zeitz, 2002), which constitutes an important but often neglected dimension of innovation. The purposeful creation of legitimacy by lobbying activities and advice activities on behalf of interest groups may be necessary in order to counteract resistance to change.

Apart from analysing the build-up of systemic support for innovation in an emerging technological field, the set of functions has also been applied to inform policy-making and formulate rationales for policy action (Negro et al., 2007). Here, the TIS framework follows the more general approach to policy legitimation found in the innovation systems literature concerning systemic failures or problems (Smith, 2000; Klein-Woolthuis et al., 2005; Laranja et al., 2008, Wieczorek and Hekkert, 2012). The underlying idea is that innovation systems are a problem oriented heuristic: resources and capabilities are mobilized and coordinated in order to find a solution to a problem (Metcalfe and Ramlogan, 2008; Gee and McMeekin, 2011). Once the TIS framework delivers an analytical output of how well the functions are fulfilled, this is followed by a definition of process goals in terms of a desired functional pattern (Bergek et al., 2008). Since weak functions signal the need for policy intervention, the identification of inducement and blocking mechanisms leads to specifying key policy issues – which are subsequently transformed into policy recommendations[73]. Wieczorek and Hekkert (2012) argue, however, that functions alone cannot form the sole basis for policy. Furthermore, functions cannot be influenced by policy in any other way than by intervention in the structure. The authors, therefore, propose a classification of structure-related systemic problems that are identified in the result of a coupled structural-functional analysis. They show that for such systematically identified problems, an integrated, systemic instrument can be proposed.

Against this policy context, the criticism on empirical studies of TIS for applying an implicit, often national scalar envelope around the system delineations becomes particularly relevant. As emphasized in pioneering work on TIS, the development of a technology or technological fields does not stop short of national borders (for an empirical illustration see Binz et al., 2014). Especially in light of on-going globalization processes, this suggests it would be rather short-sighted to govern TIS from a narrowly defined national policy perspective. International network relations and institutional interdependencies need to be acknowledged by policy-makers even though they may extend beyond their direct sphere of influence.

To conceptualize such interdependencies Coenen et al. (2012) highlight the importance of territorial embeddedness of technological innovation systems and in particular the need of a more spatially differentiated view of TIS structural components. They argue that the TIS elements operate at various geographical scales and in different locations and, thus, have varied access to different resources. To approach the territorial embeddedness of TIS, two interrelated dimensions should be accounted for: (1) institutional embeddedness and (2) transnational linkages.

To explain the uneven geography of innovation, economic geographers have extensively drawn on the notion of institutional embeddedness. It draws attention to the existence of territory-specific sets of institutions that conditions innovative behaviour among agents located in such regions and countries (Storper, 1997; Cooke and Morgan, 1993; Gertler, 2004; Asheim and Coenen, 2005). Here, institutions are broadly defined as formal and informal rules that both enable and constrain organizational and individual behaviour relevant for innovation processes (Nooteboom, 2000), Similarly, the literature on

[73] It is perhaps not by necessity that the weak functions require a policy intervention (i.e. action by public sector) but may also call for collective intervention by private actors.

national innovation systems has provided ample proof that country-specific institutions have a sustained effect on the innovation performance of the actors in the innovation system (Lundvall and Maskell, 2000). A classic example is provided by Edquist and Lundvall (1993) where they contrast the high degree of public-private coordination conducive to joint industry-university research in Sweden with more local community/industrial district mode of coordination conducive to user-producer learning in Denmark. In a related manner, the Varieties of Capitalism literature (Hall and Soskice, 2001) has argued that coordinated market economies (such as found in Germany, Japan and Scandinavia) offer institutional advantages in supporting incremental innovation based on complementarities between close inter-firm as well as public-private collaboration, high-levels of industry-specific technical skills, secure employment and a financial system able to supply long-term (*patient*) capital. This can be contrasted with liberal market economies (such as the UK and US) offering institutional advantages for radical innovation in fast-moving technology sectors based on high rates of labour mobility, inter-firm relations primarily based on markets, equity markets with dispersed shareholders and venture capital. Following Jacobsson and Bergek's (2011) call for a better understanding of TIS' interconnectedness with other innovation systems, a first step would thus entail a more explicit acknowledgement of the institutional embeddedness of the actors involved in the TIS. This is particularly pertinent for policy implications and recommendations as interventions are more likely to take hold in areas with already developed and relatively well-functioning institutions (Rodriguez-Pose, 2013). In his review, Carlsson (2006) identifies a consensus in the literature that in spite of increased globalization (see below) institutions relevant to innovation systems only change very gradually and remain largely persistent within territorial boundaries.

However, in a globalizing economy, knowledge and other innovation related resources circulate and are recombined in globally distributed *networks* of firms, universities, policy-makers and interest groups (Binz et al., 2014). Also in TIS, firms engage in global innovation networks to source critical knowledge for the development and diffusion of technologies. In the case of multi-national companies, the firm itself even acts as a conduit through which knowledge and resources circulate across national borders. Even though the lion's share of corporate R&D is traditionally performed in the home nation (Patel and Pavitt, 2000), there is an increasing internationalization tendency for these activities (Dunning and Lundan, 2009). This can be manifested through foreign direct investment, subsidiary firms, supplier networks, joint ventures or relocation. Partly these internationalization trends are fuelled by motives to access particular knowledge pools, partly to get access to distant markets. Research activities carried out in universities and other research organizations is probably even more internationalized through social networks in globally distributed epistemic communities involving active interaction with distant ties (Amin and Cohendet, 2004). Saxenian (2005) demonstrates how even individuals, in this case engineers, act as conduits of international knowledge flows by their personal mobility and thus bridge professional and economic ties to technologies and markets across developed and developing economies. Institutions, despite their territorial stickiness, are also susceptible to travel internationally, but at a markedly slower pace than knowledge or actors. Institutional flow occurs, for example, when stringent quality standards are adopted by more lenient jurisdictions from highly regulated foreign markets through global supply chains (Vogel, 1997; Corbett, 2002). Through these global networks, innovation systems are becoming internationalized, even if many of the institutions that support them remain territory-specific (Carlsson, 2006). Wieczorek et al. (2014) refer to these flows as transnational linkages and classify them as actor, technology, institutional, capital and knowledge flows.

3. Methodology

This study builds on the analysis of four national offshore wind innovation systems situated around the North Sea that had the largest online offshore wind capacity in Europe at the end of 2011: the UK – approx. 1600 MW, Denmark – 850 MW, the Netherlands – 250 MW and Germany – 200 MW. An interesting difference between these countries is their level of offshore wind political ambition and varying strategies that these countries deploy, which have led two of them (the UK and Germany) to progress rapidly, while the other two (Denmark and the Netherlands) to actually have a lower speed of offshore wind deployment.

The analysis was based on the review of scientific and grey literature, internet sources, Global Offshore Wind Farms Database 4C as of 2010, journal publications in the Web of Science (for knowledge networks identification), CORDIS database (for European project participation) and European Patent Organisation (for patents identification). *Offshore wind* served as a key word. This review was complemented with Lexis-Nexis-based media events analysis for 2010-2011 and semi-structured interviews with over 30 offshore wind stakeholders. Among the interviewees were representatives of leading industries, financial organisations, knowledge institutes and NGOs in the four studied countries. They were all experts in managerial positions (Appendix A). The interviewees were asked to assess their home offshore wind TIS in the context of the European dynamics. A five-tier scale of 1-5 (absent to excellent) and a set of diagnostic questions (presented in Appendix B) guided the discussion on each system function.

These traditional analyses of the four innovation systems were further complemented with a brief assessment of the systems' institutional embeddedness and transnational linkages. Although we did not apply any rigorous set of indicators, we did pay attention to spatial configuration of domestic value chains (presence of foreign actors, participation of national actors in foreign projects, etc.), country-specific cultural and historical aspects determining the systems' institutional structures, commitment of the actors (government, industry, society) to offshore wind; level of (university-industry) interaction, etc. Further, we looked at what the influence of the interplay of institutional embeddedness and transnational linkages on linkages effects between the four national TISs. In particular, we explored how the interrelations between the systems influence the definition of national systemic problems and how this changes the potential national policy implications. The issue of collaboration and transnational linkages emerged as a pertinent theme out of the interviews with actors.

With this focus on four countries we miss out on the rest of the global offshore wind TIS. The goal of this paper, however, is not to present a complete picture of transnational influences but to empirically support the recent theoretical contributions on the institutional embeddedness of innovation systems. Focusing on the potential interaction between four countries is empirically sufficient.

4. Four offshore wind innovation systems: a national perspective

In order to keep climate change below 2ºC, the European Council reconfirmed in February 2011 the EU objective of reducing greenhouse gas emissions by 80-95% by 2050 compared to 1990 (EU, 2011). Although in the current European policy landscape more technologies ask for attention, it is believed that without offshore wind, which is in EU projections the fastest growing renewable (Capros et al., 2010), achievement of the ambitious European goals will be very difficult, if not impossible (Jacobsson and Karltorp, 2012a).

Offshore wind has developed quite remarkably in the recent years. While in the early 90's the industry was still in its infancy with the first offshore wind turbine being set up in Denmark, in 2011 the total installed offshore wind capacity in Europe reached approximately 3300 MW and provided jobs to 35,000 people (EWEA, 2011b). The 2020 deployment potential of offshore wind is estimated by the European Wind Energy Association (EWEA) at the level of 40.000 MW, which is similar to the sum of the offshore wind ambitions expressed by the EU Member States in their National Renewable Energy Action Plans (NREAPs). Realisation of this potential would mean that offshore wind can supply 5% of the EU's total electricity demand (Capros et al., 2010), provide significant employment opportunities (170,000 jobs in 2020) and help various countries diversify their energy sources (EWEA, 2011a). Many sources, however, emphasise a number of substantial obstacles that block a wider diffusion of offshore wind in Europe (Wieczorek et al., 2013; Heptonstall et al., 2012; Deutsche Bank, 2011; De Jager et al., 2010; Jacobsson and Karltorp, 2012b).

In the following paragraphs we therefore look at the structural configuration and functional performance of the four nationally delimited TISs: Germany, the Netherlands, the UK and Denmark with the aim to identify systemic problems of each system and to shortly discuss necessary national policy response. The section is based on Wieczorek et al. (2013) and presents only a summary of a much wider set of findings complemented by observations about institutional embeddedness of the various TISs.

4.1. Germany

The German offshore wind TIS is characterized by the presence of a complete value chain, strong and highly skilled industrial players, many of which are multinationals with subsidiaries in the other three countries and heavily involved in the construction of wind farms abroad. German firms are world leaders with regard to dedicated R&D, ground-breaking wind turbine development, and the implementation of advanced offshore wind technology. For example, Siemens is one of the largest multinationals of German origin supplying 51% of European wind turbines in 2011 and one of the world's leading firms in terms of offshore wind patenting (193 patents). Enercon GmbH, the fourth-world-largest wind turbine manufacturer was the first in the world to install an offshore 4.5 MW turbine in 2002: the Enercon E-112. The German innovation system builds on a strong manufacturing culture that translates to strong engineering knowledge and on tight industry-university collaborations. Well-known knowledge institutes in the field are the University of Bremen, Leibniz University Hannover and the Alfred Wegener

Institute for Polar and Marine Research. They are, however, publishing less than the Dutch and Danish institutes.

Germany can further be characterised by a more dispersed wind farm ownership structure compared to the UK, Denmark and the Netherlands. Only 39% of approved offshore wind projects are owned by large utilities. The remaining shares in German wind farms are held by a substantial number of developers, financial investors and municipal utilities (KPMG, 2010). To meet the offshore wind challenges, there is a drive towards cluster strategies for offshore wind manufacturing in geographically closely located ports (e.g. German cluster Bremerhaven, Cuxhaven, Emden). These initiatives are the result of close cooperation between public and private sectors (EWEA, 2011a).

Procedures for offshore wind construction are administered by a large number of authorities even though the government is working on combining the licensing for offshore wind farms into one single process. The government has a coherent vision to phase out nuclear energy (in the aftermath of Fukushima accident) and to support renewables with consistent policies as well as long-term contracts to renewable energy producers (the feed-in tariff mechanism). All these factors create a strong interplay of supporting institutional conditions for offshore wind in the country.

Figure 1 shows the functional pattern for Germany with very strong entrepreneurial activities, knowledge diffusion, guidance of the search and market formation. The German offshore wind market is extremely attractive with huge orders and may very soon take over the leadership from the UK. The knowledge development is also good especially the *engineering* type. Lower legitimacy of the technology is caused by the high costs and the ownership structures of offshore wind parks. Markard and Petersen (2009) state that part of the success of renewable energy policies in Germany (and Denmark) was due to the fact that individuals (local stakeholders but also citizens in general) could benefit from investments into these new technologies, which in turn fuelled broad political support. For offshore wind this is not the case. A growing number of vocational and academic trainings cater for an inflow of skilled experts but do not cover the full demand making human resource mobilisation somewhat problematic. A serious obstacle that Germany faces in further offshore wind expansion lies in grid connection and capacity.

