The policy mix and its role for innovation: Insights from offshore wind in Germany

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PhD thesis

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THE POLICY MIX AND ITS ROLE FOR INNOVATION

Insights from offshore wind in Germany

De invloed van combinaties van beleidsinstrumenten op innovatie

De casus “wind op zee in Duitsland”

(met een samenvatting in het Nederlands)

Proefschrift

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Chapter 1

Introduction

1.1. Motivation and objectives of the thesis

The transition of the energy system towards greater sustainability has become a key objective in many countries, with Germany with its 'Energiewende' being a prime example. Such a transition refers to an increase in the share of renewable energy technologies (RET), greater efficiency in energy use as well as investments in grid extension and energy storage technologies (BMWi and BMU, 2010). Besides this technical dimension, social changes such as changes in user practices and institutional structures form an important part of such a transition (Markard et al., 2012). The reasons why such a transition is needed are manifold. The most important reason may be climate change, which is likely to have severe environmental, economic and social consequences (Stern, 2006) and which therefore requires a reduction of greenhouse gas emissions as its primary cause. In this regard, the greatest single emitter and therefore contributor to climate change is the power sector with about 40% of global carbon dioxide emissions (IEA, 2008a). Furthermore, security of supply has long been an issue for countries dependent on vulnerable – due to geography or politics – energy supplies. It could be improved by decreasing the reliance on fossil fuel imports (IRENA, 2013). A final reason is the depletion of fossil fuel resources, on which a substantial part of today's energy generation is still based, and corresponding rising prices of fossil fuels in the longer term (IRENA, 2013).

For accomplishing the energy transition a crucial role is attributed to RET (IEA, 2013a). Yet most renewable energy technologies are still emerging and rather immature, thus featuring relatively high costs (IEA, 2011a). In order to achieve greater diffusion they need to become more competitive. This implies that technological innovation is necessary to bring down costs (IRENA, 2013). However, achieving greater rates of innovation in RET is not easy, since multiple failures and barriers hinder their fast development and diffusion, including market, system and transformative failures (Klein Woolthuis et al., 2005; Negro et al., 2012; Weber and Rohracher, 2012).

In order to address these failures and remove these barriers, thus enabling an accelerated development and diffusion of RET – i.e. innovation in RET – policy intervention is needed. Thereby the diversity of failures in place requires multiple points of intervention, i.e. multiple and differing policy instruments that are tailored to the particular failures (IEA, 2011b; Lehmann, 2010a; Matthes, 2010a). In this regard environmental economics studies suggest introducing one policy instrument for each independent market failure (Braathen, 2007; OECD, 2007; Tinbergen, 1952). Such packages of interacting policy instruments targeted at a particular issue, which have also been studied for other policy fields, have been labeled 'policy mixes' (Guy et al., 2009; Matthes, 2010a). There has emerged a growing literature that more thoroughly analyzes policy mixes in the context of innovation (Flanagan et al., 2011). However, these studies have important limitations: They neglect policy mix components such as a strategic element or policy mix characteristics and thus do not account for the complexity of policy mixes, and they lack a common understanding of policy mixes. Consequently, there is a need to develop a more comprehensive conceptualization of the policy mix. Such a policy mix conceptualization should also introduce a clear and uniform terminology.

For successfully fostering innovation in emerging RET, it is vital to first understand in more detail the impacts a policy mix has on innovation in these technologies. However, very few studies exist to date that deal with this issue. On the one hand, analyzing policy mix effects on innovation at the firm level is important since it enables recommendations for improving the policy mix particularly with regard to firms as the key innovators (Rogge et al., 2011). This is essential when the goal is to foster technological innovation. On the other hand, since innovation in RET occurs within the broader innovation system, which encompasses various actors, organizations and institutions as well as the relations between them, technology-focused policy mixes do not only impact technology development in a narrow sense but also the surrounding innovation system. Therefore, the policy mix is likely to impact the functioning and performance of technological innovation systems (TIS) regarding the use und diffusion of a technology. Analyzing policy mix effects on TIS goes beyond the identification of system weaknesses, allowing for identifying policy gaps with regard to system functions (Kivimaa and Virkamäki, 2013).

Against this background, this thesis has two goals. First, it aims at developing an overarching concept of the policy mix and second, it explores the innovation impacts of such a more comprehensive policy mix. Gaining insights into how policy mixes affect innovation might contribute to designing more effective policy mixes and ultimately to more successful innovation policy.

Therefore, in a first main step an extended concept of the policy mix applicable for RET but also for sustainability transitions more broadly is developed that goes beyond the combination of policy instruments and that can serve as analytical framework for empirical analyses. Such a concept might constitute the basis for a more encompassing understanding of policy intervention to foster innovation. In a second main step, the thesis aims at gaining empirical insights into the role that the policy mix plays for innovation in emerging RET at two main levels at which innovation happens. First, effects of the policy mix are analyzed at the firm level, i.e. on corporate innovation activities, providing insights in the policy mix impact at a micro level. Second, the role of the policy mix is analyzed at the level of technological innovation systems, which provides for a systemic and more encompassing innovation perspective. That is, policy mix effects are explored not only for innovation activities as such but also for the broader system including this system's functioning and performance. This empirical step is undertaken for the case of offshore wind in Germany. This case is selected since offshore wind is to play a crucial role for achieving renewable energy targets and since there is a rich policy mix in place for fostering this technology in Germany.