Summarising, this national analysis would suggest that German policy, in order to stimulate further expansion of offshore wind, should continue to strengthen demand in its home market, make investments to academic knowledge development and training programmes. Most importantly, however, it should undertake a national action for grid renovation and improvement.

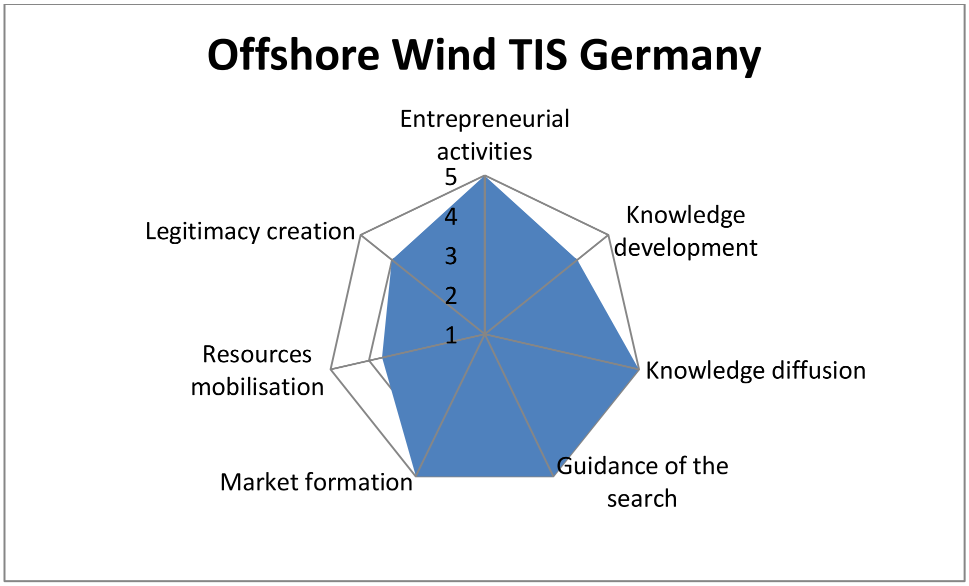

Figure 1. Overview of system function fulfilment in Germany (Wieczorek et al., 2013)

4.2. The Netherlands

Even though Dutch industry is well represented across the value chain, its activities are more geared to international markets due to a relatively weak domestic market and lack of support from government. The Netherlands' very strong offshore industry finds its origin in maritime construction and engineering. This knowledge base has been transferred to the construction of offshore wind farms making the Dutch offshore industry a very important player in the construction of European offshore wind farms. Especially construction companies (focused on foundations, substations, and wind farm installation) are involved in many international projects. There is also a strong academic tradition in wind research resulting in a solid scientific knowledge base. Dutch knowledge institutes rank very high internationally in terms of the number of publications on offshore wind. This research is more concentrated than in Germany or the UK. In particular, Delft University of Technology (TU Delft) excels in the number of journal articles per institute (44 articles), which in 2011 resulted in a 13th position in the world. TU Delft is also a leader in academic and polytechnic training in offshore wind in the Netherlands. The university closely cooperates and co-publishes with various other Dutch institutes (especially the Energy Research Centre in the Netherlands) as well as foreign knowledge institutes. Joint publications with industry are, however, less abundant. This can partly be explained by its focus on scientific research whereas industry is more concerned with developing engineering based knowledge. It seems that Dutch offshore construction industry mainly innovates in a more applied and tacit way. A good framework condition for offshore wind is related to the numerous and state-of-the-art harbour facilities in the Netherlands.

In 2011, the strong industrial lobby, composed of many offshore firms working for oil and gas but diversifying their business into offshore wind, persuaded the government to close a so-called Green

Deal, in which the government committed itself to supporting offshore wind development[74]. Critics, however, argue that the deal is only meant to camouflage the government's lack of vision and determination to act and take its earlier renewable energy commitments and obligations seriously (De Vries, 2012). Given substantial national gas reserves and austerity measures in light of the financial crisis, the Dutch government is primarily interested in cost-efficient ways of reducing carbon emissions. The Dutch feed-in premium SDE+ (Stimuleringsregeling Duurzame Energie+) implies that all renewable energy technologies need to compete for one (limited) budget. Under prevailing cost-structures, this means that offshore wind has little chances to compete with cheaper renewable energy technologies such as biomass combustion. This implies that the Netherlands has a very well developed national industry and good harbour infrastructure, but, as a consequence of national policy, a small home market. This might change however. In the recent Energy Covenant (SER, 2013) it has been agreed to strengthen national efforts to meet 14% renewable energy in 2020, for which the contribution of offshore wind is considered essential.

As the functional performance shows in Figure 2, knowledge development is well-developed mainly thanks to strong scientific knowledge. Knowledge diffusion through scientific publications is good, though university- industry collaborations could be strengthened. Entrepreneurial activities also score relatively high due to foreign activities of the large multinationals of Dutch origin (Van Oord, Sif, Balast Nedam). Guidance and market formation processes are very weak (there were no new farms constructed in 2011, some of them were delayed), so is resources mobilisation, especially human and financial. Physical infrastructure in the form of harbours and grid, although in need of renovation and adjustment is relatively better off than in Germany or the UK. A serious problem for the Netherlands is legitimacy of technology. Due to the high costs of offshore wind, the current political preference is for cheaper renewable energy technologies. Dutch policy and strategy would, therefore, need to focus on the development of home market, strengthening legitimacy and on investments in domestic programmes to support university-industry collaboration.

[74] Key concepts in this Green Deal included a substantial cost reduction through innovation and policy changes, strategic growth of the offshore wind market, achievement of the climate goals, as well as further experimental and shaping of the legislation.

Figure 2. Overview of system function fulfilment in the Netherlands (Wieczorek et al., 2013)

4.3. The United Kingdom

The United Kingdom does not have a long offshore wind tradition. Nonetheless, in October 2008, it became the world leader of offshore wind power generation (Alok, 2008). Despite a huge market, the UK innovation system is mostly dominated by foreign actors. Unlike Germany and Denmark, it does not have a single manufacturer of the required 3–7 MW wind turbines. Also, the supply chain for local components is small and not very complete. Still, in 2010/11 the UK had the highest installed capacity and more offshore wind farms than any other European country. That indicates that the UK has got a developed market (demand) but a small national industry (supply) (see also Douglas-Westwood, 2010). Large foreign utilities such as Nuon, Eneco, E-on, Centrica, RWE, Vattenfall, Dong Energy dominate as owners, developers and operators of the farms. The production of scientific knowledge in the UK is scattered (170 knowledge institutes are involved in publishing), while the UK knowledge institutes rank lowest of all four analysed countries in terms of a number of publications on offshore wind. Similarly, the UK does not have a tradition in offering education in offshore wind energy. However, since the country is expected to lead European offshore wind implementation in the coming years (EWEA, 2011a), it took serious measures to address the demand voiced by industry, especially for qualified engineers[75]. No specialisation can yet be observed in the UK in any particular knowledge area, rather the attempt seems to be to keep up with rapid market developments and to train specialists who could operate and manage the newly built wind farms. These circumstances as well as a specific consultancy culture may have been the reasons why the UK has the most consultancies involved in advising on offshore wind out of all the analysed countries.

[75] For example, in 2011, £6.5 million was allocated to engineering education in the UK in the hope of ushering in a generation of competent renewable energy workers. As a result, several UK universities (University of Edinburgh, Strathclyde and Exeter) have been preparing doctorate programmes starting in 2012 for up to 50 engineering students in technical aspects, as well as, in business and economics of offshore wind energy.

In technical terms, the UK has the greatest potential for wind energy out of all the analysed countries (EEA, 2009) and thus good conditions for offshore wind farm development. Offshore wind is a crucial element of the government's plans to reduce the carbon intensity of the power sector, increase energy security and provide affordable energy to consumers. The UK regulatory framework for offshore wind is currently based on Renewable Obligation Scheme (ROC). The scheme works through electricity suppliers needing to possess a certain amount of ROCs in order to avoid *buy-out* penalties in case of underachievement. The financial resources that become available through the penalties are granted to the holders of the ROCs, providing an additional incentive to invest in renewable energy.

The financial certainty in the UK is assured until 2014 with an average of 2 billion pounds per annum. In expectation of a large market and following the ambition of the UK government to make offshore wind a part of the UK renewable energy mix, investigations started to identify additional sources of capital that would allow for funding the projects in the period 2017-2022 (The Crown Estate, 2011). The UK has also allocated significant investments to harbour infrastructure.

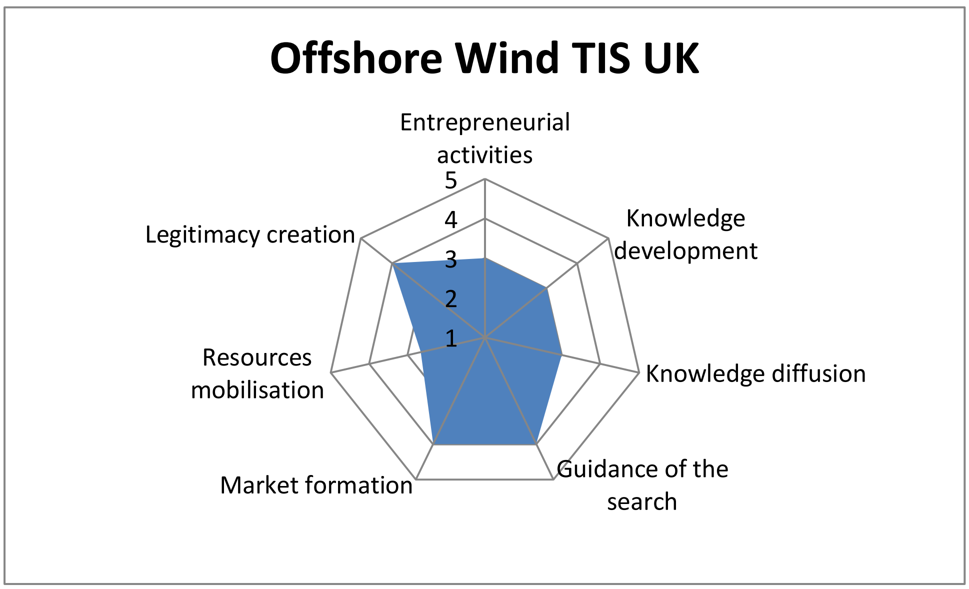

Figure 3. Overview of system function fulfilment in the UK (Wieczorek et al., 2013)

The functional performance of the UK is reflected in Figure 3. Legitimacy of technology, guidance of the search and market formation are strongest. Knowledge development and diffusion are weak but there is the perception of quite easy access to foreign knowledge. What is problematic for the UK, given this national analysis, is the lack of domestic industry, complex and lengthy permitting procedure, poor grid access and capacity and a severe lack of skilled personnel of various kinds. National policy in support of the offshore wind system should, therefore, focus on capacity building, investments in knowledge centres and training programmes, simplification of the procedure and grid improvement.

4.4. Denmark

Denmark is a pioneer and world leader in developing commercial wind power thanks to lessons learned over the years of setting up wind turbines across the country and in Europe. The Danish industry has developed through systematic innovation and experience-based learning (Karnøe and Garud, 2003), which have helped to create core competencies in production, design and installation of wind turbines that are sought worldwide. Vestas dominates in Europe, having supplied 39% of installations in 2011 and having a large number of patents on its account (344). Although Dutch companies are main suppliers of vessels (they own a total of 20 vessels compared to Danish owning 10 vessels), Danish companies are in the lead in terms of heavy vessel *installation* contracts in Europe. The Danish industry is backed up by Megawind, a public-private partnership for mega wind turbines, established in autumn 2006 as part of the Danish government's action plan to promote eco-efficient technology. Denmark is also the world leader in integrating renewable and distributed energy sources into electric power systems. The country currently has about 25% wind power penetration into the system and a very good harbour infrastructure. Douglas-Westwood (2010), one of the leading energy business analysts in the world, considers Esbjerg (DK) as a European leader when it comes to the supply chain for offshore energy.

The Danish knowledge institutes rank highest internationally in terms of the number of publications on offshore wind of all the four studied countries. In particular, Risø National Lab **for Sustainable Energy** excels in the number of journal articles ranking 6th in the world. Two other Danish universities that closely follow Risø are Aalborg University and Technical University Denmark (DTU). Academic and polytechnic training in offshore wind in Denmark is, like research, concentrated in the same organisations. The three universities have been the forerunners in enrolling and releasing yearly a number of individual master and PhD graduates with a specialisation in various aspects of offshore wind. They also give annual dedicated master programmes with focus on or with specialisation in offshore wind technology. The universities collaborate tightly with industry. DTU (Risø) has particularly good connection with industry through a number of DTU (Risø) start-ups; Dong Energy collaborates with the Department of Energy Technology at Aalborg University; Vestas sponsors PhDs at Aalborg University while Vestas, (and Siemens and LM) have offices at DTU(Risø) and in Aalborg.

The most important incentive to promote offshore wind in Denmark is a fixed feed-in tariff. However, despite being (after the UK) the country with the second-highest technical potential for offshore wind (based on area) (EEA, 2009), the offshore market ambitions of the Danish government are limited. The reasons may be relative low energy intensity (as compared to e.g. the Netherlands) and an already high share of renewable energy in the electricity mix.

The functional analysis presented in Figure 4 shows that, while knowledge development and diffusion is very strong, guidance of the search, market formation and entrepreneurial activities are less so. At the time of the analysis, in 2011, Denmark had a low rate of increase in installed capacity and in consented projects (EWEA, 2011a) and thus limited entrepreneurial activity. However, since autumn 2011 a new *greener* government[76] was established, which planned to set the goal to 50% of energy from wind and

[76] http://www.denmark.dk/en/menu/About-Denmark/Government-Politics/ accessed April 2012.

other alternative energy sources[77]. This raised hopes among the offshore wind industry for better times and increased legitimacy of offshore wind as well as higher levels of taxes on coal and gas. Regarding financial resources, Denmark has many pension funds that invest substantially in wind. They see a long-term profit from such investment because turbines are considered very reliable and wind is generally perceived as a safe business. What is problematic is the expected lack of human resources and in particular the generation gap that can occur when current professionals will have to retire. National policy, given these findings, should focus on national market formation and investments in training programmes.

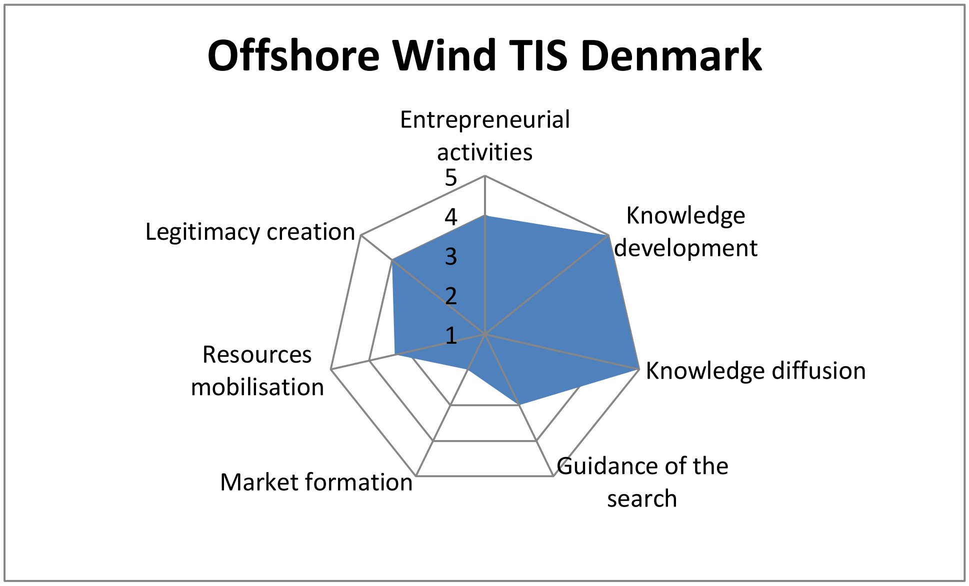

Figure 4. Overview of system function fulfilment in Denmark (Wieczorek et al., 2013)

5. Beyond a national focus: domestic problems, international solutions

The analysis of the particular national systems presented in the previous section demonstrates that the countries face a number of nation–specific obstacles to the wider diffusion of offshore wind energy. Some of these obstacles may be deeply embedded in the institutional structure of the country's innovation system and, thus, not that easily changed through policy interventions. Broadening the analytical scale reveals, however, that not all national weaknesses are necessarily problematic because the actors in the different innovation systems are to a great extent internationally oriented. As a result

[77] At the moment of this research the New Danish Energy Agreement outlined the framework for the Danish climate and energy policy until 2020 and the direction until 2050. According to this agreement CO_2 emissions in 2020 will be 34% less than they were in 1990. Energy consumption will decrease by 12% in 2020 compared to 2006. Around 35% of the country's energy will come from renewable sources and almost 50% of electricity will come from wind. It has also been decided to build a total of 3300 MW new wind power. A part of it is two new large offshore wind farms at Kriegers Flak between Denmark and Germany (600 MW) and at Horns Reef off the west coast of Jutland (400MW) http://www.offshorewind.biz/2012/04/16/new-danish-energy-agreement-makes-denmark-safe-investment/ accessed April 2012

cross-border, transnational linkages complement for missing resources and capabilities at the national level.

5.1. Transnational linkages

Exemplary is the offshore wind innovation system in the UK which, due to the lack of national manufacturing capacity and dominance of conservative fossil-fuel-based industries and power plants (KBR, 2011), is particularly open to foreign companies (actor and knowledge linkages). The international orientation of the value chain implies that significant amounts of money flow to other countries (capital linkages). Mainly Dutch companies (e.g. Balast Nedam, Mamoet van Oord, Jumbo), given conditions of a limited home market, strongly rely on the availability of markets abroad, the UK in particular (Ecofys, VSF, Van Oord, 2011)[78].

The broader spatial perspective shows that the UK, being one of the biggest offshore wind markets in Europe can take advantage of the presence of competent foreign actors, several of them established offshore firms such as Van Oord, Shell, Amec and large utilities (Nuon, Eneco, E-on, Centrica, RWE, Vattenfall, Dong Energy) (actor and knowledge linkages). These companies are often transnational enterprises with sufficient resources and experience to move across borders and are not hindered by different national regulatory schemes and permitting procedures. By setting up activities in various countries, on the one hand, they contribute to national economies of the host as they make use of and contribute to localised assets (markets, knowledge, and skilled labour). On the other hand, they reach out to the global networks, through which the assets are spread and utilised (capital linkages). By using the domestic market and wind potential of the UK, foreign companies provide the domestic innovation system with access to foreign knowledge and skilled personnel (knowledge and actor linkages) and contribute to national employment creation. Given that building domestic industrial capacity in the UK may take time, attracting international actors to enter the national value chain and to make knowledge intensive investments might be a more viable short and medium-term strategy for the UK. This may of course raise legitimacy issues. If, however, the UK policy manages to stimulate these subsidiaries to become active innovators and establish linkages to local industry, such policy may also contribute to domestic industry build-up. Simplification of the permitting procedure to attract foreign firms could form the first step of this strategy.

From the Dutch national perspective stimulating the domestic market might help the Netherlands to reduce its dependency and vulnerability to decisions of the UK and could motivate domestic entrepreneurial activities of smaller companies. A functional Dutch market is also necessary for the creation of a strong European offshore wind innovation system. However, national market formation requires strong political support, stable renewable policy across consecutive government terms, an encouraging regulatory regime and effective support programmes. These, however, are either deficient or they continue to fail in achieving the ambitious goals (Ecofys, VSF, Rabobank, 2011). Under these conditions it is not surprising that Dutch firms are tapping into other markets (actor, knowledge, capital

[78] For a detailed discussion see Wieczorek et al, 2013 where all four national value chains have been presented and discussed from the national and international perspective, i.e. who builds wind farms in the UK and how internationally active are the UK actors.

flows) and rely on higher legitimacy for offshore wind in Germany and the UK. Also, when market conditions are well taken care of nationally, firms still get involved in foreign projects.

The cross-national initiatives are not only restricted to reaping the fruits of foreign markets. Also in the area of knowledge development and exchange many international relations exist (knowledge linkages). The leading Dutch university in wind research, TU Delft, interacts more frequently with German suppliers of turbines than with national players (Wieczorek et al., 2013). In EU-funded programs many cross-national research collaborations take place (Wieczorek et al., 2013) (knowledge linkages). These collaborations are not limited to research organisations and knowledge collaboration but also encompass companies such as Vestas, Dong, Lloyd, Garrad Hassan and Partners and involve a degree of human resource mobility (actor linkages).

Denmark does not have a very big home market. It is a small and comparatively not very energy-intensive country. It does not need all the offshore wind electricity that it has the potential to produce. Excess would need to be sold abroad. This would increase Denmark’s dependence on foreign markets and given that offshore wind is still very expensive and the country operates with a feed in tarrif, this would also imply that the Danish tax payers would have to subsidize the country's electricity exports. In case of Danish knowledge institutes and entrepreneurs, they do need foreign markets to sell knowledge and technology and stay internationally competitive (technology, knowledge and capital linkages).

The German TIS is most optimised of all four analysed systems and its operation does not seem to directly depend on the other countries’ markets. It could therefore operate without a strong dependence on international collaboration. However, a well-functioning German TIS is important for the other (national) TISs in Europe and it gives German industry sufficient competitive advantage to expand internationally and make use of the opportunity of earning extra benefits from international collaboration. Germany also faces what we call cross-cutting problems such as availability of trained personnel and grid quality (see Table 1). For these issues national policy makers cannot rely on potential contributions by innovation systems in other countries. However, given the already developed collaborations and interdependencies, and in view of the need for common electricity market, they might consider national grid improvements that would be compatible with the European network. That would further enhance the creation of a common European market. Collaboration is then more beneficial than proceeding solitarily.

Taking a more international perspective of the four countries demonstrates that the nation-specific obstacles identified based on the nationally delimited TISs analyses do not necessarily have to be very problematic in light of transnational linkages effects. The international orientation of national actors resolves already some of the weak parts of national offshore wind innovation systems. Table 1 summarises the nation-specific problems in the first column and the potential policy response in the second column. The third column shows how developments in neighbouring innovation systems may affect the nation-specific problems and the fourth column describes the potential impact on policies. The table shows that some of the national weaknesses may need less attention by national policy makers since the transnational linkages of the innovation systems may create effects that partly solve these issues.

Table 1. Overview of problems based on the national TIS analyses, the linkage effects between the countries and their policy implications

	problem	national response	linkage effect	implications for problems and policy
DE	scientific knowledge development could be better	additional investments in national knowledge centres	knowledge in DK & NL	not a big problem if cooperation with foreign knowledge institutes is possible
	lack of trained personnel	investments in national training programmes	cross-cutting problem	need to cooperate to have access to wider set of resources
	poor grid access and capacity	national action for grid improvement	cross-cutting problem	need to cooperate on supra grid development
NL	lack of home market	domestic market formation	market in the UK & DE	market formation less of a problem if access to neighbouring markets is possible
	lack of legitimacy	national lobby and framing	higher legitimacy in DE & the UK	potential spill-over's when coordinated
	lack of knowledge exchange	programme to support university-industry collaboration	international knowledge exchange	no serious problem due to mobility of multinationals
	grid in need of renovation	national action for grid improvement	cross-cutting problem	need to cooperate on supra grid development
	lack of trained personnel	investment in national training programmes	cross-cutting problem	need to cooperate to have access to wider set of resources
UK	lack of home industry	capacity building in the country	industry in neighbouring countries	capacity building and labour creation by foreign firms
	lack of knowledge and experience	investments in national knowledge centres	knowledge in DK & NL	need to coordinate cooperation with foreign knowledge institutes
	lack of trained personnel	investments in national training programmes	active industry & knowledge institutes abroad, cross-cutting problem	need to attract foreign personnel, educate home specialists abroad
	poor grid access and capacity	national action for grid improvement	cross-cutting problem	cooperate on supra grid development
	long and complex admin procedure	simplification of the procedure	selected other countries face similar problem but to a lesser extent	need to simplify and align procedures to attract foreign companies
DK	lack of home market	market formation	market in the UK & DE	market formation less of a problem if access to neighbouring markets is possible
	expected lack of trained personnel	investments in training programmes	cross-cutting problem	need to cooperate to have access to wider set of resources

5.2. International complementarities and policy implications

Our analysis shows that most of the institutional structures (in relation to market formation, legitimacy, guidance of the search) for offshore wind are strongly nation-specific but that business activities, entrepreneurs and knowledge easily move across borders (capital, actor, knowledge and technology linkages). Analytically we can separate two different policy strategies: (1) a strongly nationally oriented policy that is supportive of offshore wind and (2) an internationally coordinated policy strategy.

Strengthening of national TISs, especially in countries like the Netherlands where it is very weak, is not only important for the creation of national markets but also for the formation of the European offshore wind innovation system. It provides independence of other countries' decisions, keeps the financial returns on national investments within national borders (issue in the UK) and may be essential from an energy security perspective. It implies, however, the need to develop sufficient national capacity in all areas relevant for innovation in offshore wind, including knowledge, actors capacities and markets. Not all countries, as we have shown in section 4, have sufficient predispositions to do that and these qualities are not easily obtainable because they are deeply rooted in historically conditioned institutions (they are e.g. manifested by a strong manufacturing culture of Germany or consultancy tradition in the UK). The financial returns argument is also tricky because in conditions of open markets and international mobility of corporations, profits captured in foreign markets usually return to the home country in the form of R&D funds fuelling national investments in technology development. This is, however, not the case for offshore wind in the UK: two of the 5 research centres of Vestas: Vestas Turbines R&D and Vestas Technology UK Ltd, are located in the UK. Strengthening of national TISs without collaboration may also mean less learning from other contexts and other practices.

As a think piece for the second strategy we refer to Figure 5. This figure illustrates the functioning of all four offshore wind national innovation systems and it adds a virtual "North-Western European" offshore wind innovation system. This interrelated perspective on the innovation systems shows that there is a lot of potential through increased coordination. The countries together seem to have all necessary ingredients for well-functioning North-Western European TIS. Weaknesses in one country are compensated by strengths in other countries. While the Netherlands, for example, specialises primarily in the construction of wind farms with focus on foundations, Denmark in wind turbine manufacturing and heavy vessels, the UK in sub-sea cables installation. Germany is active in many areas of the value chain and has an attractive market. While the Netherlands has a strong research-oriented knowledge base, Germany is leading in engineering knowledge. Denmark covers the knowledge base most comprehensively but has lower market ambitions. The UK, despite its shortcoming in knowledge and domestic industry, has huge market potential and best climatic conditions for offshore wind parks. From this perspective it may thus make sense to develop a common or at least more closely coordinated North-Western European policy and action plan related to offshore wind. Such a collaborative effort is in a much better position to optimise the use of the various assets in the four countries analysed in this paper than when each country tries to focus solely on strengthening its domestic innovation system. Moreover, some shortcomings in national systems may be of a more persistent nature due to place-based path-dependencies and institutional embeddedness (e.g. the Dutch preference for cost-efficient renewable energy policy, the UK's lack of domestic offshore industry or Denmark's relatively mature and saturated wind market). Solutions to these problems may not always be addressed effectively through national policy interventions as they need to 'work against the system' and are thus easily victim to *policy-failure*. In this light, stimulating or strengthening transnational linkages may offer a more conducive way to approach domestic problems in the innovation system. In appendix C we propose how this collaborative vision could be realised.

When coordinated policy is not possible or not aimed for by national policy makers, the linkages effects between innovation systems are still very relevant. We conclude, therefore, that explicit acknowledgement of the institutional embeddedness and transnational linkages of nationally delineated technological innovation systems has a substantial impact on the analysed strengths and weaknesses of an innovation system and the policy recommendations that follow from the analysis. Based on this empirical analysis we concur with the contribution by Coenen et al. (2012) who claim that analysts should be more explicit in taking the geographical context of a nationally delineated TIS into account.

We have also shown that coordinated policy efforts beyond national boundaries may be worthwhile exploring. In addition to the earlier described complementarities of the national offshore wind TIS there are other arguments why a coordinated policy effort is worthwhile exploring. The first is that in case of a coordinated effort, the locations for offshore wind farms are not related to national interests but to arguments of lowest construction costs and highest wind speeds[79]. Another argument is that in order to drive the costs down it is necessary to experiment with new turbine designs and foundations. A larger market makes it easier to invest in innovation and experimentation zones. Third, a homogeneous North-European market gives greater certainty, security and flexibility than in case of a sum of (varied) national markets since supranational policies are generally more stable than national policy plans. Fourth, a common market may help maximise the European competitive advantage before other regions do it cheaper since a European perspective can make optimal use of national strengths and thereby speed up knowledge development and innovation. Fifth, in the current decade North-Western European countries face a new energy investment cycle and the infrastructure built several decades ago is in need of replacement. Its gradual substitution with a European grid would make it easier for the Member States to manage variable electricity generation from many distributed sources and diminish the need for (expensive) storage facilities. It would also contribute to the reduction of even deeper dependence on the fossil resources.

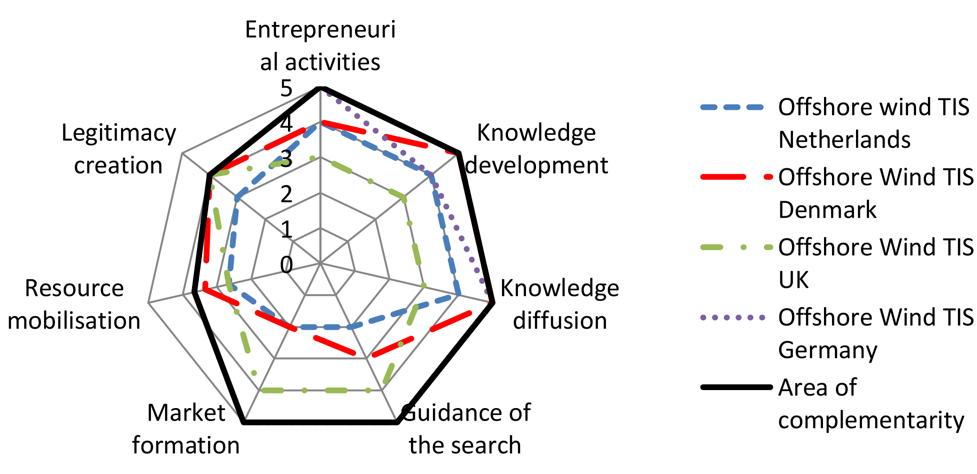

Figure 5. System functions fulfilment in the four analysed countries in 2011 (Wieczorek et al., 2013)

[79] Realisation of this potential would imply the necessity to quit national and introduce a European subsidy scheme for offshore wind.

6. Conclusions

In this paper we aimed to address the myopic bias of the national focus of the TIS studies. We used offshore wind in North-Western Europe as empirical evidence of interconnectedness and interdependency of four offshore wind TISs in 2011: the UK, Denmark, Germany and the Netherlands.

At the conceptual level we showed that an explicit acknowledgement of the role of transnational linkages in the domestic TIS performance and a stronger appreciation of the territorially specific institutional embedding of a national TIS has implications for the type of conclusion that are drawn from the systemic analysis and the type of policy strategy. TIS studies should not underestimate the persistence of certain systemic problems due to path-dependencies and institutional embeddedness. Rather than a quick policy fix, addressing these problems may very well require gradual institutional change. Related to this, we also conclude that it is indeed useful to assess national TIS in relation to their wider international context and that studying several national TISs helps shed light on their interactions. In some cases, national system failures are effectively counteracted by the characteristics of the innovation systems in related countries. We propose that a focus on a limited number but carefully selected national TISs that are interconnected (by e.g. being part of the same value chain), may be more revealing and less complex than trying to get grips of the complete global TIS (for a similar reflection see Binz et al., 2014).

Related to the empirical case, we observe that according to the national analyses the countries face a number of nation–specific obstacles to the wider diffusion of offshore wind energy. Broadening of the analytical scale reveals, firstly, that the differences in the inclination to innovate in offshore wind and the related problems are conditioned by *deep* country-specific institutional circumstances. Out of the four analysed TISs, Germany is being characterised by the strongest support from the national institutions, while the Netherlands by the least. Because offshore wind as a technological field transcends national borders, actors in a nationally delineated TIS make use of strengths of other innovation systems. As a consequence, innovation systems may partly complement each other's deficiencies. These linkages effects make the countries mutually interdependent and may qualify the nation-specific obstacles to be less of a challenge for the overall TIS. Secondly, explicit inclusion of spatial sensitivity to the analysis of particular national TISs reveals that the countries face a set of common, non-idiosyncratic problems, which form a serious obstacle to innovation in offshore wind. National policies based on protection of national industry and markets are not able to address these problems in an effective and sustained way. We show that an internationally coordinated, systemic policy may be more effective in dealing with these problems and at the same time make it possible to fully exploit national synergies. Thus, selective cooperation between countries in technology development and aligned policy instruments could potentially be a very effective way to speed up technological transitions[80].

[80] Footnote: It should be noted that in spite of policy coordination, individual firms may very well chose to refrain from international collaboration or choose its collaborators selectively in light of competition aspects in an open market.

By way of future outlook, it should be noted that in this paper we did four separate TISs analyses yet incorporated transnational linkages and institutional embeddedness explicitly in the analysis. For future research it would be recommended not to take national boundaries as a starting point but rather look at how the actors in the TIS define the system themselves following their value chains: where the market is, where knowledge is generated, which (territory-specific) institutions matter for the various actors; how the actors are influenced by certain institutions, how their investment decisions are influenced etc. and subsequently construct the system in a bottom up way. This would also give analysts a chance to assess which institutions matter most, whether these institutions are related to market formation or to knowledge generation, directions of search, entrepreneurial experimentation, etc. This would also free the analysts from imposing institutions on actors.

References

Alok J, (2008). UK overtakes Denmark as world's biggest offshore wind generator". *The Guardian* (London), 21 October

Amin A, Cohendet P, 2004. Architectures of knowledge. Firms, communities and competencies. Oxford, Oxford University Press.

Asheim BT, Coenen L, 2005. Knowledge Bases and Regional Innovation Systems: Comparing Nordic Clusters. Research Policy, 34:1173-90

Bergek A, Jacobsson S, Carlsson B, Lindmark S, Rickne A, 2008. Analyzing the functional dynamics of technological innovation systems: A scheme of analysis. Research Policy, 37:407-29

Berkhout F, Wieczorek AJ, Raven R, 2011. Avoiding environmental convergence: a possible role for sustainability experiments in latecomer countries? International Journal of Institutions and Economies, 3(2):367-385

Binz C, Truffer B, Coenen L, 2014. Why space matters in technological innovation systems - Mapping the global knowledge dynamics of membrane bioreactor technology. Research Policy. 43(1):138-155

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, Technological Forecasting and Social Change, 79:155–71

Binz C, Truffer B, 2012. Conceptualizing leapfrogging with spatially coupled innovation systems: the case of onsite wastewater treatment in China. Technological Forecasting and Social Change, 79(1):155-71

Capros P, Mantzos L, DeVita N, Tasios A, Kouvaritakis N, 2010. Trends to 2030-update 009,European Commission-Directorate General for Energy in collaboration with Climate Action DG and Mobility and Transport DG. Office for official publications of the European Communities, Luxembourg, ISBN 978-92-79-16191-9

Carlsson B, (Ed.) 1997. Technological Systems and Industrial Dynamics, Kluwer Academic Publishers, Boston, Dordrecht, London

Carlsson B, Stankiewicz R, 1991. On the nature, function, and composition of technological systems. Journal of Evolutionary Economics 1:93-118

Carlsson, B., 2006. Internationalization of innovation systems: A survey of the literature. Research policy, 35(1), 56-67

Chesbrough, H. W., 2003. Open innovation: The new imperative for creating and profiting from technology. Harvard Business Press

Coenen L, Benneworth P, Truffer B, 2012. Towards a spatial perspective on sustainability transitions. Research Policy, 41:968–79

Coenen L, Diaz-Lopez F, 2010. Comparing systems approaches to innovation and technological change for sustainable and competitive economies: an explorative study into conceptual commonalities, differences and complementarities. Journal of Cleaner Production, 18(2):1149-60

Coenen L, Raven, R, Verbong, G, 2010. Local niche experimentation in energy transitions: A theoretical and empirical exploration of proximity advantages and disadvantages. Technology in Society, 32:295-302

Coenen L, Truffer B, 2012. Places and spaces of sustainability transitions: geographical contributions to an emerging research and policy field'. European Planning Studies, 20(3):367–74

Cooke P, 2001. Regional Innovation Systems, Clusters and the Knowledge Economy. Industrial and Corporate Change, 10(4):945-74

Cooke P, Morgan K, 1993.The network paradigm: new departures in corporate and regional development ' Environment and Planning D, 11:543-64

Corbett A, 2002. Ideas, Institutions and Policy Entrepreneurship in European Community Higher Education, 1955–95 *(University of London, Unpublished PhD thesis)*

De Jager D, Klessman C, Stricker E, Winkel T, de Visser E, Koper M, Ragwitz M, Held A, Resch G, Busch S, Panzer C, Gazzo A, Roulleau T, Gousseland P, Henriet M, and Bouille A, 2010. Financing Renewable Energy in the European Energy Market. Project No. PECPNL084659, Ecofys, European Commission, DG Energy, Belgium

De Vries E, 2012. Rotation Consultancy, WindpowerMonthly, Personal communication, April

Deutsche Bank Climate Change Advisors, 2011. UK Offshore Wind: Opportunity, Cost and Financing.

Dewald U, Truffer B, 2011. Market Formation in Technological Innovation Systems—Diffusion of Photovoltaic Applications in Germany. Industry and Innovation, (18)3:285–300

Douglas-Westwood, 2010. Offshore Wind: Building an Industry. Analysis and scenarios for industrial development, www.renewable-uk.com

Dunning JH, Lundan SM, 2009. The MNE as a creator, fashioner and respondent to institutional change', in S. Collinson and G. Morgan (eds.), The Multinational Firm, Blackwell Publishers, Oxford

Edquist C, 1997. (Ed.), Systems of Innovation: Technologies, Institutions and Organizations. Pinter Publishers, London

Edquist C, Lundvall BA, 1993. Comparing the Danish and Swedish systems of innovation. National innovation systems, 265-98

EEA, 2009. Europe's onshore and offshore wind energy potential. Technical report No 6/2009

EU, 2011. European Union roadmap for moving to a competitive low carbon economy in 2050, COM (2011) 112, Brussels, EU

EWEA, 2011a. Wind in our sails - The coming of Europe's offshore wind energy industry. The European Wind Energy Association. 11/2011

EWEA, 2011b. Pure Power, Wind energy targets for 2020 and 2030.

EWEA, 2012. Creating internal energy market in Europe, September

Freeman C, 1987. Technology Policy and Economic Performance. Pinter Publishers, London

Gee S. McMeekin, A. 2011.Eco-innovation systems and problem sequences: the contrasting cases of US and Brazilian biofuels. Industry and Innovation 18(3):301-315

Gertler MS, 2004. Manufacturing Culture: The Institutional Geography of Industrial Practice. Oxford University Press

Hall PA, Soskice D, 2001. An Introduction to Varieties of Capitalism. In: Peter A. Hall David Soskice (eds.), Varieties of Capitalism: The Institutional Foundations of Comparative Advantage Oxford: Oxford University Press, 1–70.

Hekkert M, Suurs R, Negro S, Kuhlmann S, Smits R, 2007. Functions of innovation systems: A new approach for analysing technological change, Technological Forecasting and Social Change, 74: 413-32.

Heptonstall PR, Greenacre GP, Cockerill T, 2012. The cost of offshore wind: Understanding the past and projecting the future. *Energy Policy,* 41:815-821

Hillman K, Suurs R, Hekkert M, Sanden B, 2008. Cumulative causation in biofuels development: a critical comparison of the Netherlands and Sweden, Technological Analysis and Strategic Management, 20:592–612

Jacobsson S, Bergek, A, 2011. Innovation system analyses and sustainability transitions: Contributions and suggestions for research. Environmental Innovation and Societal Transitions 1(1):41-57

Jacobsson S, Karltorp K, 2012a. Mechanisms blocking the dynamics of the European offshore wind energy innovation system - challenges for policy intervention, Energy Policy, submitted

Jacobsson S, Karltorp K, 2012b. Formation of competencies to realize the potential of offshore wind power in the European Union. Energy Policy, 44:374-84

Jacobsson S, Lauber V, 2006. The politics and policy of energy system transformation – explaining the German diffusion of renewable energy technology, Energy Policy, 34:256–76

Jensen MB, Johnson B., Lorenz E, Lundvall BÅ, 2007. Forms of knowledge and modes of innovation. Research policy, 36(5):680-693

Karnøe P, Garud G, 2003. Bricolage versus breakthrough: distributed and embedded agency in technology entrepreneurship Research Policy, 32(2), 277–300

Klein-Woolthuis R, Lankhuizen M, Gilsing V, 2005. A system failure framework for innovation policy design. Technovation 25: 609-619.

KPMG, 2010. Offshore wind in Europe. 2010 Market Report

Laranja M, Uyarra E. Flanagan K, 2008. Policies for science, technology and innovation: Translating rationales into regional policies in a multi-level setting' Research Policy 37(5):823–835

Lundvall BÅ, (Ed.), 1992. National Systems of Innovation – toward a Theory of Innovation and Interactive Learning. Pinter Publishers, London

Lundvall BÅ, Maskell P, 2000. Nation states and economic development – from national systems of production to national systems of knowledge creation and learning. In Clark, G.L., Feldman, M.P. and

Gertler, M.S., editors, The Oxford handbook of economic geography, Oxford: Oxford University Press, 353–72

Makridis C, 2013. Offshore wind power resource availability and prospects: A global approach, Environmental Science and Policy, 33: 28-40

Malerba F, 2002. Sectoral systems of innovation and production. Research Policy 31:247–64

Markard J, Petersen R, 2009. The offshore trend: structural changes in the wind power sector. Energy Policy, 37(9):3545-56

Markard J, Raven R, Truffer B, 2012. Sustainability transitions: an emerging field of research and its prospects*. Research Policy*, *41*(6):955-67

Metcalfe S, Ramlogan R, 2008. Innovation systems and the competitive process in developing economies." The Quarterly Review of Economics and Finance, 48(2):433–446.

Negro S, Hekkert M, 2008. Explaining the success of emerging technologies by innovation system functioning: the case of biomass digestion in Germany, Technological Analysis and Strategic Management, 20: 465–82

Negro S, Hekkert M, Smits R, 2007. Explaining the failure of the Dutch innovation system for biomass digestion – a functional analysis. Energy Policy, 35:925–38

Nelson RR, (Ed.), 1993. National Systems of Innovation. A Comparative Analysis. Oxford University Press, Oxford

Nooteboom B, 2000. Learning and innovation in organizations and economies. Oxford University Press.

Patel P, and Pavitt K, 2000. National systems of innovation under strain: the internationalisation of corporate R&D. In: Productivity Innovation and Economic Performance. Cambridge University Press, 217-235, ISBN 521780314

Raven R, Schot J, Berkhout F, 2012. Space and scale in socio-technical transitions. Environmental Innovation and Societal Transitions, 10(4):63-78

Rodríguez-Pose A, 2013. Do institutions matter for regional development?. Regional Studies, 47(7), 1034-47

Saxenian AL, 2005. From Brain Drain to Brain Circulation: Transnational Communities and Regional Upgrading in India and China, Studies in Comparative International Development

SER, 2013. Energieakkoord voor duurzame groei.

Smith K, 2000. Innovation as a systemic phenomenon: rethinking the role of policy. Enterprise and Innovation Management Studies 1:73-102.

Späth P, Rohracher H, 2012. Local Demonstrations for Global Transitions—Dynamics across Governance Levels Fostering Socio-Technical Regime Change Towards Sustainability. European Planning Studies, 20(3):461-79

Storper M, 1997. The regional world: territorial development in a global economy. Guilford Press

The Crown Estate, 2011. Report from the Financing Sub-group to the Offshore Wind Developers Forum. 21 June, 2011

Truffer B, Coenen L, 2012. Environmental Innovation and Sustainability Transitions in Regional Studies, Regional Studies, 46(1):1-21

Vogel D, 1997. Trading up and governing across: transnational governance and environmental protection. Journal of European Public Policy 4(4):556–571

Wieczorek AJ, Hekkert M, 2012. Systemic instruments for systemic innovation problems: A framework for policy makers and innovation scholars. Science and Public Policy, 39:74–87

Wieczorek AJ, Negro SO, Harmsen R, Heimeriks GJ, Hekkert MP, 2013. A Review of the Western European Offshore Wind Innovation System. Renewable and Sustainable Energy Reviews, 26:294–306

Wieczorek, AJ, R Raven and F. Berkhout, submitted. Transnational linkages in sustainability experiments. The case of solar PV in India. Environmental Innovation and Societal Transitions, 2014. Paper presented at IST conference Zurich in June 2013

Woolley O, 2013. Governing a North Sea grid development: The need for a regional framework treaty. Competition and Regulation in Network Industries, 14(1):73-97

Zimmerman MA, Zeitz GJ, 2002. Beyond Survival: Achieving New Venture Growth by Building Legitimacy. The Academy of Management Review, 27(3):414-31

Appendix A

Semi-structured interviews (ca 1h each) during EWEA Conference, 29 November-1 December, 2011, Amsterdam, The Netherlands with representatives of:

4C Offshore, UK, Director Product Development
A2Sea, Denmark, Business Developer
Alstom, The Netherlands, Country Sales Director, Grid
DONG Energy, Denmark (Dong DK), Senior Manager Operations and O&M Management
DONG Renewable Energy, UK (Dong, UK), Offshore wind Project Development Manager
Ecofys, Wind Energy, The Netherlands, Unit Manager
Esbjerg Business Development Centre, Denmark, Business Consultant
EWEA, Brussels, Research officer 1
EWEA, Brussels, Research officer 2
EWEA, Brussels, Policy lobbyist
Germanischer Lloyd Renewable Certification (GL), Germany, Head of Group Project Management
JDR Cable Systems LTD, UK, Sales Director
Jutlandia, Denmark, HSEQ Manager
KBR Power, UK, Senior Business Developer
KBR Power, UK, Technical Professional
Kema, Arnhem, The Netherlands, Consultant Wind Energy
MPI Workboats, UK, Operations Manager
Netherlands Wind Energy Association (NWEA), The Netherlands, Senior Advisor
Offshore Centre Denmark (OCD), Renewables Manager
PMSS, UK, Director
Rabobank, The Netherlands, Senior Associate
RenewableUK, UK, Offshore wind Development Manager
RWE; Germany, Executive Support Manager
Seas NVE, Denmark, Project Engineer
Seas NVE, Denmark, Project Manager
Siemens Wind Power A/S, Denmark, Strategic Recruiting Specialist
Technical University Delft, Professor of Future Energy Systems
Siemens Wind Power A/S Germany, Senior Sales and Marketing Manager
Typhoon Offshore, UK, Head of UK Operations
Van Oord Offshore Wind Projects BV, The Netherlands, Regional Manager
Volker Staal en Funderingen (VSF), The Netherlands, Director
Volker Staal en Funderingen (VSF), The Netherlands, Project Engineer

A working session (ca 8h) on Systemic policy for offshore wind in the Netherlands and Europe, 21 June 2012, Utrecht, The Netherlands with:

Van Oord, ECN, NWEA Manager Business Development
FLOW, Director
Offshore Monthly, Rotation Consultancy, Expert
Ampelmann TU Delft, Project manager, CEO,
Nuon/Vattenfall, Manager Offshore New Developments
Out-Smart, Founder and CEO

Appendix B

Diagnostic questions to determine the functioning of innovation systems

Key process/ functions	Diagnostic question
Entrepreneurial activities	- **Are there sufficient[81] and suitable types of actors contributing to entrepreneurial experimentation and up-scaling?** - **Are the amount and type of experiments of the actors sufficient?** - **How much technological up scaling takes place?**
Knowledge development	- **Are there enough actors involved in knowledge development and are they competent?** - **Is the knowledge sufficiently developed and aligned with needs of actors in the innovation system?**
Knowledge exchange	- **Are there sufficient network connections between actors through which knowledge is exchanged?**
Guidance of the search	- **Do actors and institutions provide a sufficiently clear direction for the future development of the technology?**
Market formation	- **Is the size of the market sufficient to sustain innovation and entrepreneurial experimentation?**
Resource mobilisation	- **Is the availability of financial resources sufficient?** - **Are there sufficient competent actors / well trained employees?** - **Is the physical infrastructure sufficient?**
Creation of legitimacy	- **Do actors, formal and informal institutions sufficiently contribute to legitimacy?** - **How much resistance is present towards the technology, project set up or permit procedure?**

[81] Since innovation does not recognise an optimum, it is impossible to judge whether there is *enough* of it. Our discussion on the *sufficiency* of innovative activity in the areas defined by the system functions is, therefore, based on the qualitative evaluation of the capacity of the four analysed systems to grow and accelerate. At the same time we refrain from any quantitative assessment in the context of reaching the European and national targets.

Appendix C

Elements of collaboration-based European policy on offshore wind

Market Harmonisation Action

While the electricity market liberalisation process in Europe is underway, several countries lie behind and the level of integration of the national markets is low. The liberalisation process is also designed to support established large-scale conventional power generators with limited space to alternative providers (EWEA, 2012). The Market Harmonisation Action would be a mechanism, through which the regulatory framework behind the liberalisation process is redesigned to make space for renewable energy sources. It would also aim at developing a power trading framework including harmonised market rules and support mechanisms (e.g. green certificates or tax exemptions). One of the important outcomes of the Action would be the creation of a European subsidy scheme and a level playing field for all power technologies by, among others, the removal of subsidies for fossil fuels and nuclear energy.

EU Grid Initiative

In the first period of its operation, the Initiative would provide a platform for discussing the future European electricity transmission network. The aim would be to align the varying visions and expectations but also provide space for national diversity and a step-wise, organic, grid reinforcement. Such an organic model would be more receptive to ongoing natural developments and would allow countries to benefit from each other. Other outcomes of the Initiative would be the establishment of a clear legal framework for pan-European transmission management including binding guidelines and network codes. Such framework is considered indispensable for the North Sea states' ability to set and maintain the development of a shared transmission network in a mutually beneficial way (Woolley, 2013). The Initiative would build upon and bring together or cooperate with other current initiatives by various parties such as by OffshoreGrid[2], TEN-E Programme[3] or ENTSO-E[4].

R&D and Demo Programme

The objectives of this programme are: the development of low-cost technologies, optimisation of the value chain and improving the economics of offshore wind by setting the green value of kWh, the most efficient manner to trade it within Europe, evaluation of the effectiveness of the various support schemes (FIT, subsidies) and the strategies for their potential timely phase out. The programme would particularly encourage university-industry collaboration and would have two modules. By default it would support projects that are *feasible*. However, it would also have substantial budget available to making projects *profitable*. Proponents of the latter, to be eligible for funds, would need to demonstrate the outcomes of their work in the Innovation Zones (described below).

Innovation Zones

Innovation Zones are test fields: dedicated spaces at sea or parts of existing wind farms that expedite first generation of projects and technologies before their commercial scale-up. The data and

[2] www.offshoregrid.eu, accessed April 2012
[3] www.ec.europa.eu/energyinfrastructure/tent_e/tent_e_en.htm, accessed April 2012
[4] www.entsoe.eu, accessed April 2012

experiences (including failures) gathered in the Innovation Zones would be fed into a monitoring evaluation programme, an open database, with the aim to facilitate better informed decisions on second generation projects.

Expert Mobility Programme

Expert Mobility Programme is part of the R&D and Demo Programme and aims to support offshore wind researchers in gaining practical experience by spending 1-2 years in the industry or in Innovation Zones. Such a programme would facilitate skills development, knowledge diffusion and reduction of training costs. It would also encourage greater collaboration between business and academia and support the process of trust building and network expansion.

European Technology Platform

A European Technology Platform (TPWind) and a SET Plan (incl. EERA Wind) already exist and fulfil their function of fora for the crystallisation of policy and technology research and development pathways for the wind energy sector. It also provides an opportunity for informal collaboration among Member States. Support to such programmes or their successors should continue. Such initiatives support network formation, confidence building and setting of the R&D priorities.

European Offshore Wind Academy

Europe already has a European Academy of Wind Energy, which focuses on training experts in both onshore and offshore wind energy. We suggest, given the severe deficiency of high and middle level offshore wind technicians, to establish a European Offshore Wind Academy dedicated to emerging and urgent issues of the offshore wind system. The Academy would provide a variety of vocational and academic training and take a form of cooperation between the leading knowledge institutes and industrial partners. The Academy would complement the national educational efforts by e.g. stimulating international collaboration on PhD projects.

Chapter VII

Conclusions

1. Introduction

Technological Innovation System (TIS) perspective became a popular tool to analyse and understand the diffusion of particular, mostly renewable, technologies and their contribution to sustainability transitions. The core of the current TIS studies comprises of the analyses of the emergent structural configuration (actors, networks, technology, institutions) and major processes (functions) that support formation and development of innovations. The approach is often used to identify the so-called system problems and propose systemic policy and instruments to address them in a coherent way.

The approach and the related empirical studies, however, suffer from a number of limitations. The first limitation is lack of a clear conceptualisation of the system problems. The second flaw is a very general character of policy advice based thereon. Third shortcoming refers to the predominantly national delimitation of the studied systems and a lack of explicit recognition of the spatial context, in which innovations and transitions occur. Fourthly, not many of the TIS studies elaborate on systemic problems and policy in systems of various stages of development.

This thesis aims to contribute to the TIS literature by addressing these four shortcomings. Its overall objective is to contribute to the improvement of knowledge regarding innovation processes for sustainability through the conceptualisation and identification of systemic problems and instruments in renewable energy Technological Innovation Systems that are in various stages of development and of differing geographical delimitation.

This concluding chapter summarises major outcomes of this research by providing answers to the thesis' main research questions.

2. Systemic instruments for systemic problems

RQ1: Based on the recent insights from the system innovation studies how can systemic problems and systemic instruments be conceptualized and identified?

Building on the recent insights from the innovation studies, four innovation systems concepts: the structure and functions of innovation systems, systemic problems and systemic instruments were brought together into a systemic framework that helps analyse and stimulate technological innovation. The concepts have all the same systemic, evolutionary foundations but they were developed relatively independent and they were therefore poorly aligned. They were also used rather independently to inform policy process while they differ and concern different aspect of policy process (analysis, identification of problems, design of policy tools).

The structural and functional analyses are promising analytical tools to evaluate system's performance but it is unclear how exactly structure relates to the seven system functions. This research suggests that the functional analysis complements the structural one by being a manifestation of the way in which an innovation system is organised. Each structural element may have impact on each of the functions: missing entrepreneurs not only hinder function F1 entrepreneurial activities but their absence may also have negative impact on the guidance of the search F4 or production of knowledge F2 especially when systems are based on engineering knowledge like in the case of offshore wind. It is therefore not justified to try to connect selected structural elements with selected functions (e.g. knowledge institutes with knowledge production, or government with guidance of the search) even though these are major process performed by these organisations. The cases presented in this thesis confirm that other actors, than the *usual suspects* may also have influence on system functioning.

Clarifying the link between the functions and the structure of innovation systems is also necessary for practical reasons. Functions cannot be influenced by policies otherwise than through alteration of the structural components. In that sense functions *signal* problems but it is the structural element of the system that is responsible for the functional weakness. That further implies and is confirmed by all analysed cases in this thesis, that systemic problems have structural characteristics. To identify their typology therefore it is critical to clarify the structural configuration of innovation systems. Based on the literature overview four elements have been identified in this thesis: actors, institutions, infrastructure and interactions. Each of the elements may be missing or have inappropriate properties adding an extra subcategory to the typology of the four (actor, institutional, interaction and infrastructural) problems, namely the presence or capacity aspects. Because the problems are identified based on a coupled structural-functional analysis, they cannot be accused of being static. The mechanisms blocking the systemic functions identified in the literature can easily be expressed along the categories and types (presence, capacity) of systemic problems. The advantage of the proposed systemic problems typology (actor problems, institutional problems, interaction problems and infrastructural problems) is that it provides a complete *checklist* of all possible problems that may occur within a specifically defined system. Together with the 4 subcategories (related with presence or capacity of each element) the problems specify areas for policy intervention: e.g., actors may be missing or have insufficient capacity, interaction may be absent or be too strong or too week.

Policy instruments, therefore, to be able to address all 4 major types of systemic problems and the 4 subcategories (related with presence or capacity of each element) should focus on one or more of the following 8 goals:

1. Stimulate and organise the participation of various actors (when actors are missing);
2. Create space for actors capability development (when actors do not have sufficient capacities))
3. Stimulate occurrence of interaction among heterogeneous actors (when interactions are absent);
4. Prevent too strong and too weak ties (when interactions are too strong or too weak);
5. Secure presence of (hard and soft) institutions (when institutions are lacking);
6. Prevent too weak or too stringent institutions (when institutions are too stringent or too weak);
7. Stimulate physical, financial and knowledge infrastructure (when it is missing);

8. Ensure adequate quality of the infrastructure, strategic intelligence serving as a good example of specific knowledge infrastructure (when the infrastructure is malfunctioning).

The goals guide selection of individual tools in a way that allows for their mutual reinforcement, coherence and orchestrated impact. Such an integrated, smart bundle of individual (traditional, e.g. financial, regulatory, and participatory instruments), is called a systemic instrument. Its purpose is to create opportunities for system development by influencing elements and connections within the system that would not emerge otherwise. Systemic innovation policy instruments can also be defined as *policy mixes* (OECD, 2012) but explicitly designed to tackle the systemic problems of the innovation system in an orchestrated way.

By discouraging negative elements, securing presence of positive ones and by adjusting their capacities, actors not only have the chance to provide better environment for innovation but they may also influence the direction of technological change towards e.g. more sustainable goals. The proposed systemic framework linking structure with functions, problems and instruments could therefore be seen as a decision support tool to all actors that are concerned with complex systemic problems.

3. Systemic problems in a nascent and nationally delimited TIS

Two nationally delimited, Dutch, technological innovation systems have been analysed: a nascent aquatic biomass and an emergent offshore wind innovation system.

RQ2: What are the systemic problems in a nascent and nationally delimited technological innovation system of aquatic biomass in the Netherlands and how can they be addressed?

The development of the Dutch aquatic biomass system has been studied using longitudinal functional analysis interwoven with structural analysis. The longitudinal analysis concerned events in the period of 1998-2012 and was based on Lexis-Nexis database, literature review and personal communications with experts in the field. It was particularly useful to understand how system emerged in the Netherlands and what factors influenced its early formation.

The structural analysis demonstrated that the Dutch aquatic biomass Technological Innovation System is a typical example of a nascent system: low level of structuration, value chains in flux with high variety of actors focusing on R&D, technology at the stage of concepts or ideas and a strong dominance of expectations. In terms of process, the analysis showed that after a slow 8-year long take off in 1998-2006, the system experienced a visible acceleration in 2007-2008. After the financial crisis of 2008 and change of cabinets in 2010, it lost its momentum but the earlier projects, the scientific reports, the European commitment to renewables, and the same crisis (high oil prices) kept the system alive. The functional pattern revealed that especially the direction of the search (F4), legitimacy creation (F7) and developments in a system context played critical role in the development of this nascent system. Guidance (F4) in the form of governmental intervention has had impact on resources mobilisation (F6), which further either stimulated or hindered entrepreneurial activities (F1), research (F2) and knowledge diffusion (F3). Uncertainties about the direction of the search, high promises of potential market and lack of ability to meet these promises on the short and medium term caused that no serious critical mass and legitimacy processes took place in the system (F7).

This coupled structural-functional analysis allowed to identify the structural reasons behind the functional weaknesses: incomplete value chain (actors, presence problems), lack of coordination in this emerging field, for example the link between energy and other products was not well communicated (interaction, presence and capacity problems), lack of necessary institutions, too high expectations (institutional, presence and capacity problem) and underdevelopment of infrastructure (infrastructural presence and capacity problems).

This case also demonstrated that the strength of the functions not only depends on the influence from the structure-related dynamics but also from the context developments of three types. First type relates to the spatial variation of the structural configuration of the TIS, we term these factors *transnational linkages*. They are of various kinds: many incumbent actors who diversify their business to aquatic biomass activities, have strong international relations with foreign markets and access to international knowledge. Via CORDIS collaborations also the knowledge institutes have a chance to establish broader networks and access knowledge assets of other countries. These collaborations, however, are not very well established yet and the Dutch aquatic biomass system does not seem to be well-connected internationally.

The second type of context developments that have had a strong influence on aquatic biomass in the Netherlands are *other TISs activities*. These can be of two types. First relates to the impacts of knowledge development, entrepreneurial activities, legitimation processes, resources mobilisation, etc. in aquatic biomass in other countries. The second are impacts from TISs built around other technologies, often incumbent, such as the Dutch oil-and-gas regime. These impacts, on the one hand brought attention to aquatic biomass as a radically different and sustainable alternative to fossil fuels, but on the other, they added to very high Dutch expectations and kept the system from developing .

Finally, factors of a *landscape type*, next to impact of other TISs have a relatively strong influence on the development of this system. First, the climate change debate stimulated the Dutch government to pay attention to persistent environmental problems and motivated energy innovation agenda. With time, European commitment to renewables was institutionalised into a directive and expectations regarding promising sea activities were officially voiced. These developments kept the Dutch aquatic biomass system alive when the world crisis stroke and the new Dutch cabinet changed national priorities and continued its support to incumbent oil and gas industry. The same crisis, however, brought about high oil prices and renewed hope in the 3rd generation biofuels also from aquatic forms of biomass.

The most appropriate policy for such an embryonic system would be the support to its internal formation with an eye on international cooperation. The system actors should try to formulate a common vision that is based on tangible results from research and pilot projects and start organising themselves by cooperating domestically and with international experts. A systemic instrument in the form of Aquatic Biomass Organisation could help the actors advance this novel and promising area. In line with the systemic instruments goals such an organisation would focus on two key issues: firstly on aligning the various expectations and development of a common strategic vision for this system so as to avoid overly hopes in conditions of underdevelopment of the field (addressing interaction, institutional and infrastructural problems); and, secondly, on the formation of the value chain, coordination of domestic activities and their solid embeddedness in the broader aquatic biomass TIS (addressing actors and interaction problems).

Analysis of this case proves that more careful study of the system context should be a necessary part of the TIS analysis. Omitting it may have serious implications for the identification of problems and design of effective policy. The following case therefore studies in more detail the implications of taking national perspective vis-à-vis a broader view of the system environment for the identification of problems and national strategic choices.

4. Systemic problems in an emergent and nationally delimited TIS

RQ3: What are the systemic problems and instruments in a more mature and nationally delimited technological innovation system of offshore wind in the Netherlands?

The analysis of the Dutch offshore wind Technological Innovation System followed the five stages of the systemic framework and presented a snapshot of system dynamics in 2010-2011. The review of the system's structural configuration was complemented with functional analysis based on Lexis Nexis media events analysis for 2010-2011 and personal communications with over 30 offshore wind stakeholders.

The lesson learnt from the structural analysis was that the Dutch offshore wind innovation system is in a growth phase with well-established products and markets, industrial production, value chain composed of competent actors and developing institutional structures. The system also seems to be well embedded in a broader, North European TISs encompassing Germany, Denmark and the UK. The analysis of the dynamics of the Dutch offshore wind innovation system in 2010-2011 revealed a similar pattern to that found in the nascent aquatic biomass with that difference that here market formation processes played an increasingly important role. Still, two critical factors in the formation of this system were poor legitimacy of offshore wind (F7) and the related lack of guidance of the search (F4). Both have strong impact on the other innovation system processes, in particular the market formation (F5) and resources mobilisation (F6). Even though the entrepreneurial activities (F1) as well as knowledge creation and diffusion (F2 and F3) are currently strong in the Netherlands, in the long run, they may get negatively affected by poor market formation (F5) and deficiency of resources (F6).

Such analysis allows to observe that addressing of the legitimacy (F7) as well as the guidance of the search (F4) problems and simultaneously constructing home market (F5) are therefore key to improving the performance of the remaining system processes due to the feedback loops that exists between the functions. In practice, improvement of the two system processes implies tackling of the following problems: lack of human resources (actors, presence problem); poor overlap in knowledge base of industry and knowledge institutes, poor international collaboration on scientific knowledge, (interaction, capacity problems); lack of vision and goals for environmental, industrial and innovation policies, unstable regulatory regime, lack of innovative subsidy schemes, ineffective support programmes, cost of technology (institutional presence and capacity problems) and finally, lack of financial resources, reliability and availability of technology, grid access and capacity (physical infrastructure, capacity problems).

Dutch policy and strategy in support of the system based on this national delimitation would therefore need to focus on the development of home market, national lobby and framing as well as on investments in domestic programme to support university-industry collaboration. Elements of systemic instruments based on this analysis would include following elements: National institutional improvements (Green Deal 2.0, utilisation of academic culture, decision regarding achievement of carbon targets, etc.), National R&D and Demo Programme, Tax Incentive, Learning Scheme, National Monitoring and Evaluation Program, National Innovation Zones, National Expert Mobility Programme. These elements have multiple impacts on a number of systemic problems.

5. Impact of system environment on identification of systemic problems in an emergent TIS

RQ3: What is the impact of system environment on the identification of systemic problems and instruments in more mature technological innovation systems of offshore wind in the Netherlands?

As much as the nation states are important to facilitating transition processes, organising policy purely at national level can overlook the impact of the context on a national TIS. For example, while scientific knowledge is produced locally or nationally; engineering knowledge is created by international companies and therefore diffused via European market interaction, a wider than national context. Further extension of the policy analysis by taking into account the impact of developments in the system context, therefore, additionally extends the recommendations.

Major context developments that played an important role in the formation of the Dutch offshore wind innovation system until 2011 include landscape type of developments such as: EU commitment to offshore wind, good global offshore wind position and clear EU climate targets coupled with the availability of European R&D funds but also financial crisis of 2008. Not without importance was the impact of neighbouring offshore wind TISs such as the UK, Germany or Denmark. The UK is young but large and promising market that the Dutch companies already use. Denmark and Germany excel in turbine manufacturing and both have strong engineering knowledge production. Germany additionally has a strong support of the government to offshore wind. The Dutch offshore wind innovation system also reveals a degree of transnational linkages: many actors are global players active in international markets which stimulates capital, technology and knowledge linkages. Explicit acknowledgement of the role of context developments in the domestic TIS performance and a well-informed scan of the spatial embedding of a national TIS has implications for the type of conclusion that are drawn from the systemic analysis and the type of policy strategy. It can, namely, reveal that many Dutch national weaknesses can be addressed by using the strength and resources of other countries or regions in the process of collaboration.

Additional, national analyses of the neighbouring offshore wind TISs reveal that, in fact, they all face a number of nation–specific obstacles to the wider diffusion of offshore wind energy. Broadening of the analytical scale shows that the offshore wind as a technological field trespasses national borders and that the neighbouring countries make use of each other innovation systems for access to resources and thereby complement each other deficiencies. These transnational linkages effects make the countries mutually interdependent and cause that the nation-specific obstacles become less challenging. Furthermore, explicit inclusion of spatial dynamics to the analysis of particular national TIS's demonstrates that the countries face a set of common problems, which form a serious obstacle to innovation in offshore wind in all of Europe. National policies based on protection and building of national industry and markets are not able to address these problems in an effective way.

A Europe-wide coordinated, systemic policy may be more effective in dealing with these problems than uncoordinated national policies. It can make it possible for the various countries to fully exploit national synergies and cooperate in technology development. Elements of such systemic instrument could include: EU Market Harmonisation Action, European Technology Platform, European Offshore Wind Academy, EU Grid Initiative. Such aligned policy instruments could be a very effective way to speed up technological transitions.

Summarising, it is useful to study national TIS in relation to its context and studying several national TIS's simultaneously helps shed more light on their interactions. A focus on a carefully selected national TIS's may be more beneficial than trying to get grips on the complete global TIS, which is very hard due to the sheer complexity.

6. Methodological observations

This thesis aimed to develop a scheme for analysing Technological Innovation Systems and a systemic policy framework. More specifically, it aimed at identifying systemic problems and instruments to address them. The analysis of empirical cases showed that the framework is a flexible format allowing for various types of analysis: a snapshot of the systems versus longitudinal overviews, a nascent innovation system versus an emerging innovation system and a national focus versus a cross country comparison. The empirics also demonstrated that functional analysis may be interwoven with the analysis of structural configuration (as in chapter 3, 5 and 6) or making the story more lively and dynamic than in case of separate mapping of structure and functions (as in chapter 4).

For identification of systemic problems it is useful to first identify the functional pattern and the weakest functions instead of clarifying completely all inducement and blocking factors. The typology of systemic problems proves very valuable as a checklist verifying the completeness of analysis. It also neatly guides selection of policy strategy following the eight systemic policy goals and allows analysts to be more specific in their policy advice and go beyond the general type of policy recommendations.

Problems and policy depend very much on the stage of system development. Strong market formation processes and institutional change are important for systems in a growth or more mature stages, they are less so for the nascent systems. Nascent systems are mostly preoccupied with accumulation of knowledge, formation of the value chain and networks, alignment of institutions and gaining legitimacy. Furthermore, the technology in systems in embryonic stage is often not well developed and appears more in the form of ideas. Very few formal institutions exist and cognitive elements such as expectations and promises dominate.

Concerning context developments, this thesis had an explorative character in that regards. Initiated a couple of years ago, just like many other studies, it took the national delimitation of the selected empirical cases as a starting point. Its original ambition was to design and test the systemic policy framework. During the analysis, however, it became clear that national technological systems are significantly influenced by what happens in their broader environment and that these forces need to be taken into account. Taking the system environment properly into account helps show policy makers what choices they have and how possibly the problems could be addressed. Three types of developments in the broader system context have been identified in this research: transnational linkages, impact of other TISs and landscape impacts. While transnational linkages are best manifested in the structural analysis, impact of other TISs activities and landscape factors are better captured by the functional analysis, especially when carried out based on events analysis. The TIS approach and in particular the systemic policy framework proves flexible enough to take these *spatial additions* into account.

7. Follow-up research

Increasingly studies concerned with global environmental change and its detrimental effects advocate the need for a *systemic* alteration of the way in which humanity satisfies its needs for energy, food, housing or water. In particular, the sustainability transition literature, also often referred to as *system innovation* studies, emphasizes the need to look at and transform the entire systems at the level of societal functions – the so-called *socio-technical systems* or *systems of provision* (Elzen and Wieczorek, 2005; Geels, 2005).

Although the systems advocated by sustainability transitions and innovation system schools: the socio-technical systems and the innovation systems, may overlap in reality, theoretically they do differ from each other. While the socio-technical systems aim at provision of human needs (mobility, food, housing), the innovation systems aim at innovation. In terms of a structure of both systems, originally the innovation systems did not include the *material components* that the socio-technical systems included but with time innovation systems scholars began to treat it as part of the innovation system, labelling it *technology* (Hekkert et al, 2007; Bergek et al, 2008) or *infrastructure* of various kinds (Wieczorek and Hekkert, 2012). Furthermore, innovation studies are focused on the dynamics of particular innovation and diffusion of a particular technology, in case of transition studies the focus is on the prospects and the dynamics of broader transition processes, so a variety of innovations (Markard and Truffer, 2008). There is a growing literature that is attempting to compare the two schools both theoretically (Markard and Truffer, 2008) as well as empirically (Lovio and Kivimaa, 2012). This literature seems to converge in recognising: i) the differing objectives of the two approaches, and ii) their partial complementarily. It is especially being argued that the empirical differences turn out to be smaller than the theory would suggest (Lovio and Kivimaa, 2012).

Given that both schools use the concept of *systemic* but in relation to two (originally) differently conceptualised entities, an interesting follow up research would be one that focuses on better understanding of how the two schools define *system* and on verifying what it implies for *systemic* problems and policy. This type of research could shed more light on whether clarification of the systems' structure, processes and boundaries is critical to identification of *any* system's problems and policy that would address them.

References

Bergek, A., Jacobsson, S., Carlsson, B., Lindmark, S., Rickne, A., 2008. Analyzing the functional dynamics of technological innovation systems: A scheme of analysis. Research Policy, 37:407-29

Geels, F.W., 2005. Processes and patterns in transitions and system innovations: Refining the co-evolutionary multi-level perspective. Technological Forecasting and Social Change, 72(6):681-696.

Elzen, B., Wieczorek, A.J. (eds), 2005. Transitions towards sustainability through system innovation Transitions towards Sustainability through System Innovation. *Technological Forecasting and Social Change*, 72(6):651-662

Hekkert, M., Suurs, R., Negro, S., Kuhlmann, S., Smits, R., 2007. Functions of innovation systems: A new approach for analysing technological change, Technological Forecasting and Social Change, 74:413-32

Lovio, R., and Kivimaa, P., 2012. Comparing alternative path creation frameworks in the context of emerging biofuel fields in the Netherlands, Sweden and Finland. European Planning Studies 20:773-790

Markard, J., Truffer, B., 2008. Technological innovation systems and the multi-level perspective: towards an integrated framework. Research Policy 37:596–615

Wieczorek, A.J., Hekkert, M.P., 2012. Systemic instruments for systemic innovation problems: A framework for policy makers and innovation scholar. Science and Public Policy, 39:74-87

Wieczorek, A.J., Hekkert, M.P., Coenen, L., Harmsen, R., 2014. Broadening the national focus in technological innovation system analysis: the case of offshore wind. Environmental Innovations and Societal Transitions, accepted for publication

Summary

Technological Innovation System (TIS) perspective became a popular tool to analyse and understand the diffusion of particular, mostly renewable, technologies and their contribution to sustainability transitions. The core of the current TIS studies comprise of the analyses of the emergent structural configuration (actors, networks, technology, institutions) and major processes (functions) that support formation and development of innovations. The approach is often used to identify so the called system problems and propose systemic policy and instruments to address them in a coherent way.

The approach and the related empirical studies, however, suffer from a number of flaws. This thesis aims to contribute to the TIS literature by addressing four specific gaps. Firstly, it conceptualises and empirically underpins the notion of the system problems and systemic instruments. Secondly, it argues that the use of both concepts in combination with a coupled structural and functional analysis enhances and specifies the policy advice. Thirdly, the thesis demonstrates how the national delimitation of the system and a lack of explicit recognition of the spatial context in which innovations and transitions occur, impacts the definition of the problems and the related policy advice. Fourthly, it goes beyond the focus on emerging technological systems by studying problems of and policy for less developed, juvenile system.

Its overall objective is to contribute to the improvement of innovation processes for sustainability through the definition and identification of systemic problems and instruments in renewable energy Technological Innovation Systems that are in various stages of development and of differing geographical delimitation. Two empirical domains: aquatic biomass and offshore wind are used to illustrate the theoretical claims.

Samenvatting

In dit proefschrift staat een perspectief van Technologische Innovatie Systeem (TIS) centraal. Dit perspectief werd een populaire tool voor het analyseren en begrijpen van de verspreiding van bepaalde, meestal hernieuwbare technologieën en hun bijdrage aan transities naar duurzaamheid. De huidige TIS studies richten zich op analyses van de actoren, netwerken, technologie, en instellingen (de *structurele configuratie* van het system) en op hoofdprocessen (*functies*) die de innovaties ondersteunen zoals markt formatie of kennis ontwikkeling. Het perspectief wordt ook toegepast op de praktijk en dan gebruikt om het technologische innovatiesysteem te identificeren, en om een systemisch beleid en instrumentarium te ontwikkelen om belemmeringen voor de diffusie van die technologie aan te pakken.

Het bestaande TIS perspectief en de bijbehorende empirische studies hebben echter een paar tekortkomingen. Dit proefschrift behandelt er vier en voor elk daarvan wordt ook een voorstel voor een nieuwe aanpak gedaan. Ten eerste wordt een voorstel gedaan voor het conceptualiseren en empirisch onderbouwen van het idee van het systeem problemen en systemische instrumenten. In de tweede plaats wordt besproken dat het gebruik van beide concepten, in combinatie met een gekoppelde structurele en functionele analyse, het beleidsadvies helpt te verbeteren en specificeren. Ten derde wordt het belang van de ruimtelijke afbakening besproken. Duidelijk wordt gemaakt hoe de nationale afbakening van het systeem en een gebrek aan expliciete erkenning van de ruimtelijke context waarin technologieën verspreiden, de definitie van de problemen en de daarmee verband houdende beleidsadvies beïnvloeden. Ten vierde, wordt een verkenning gedaan van TIS voorbij de focus op opkomende technologische systemen, door het bestuderen van problemen en het beleid voor de minder ontwikkelde, priel systeem.

Samenvattend beoogt dit proefschrift zo bij te dragen aan duurzame innovatie. Twee empirische domeinen zijn gebruikt - aquatische biomassa en wind op zee - om de theoretische argumenten te illustreren.

Acknowledgements

I started this PhD research at that time when the TIS approach only began to emerge. In the context of my collaboration with KSI, a lively debate unfolded about the usefulness of this framework in the sustainability transitions research. When the PhD position was announced on systemic instruments in the group that worked with TIS, I decided to apply and learn hands-on about the differences between the two fields. It took me a couple of years to complete this work and extra effort to keep it novel. In that journey I collaborated with many great people to whom I am very grateful for the inspiring talks, advice and encouragement.

First, this thesis would be utterly impossible without the very generous help that I have received from Marko Hekkert. I would like to acknowledge, Marko, your almost eternal patience with me. I did this research while running an international programme on Industrial Transformation, working with the KSI on internationalisation of the sustainability transitions research and when the IT program ended, on a new project on experiments in Asia. In the final period I also taught at the Pioneers into Practice programme of the Climate-KIC to support the three additional years that I needed to finish this research. When I have done some counting it turned out that parallel to this PhD I have organised 3 large international conferences, designed about 10 international scientific workshops and 5 public debates. I co-authored 8 unrelated papers, published 3 book chapters, guest edited 2 special issues and participated in a countless number of meetings, seminars and workshops all over the world. I was on average 2-3 times per year away in Asia. Such circumstances are really far from being favourable to doing ones' PhD, but thanks to your tolerance and openness, Marko, it was not only doable but also pleasant. I particularly would like to thank you for giving me the space to do what I wanted and for showing so much respect to my other work. Your understanding was critical for me to get to this point! I am trully grateful for this.

Secondly, I would like to sincerely thank Alison Gilbert for your help in English revision of introductory chapter 1 and concluding chapter 7. Many thanks to Ruud Smits, Geert Verbong, Ellen Moors, Floortje Alkemade and colleagues from the Copernicus Institute of Sustainable Development at Utrecht University for your valuable comments on the earlier drafts of what became a Chapter 2. Also thank you to researchers from the STEPS group of Twente University for an extremely inspiring debate on the framework and for a number of useful suggestions that helped finalise that paper. I would like to thank Frans van der Loo and Lars Coenen for your valuable comments on the earlier drafts of the paper based on which Chapter 3 was made. I acknowledge all the stakeholders I could interview to verify my desk top research on aquatic biomass. Chapter 4 was written based on collaboration with Gaston Heimeriks, Robert Harmsen, Marko Hekkert and Simona Negro. Many thanks to you all for a great team spirit! Chapter 5 is based on a report prepared for the JRC's Institute for Energy and Transport. I acknowledge valuable and constructive contributions of: Sylvian Watt-Jones (Utrecht University); Eize de Vries (Rotation Consultancy, consultant for Windpower Monthly), Ernst van Zuijlen (Flow, NWEA); Theo de Lange (Van Oord); Jan van der Tempel (TU Delft), and Remco Borsma (NUON), Staffan Jacobsson (Gothenburg University Sweden), Morten Holmager (Offshore Center Denmark), Athanasia Arapogianni (EWEA, Brussels) and Michiel Heemskerk (Rabobank). Chapter 6 would not be possible without the inspiring collaboration with Lars Coenen. Thank you, Lars, for clarifying the difference between the institutional thickness and territorial embeddedness to me! I would also like to thank Lydia Sterenberg for your valuable comments on the earlier versions of that paper, for correcting my Dutch translations, for saving me in the last moments before the deadlines and for the many great talks we had!

Thirdly, even though I did not have much chance to socialise with colleagues from the Innovation Department of Utrecht University, I would like to thank you all for your constructive feedback and comments on the work I presented at the department meetings. In particular, I want to thank Ruud Smits for making me realise that I should trust my intuition more and go for what I strongly believe in. Interacting with you, Ruud, was a life lesson. I would also like to acknowledge the support of Floortje Alkemade. Thank you, Floortje, for trying and for always being sincere. It is a rare quality I highly appreciate! On the other side I had my IVM colleagues, to whom I am deeply grateful for all the encouragement, nice words and many talks that made the working burden much less, especially Harry Aiking, Bert van Hattum, Alison Gilbert, Kees Swart, Els Hunfeld, Pier Vellinga, Johan Mes, Edward Guttenberg, Yvonne van Hilst, Elissaios Papyrakis and others. A big word of thank goes to Frans Berkhout for, firstly, letting me do this extra work even though it was often on the cost of the IT time and secondly, for your continuous reassuring me that I can do this. It saved me once from stopping. When IT finished I took on a new project and kept combining the tasks in two places. A new group of people, this time from Eindhoven University, had to begin waiting for me to deliver. I particularily would like to thank Rob Raven for your being so understanding and Geert Verbong, Frans Sengers, Suyash Jolly, Bram Verhees and Henny Romijn for all the nice talks we had about TIS.

Finally, I want to sincerely thank my dear family, especially Basia and Rysio Nowak for always being ready to travel to the Netherlands to help us run the household; ciocia Tereska for an endless supply of lifesaving cookies (for which you will get a medal one day); my beloved Carol for laughing together so much. And my dearest parents, Kate and Henry Wieczorek: you are unique at a world scale, you do what other parents find difficult: you never give advice unless asked, you never impose anything on your adult children and you let them taste life even though sometimes it is scary for you to watch. I feel truly blessed to be yours and I love you dearly! Last but not least: Przemciuniu and Oliwko – you had to bear with me, this doctorate and the extra work for a number of long years. Thank you for understanding how important it was for me and for enduring all the consequences of this crazy time. Kocham Was jak stąd do Księżyca gazylion razy pomnożone przez nieskończoność plus jeden! It is over now! We can finally go to Rome and open this bottle of Moët that is waiting on the shelf!

Curriculum Vitae

Anna J. Wieczorek is a researcher at the Institute for Environmental Studies at the Vrije Universiteit Amsterdam (IVM/VU) and a lecturer in the Department of Industrial Engineering and Innovation Sciences of the Eindhoven University of Technology.

Her scientific interests concentrate on two areas. The first concerns conditions in which sustainability transformations unfold in various geographical and economic contexts and the particular role of experiments in this process. The second interest is in innovation policy and instruments in the context of emerging (mostly renewable) technologies. Anna's main empirical domains are energy and mobility.

In the context of her work Anna acquired and coordinated a number of European and international projects and was involved in the design of many educational programs. For 12 years, until 2011 she has been the executive officer of the Industrial Transformation Science Project of the International Human Dimension Program. Within that task Anna facilitated research on applying insights from the emerging stream of system innovation in the context of analyzing economic and environmental transitions occurring in developing Asia.

She is now a member of the Steering Group of a European Research Network on Sustainability Transitions (STRN), serves as a co-designer and a mentor of the Pioneers into Practice professional education program of the Climate-KIC and advises the Lower Silesian regional government on aligning its strategies and investment programme on the transition to a low-carbon economy with that of the Climate-KIC.

Publications

Wieczorek, A.J., Hekkert, M.P., Negro S.O., Heimeriks, G.J., submitted. Analysis of a nascent renewable energy innovation system: aquatic biomass in the Netherlands, 2014

Wieczorek, A.J., Raven R., Berkhout, F., submitted. Transnational linkages in sustainability experiments. A typology and the case of solar photovoltaic energy in India. Environmental Innovation and Societal Transitions, 2014, Paper presented at the IST, June 2013, Zurich

Wieczorek, A.J., Hekkert, M.P., Coenen, L., Harmsen, R ., 2014. Broadening the national focus in technological innovation system analysis: the case of offshore wind. Environmental Innovations and Societal Transitions, accepted for publication

Wieczorek, A.J., Negro, S.O., Harmsen, R., Heimeriks, G.J., Hekkert, M.P., 2013. A Review of the Western European Offshore Wind Innovation System.Renewable and Sustainable Energy Reviews, 26: 294-306, http://dx.doi.org/10.1016/j.rser.2013.05.045

Talik, S., Bielewska, A., Wieczorek, A.J., 2013. Low-carbon economy in Poland - The challenges of transformation, Przeglad Elektrotechniczny, 89(7): 310-314

Luo, L., Lacal-Arantegui, R., Wieczorek, A.J. Negro, S.O., Harmsen, R., Heimeriks, G.J., Hekkert, M.P., 2012. A Systemic Assessment of the European Offshore Wind Innovation Insights from the Netherlands, Denmark, Germany and the United Kingdom, Petten, The Netherlands: Joint

Research Centre, JRC Scientific and Policy Reports, http://setis.ec.europa.eu/publications/jrc-setis-reports/systemic-assessment-of-european-offshore-wind-innovation

Wieczorek, A.J., Hekkert, M.P., 2012. Systemic instruments for systemic innovation problems: A framework for policy makers and innovation scholar. Science and Public Policy, 39: 74-87 http://dx.doi.org/10.1093/scipol/scr008

Berkhout, F., Wieczorek, A.J. and Raven, R., 2011. Avoiding environmental convergence: a possible role for sustainability experiments in Latecomer Countries?International Journal of Institutions and Economics, 3(2): 376-385 http://ijie.um.edu.my/RePEc/umk/journl/v3i2/abst8.pdf

Berkhout, F., Verbong, G., Wieczorek A.J., Raven, R., Lebel, L., Bai, X., 2010. Sustainability experiments in Asia: innovations shaping alternative development pathways? Environmental Science and Policy, 13(4): 261-271 http://dx.doi.org/10.1016/j.envsci.2010.03.010

Berkhout, F., Angel, D., Wieczorek A.J., 2009. Sustainability transitions in developing Asia: Are alternative development pathways likely? Technological Forecasting and Social Change, 76(2): 215-217, http://dx.doi.org/10.1016/j.techfore.2008.04.003

Berkhout, F., Angel, D., Wieczorek A.J., 2009. Asian development pathways and sustainable socio-technical regimes, Technological Forecasting and Social Change, 76(2): 218-228 http://dx.doi.org/10.1016/j.techfore.2008.03.017

Bai, X., Wieczorek A.J., Kaneko S., Lisson S., Contreras A., 2009. Enabling sustainability transitions in Asia: The importance of vertical and horizontal linkages, Technological Forecasting and Social Change, 76 (2): 255-266, http://dx.doi.org/10.1016/j.techfore.2008.03.022

Wieczorek, A.J., Berkhout, F., 2008. Transitions to sustainability as societal innovations. In Boersema, J. and Reijnders, L. (Eds.), Principles of Environmental Sciences. Springer

Olsthoorn, X. and Wieczorek, A.J. (Eds), 2006. Understanding Industrial Transformation - Views from different disciplines. Springer

Jacob, K., Biermann, F., Kerkhof, M. van de, Wieczorek, A.J., 2006. Contributions to transformation research from political science. In Olsthoorn, X. and Wieczorek, A.J. (Eds.), Understanding Industrial Transformation - Views from different disciplines: Springer

Elzen, B., Wieczorek, A.J., 2005. Editorial introduction: Transitions towards sustainability through system innovation. In: Elzen, B. and Wieczorek, A.J. (eds) Transitions towards Sustainability through System Innovation – special issue of Technological Forecasting and Social Chane, 72(6): 651-662 http://dx.doi.org/10.1016/j.techfore.2005.04.002

Kerkhof, M. van de, Wieczorek, A.J., 2005. Learning and stakeholder participation in transition processes towards sustainability: Methodological considerations. Technological Forecasting and Social Change, 72(6): 733-747 http://dx.doi.org/10.1016/j.techfore.2004.10.002

Wieczorek, A.J., Kuik, O.J.,Berkhout, F., 2004. Interdependenz oder Autonomie: Kohlenstof-flüsche zwischen Ost und West. Osteuropa 54: 292-299

Wieczorek, A.J., Vellinga P., 2004. Moving towards systems innovation. Ökologisches Wirtschaften, 3-4, 27-29

Wieczorek, A.J., Vellinga, P., 2004. The need for Industrial Transformation. Organising decoupling. Ökologisches Wirtschaften, 2, 11

Kuik, O.J., Berkhout, F., Wieczorek, A.J.,2003. Editorial Introduction: Russian carbon and Europe's climate. In Kuik, O., Berkhout, F. and Wieczorek, A.J. (Eds.), Russian Carbon and Europe's Climate. Special issue of International Environmental Agreements: Politics, Law and Economics, 195-198.

Faaij, A., Minnesma, M.,Wieczorek, A.J., 2003. Sustainability of large-scale international trade in energy from biomass. Novem, the Netherlands, International workshop report 2GAVE03.07

Wieczorek, A.J., Vellinga, P., 2003. Preface. In Deb, K. and Srivastava, L. (Eds.), Transition to-wards sustainable development in South Asia. New Delhi, India. The Energy and Resources Institute: xi

Vellinga, P., Wieczorek, A.J., 2003. From chaos to convergence in industrial transformation research. In Deb, K. and Srivastava, L. (Eds.), Transition towards sustainable development in South Asia. The Energy and Resources Institute. New Delhi, India: 3-8

Mucha, M., Piekielna, J., Wieczorek, A.J., 1999, Characterisation and morphology of biodegradable chitosan / synthetic polymer blends. Macromolecular Symp., 144: 391–412 http://doi:10.1002/masy.19991440137