1.2. Theoretical background

Policy mixes

Policy mixes are defined – most simply – as combinations of interacting policy instruments (Boekholt, 2010; de Heide, 2011). Before turning to policy mixes as such the general rationale for policy intervention for fostering innovation – different kinds of failures that hinder innovation – will be explained. A crucial market failure is the pollution externality of fossil fuel-based technologies that compete with RET, which accrues from few polluters causing damage that society as a whole has to bear (Lehmann, 2010b). Although this externality is currently addressed by the EU Emissions Trading System (ETS), it is not satisfyingly remedied due to a persistent low price of CO_2 allowances (European Energy Exchange, 2014). Another market failure is the knowledge spillover externality. This externality is based on the public good character of innovation and causes a low willingness to pay by private actors (Lehmann, 2010b; Verbruggen et al., 2010), so that consequently they invest too little in innovation. Besides these neoclassical market failures, transition studies have pointed to further system and more overarching transformative failures.. These include – but are not limited to – infrastructural failures (deficits in physical infrastructure such as the power grid), interaction failures (too limited or too dense exchange with third parties), directionality failures (lack of given direction for transformative change) and reflexivity failure (lack of ability of a system to monitor processes of self-governance) (Klein Woolthuis et al., 2005; Weber and Rohracher, 2012).

To address these failures, policy mixes are needed rather than single policy instruments. This can be justified by several reasons. To begin with, environmental problems mostly are of a “multi-aspect” nature, e.g. not only the amount of emissions is important but also where and when they occur. A policy mix is needed then with one policy instrument per aspect or failure that is to be addressed (Tinbergen, 1952). Second, neoclassical economics studies state that in real-world settings there are numerous deviations from a perfect market setting such as constraints in policy implementation, suggesting often a second-best rather than a first-best world and thus the need for policy mixes (Lehmann, 2010a; OECD, 2007). In such a setting policy instruments applied in combination may reinforce each other and compensate for disadvantages of single policy instruments. The same may hold for non-market failures, such as system and transformative failures. Finally, policy mixes have the potential to limit uncertainties regarding compliance costs, enhance enforcement possibilities and reduce administrative costs (OECD, 2007).

Against this background, various streams of literature have recognized that intended policy effects are usually not achieved by a single policy instrument but by a variety of policy instruments, i.e. a policy mix (Jänicke et al., 2000). In practice policy mixes can also frequently be found, e.g. for addressing environmental innovation issues. Policy evaluation studies should consequently focus on analyzing policy mixes, as evaluating only single instruments may actually be impossible since their effects are influenced by the remaining policy mix (Ringeling, 2005).

Originating in the literature on economic policy in the 1960s, the term policy mix was first applied in monetary policy and later diffused into other areas of economic policy to analyze interactions between different policy instruments (Flanagan et al., 2011). Among others, it diffused into the literature of environmental policy, where it has served to analyze interactions between several climate policy instruments, among them the EU ETS (Sorrell et al., 2003). Studies have also dealt with the effects of policy mixes (as opposed to single instruments) on economic effectiveness and efficiency (Braathen, 2007; OECD, 2007) or they have argued why several policy instruments are needed and how they need to be designed in order to successfully mitigate climate change (Lehmann, 2010a, 2010b; Matthes, 2010b). Another stream of literature that adopted the policy mix term is innovation policy. In the early 2000s an expert group on EU national innovation policies stated that a prerequisite for policy learning was to understand how individual policy instruments were combined in policy mixes and which effects these combinations exerted. This expert group greatly contributed to mainstreaming the term policy mix into EU policy analysis activities (Flanagan et al., 2011). An example of the importance the term policy mix has gained in EU innovation policy is a study commissioned by the EU in the mid 2000s with the aim to inform policy makers on which portfolios of policy instruments are most effective for achieving a higher quantity and performance of research investments (Nauwelaers et al., 2009). This study developed a framework for creating and implementing an efficient policy mix for R&D, thereby considering the effects interactions of policy instruments can exert on R&D as well as effects of policy instruments from other policy fields, such as environmental policy.

Three important aspects that might be relevant for policy mixes have been studied in the literature, although their relation to policy mixes has not always been made explicit. First, interactions between several policy instruments that address the same environmental problem have been discussed as determining features of policy mixes (Lehmann, 2010a). These interactions may positively or negatively affect the performance of policy mixes. They may lead to a reinforcement of the positive effects of two policy instruments or even turn a potential negative effect of a single policy instrument into a positive one. Yet interactions may also thwart the otherwise positive effect of one instrument (Sorrell et al., 2003).

In other words, policy instruments may be complementary or counterproductive. An example for the former is a voluntary policy instrument that is implemented together with a command-and-control regulation. If the command-and-control instrument requires a firm to achieve a certain level of environmental performance, an additional voluntary measure may encourage firms to achieve additional improvements. The combination of these policy instruments thus triggers environmental improvements, which could not be achieved if either were employed in isolation. In contrast to this, policy instruments may be counterproductive. An example is the coexistence of a command-and-control instrument with an economic instrument that both aim to reduce firms' emissions. While the economic instrument aims to achieve the emissions reduction via a price signal that lets firms freely choose to what extent they want to reduce their emissions or rather pay for them – probably choosing the least costly option – the command-and-control instrument imposes a certain level of emissions on the firm. In doing so it limits the choice of the firm between reducing its emissions and paying for them, thus compromising the economic instrument (Gunningham and Sinclair, 1998).

The latter case, in which policy instruments exert counterproductive effects, should be avoided. Thus a second relevant aspect of – or rather condition for – policy mixes is their coherence or consistency. This aspect has been discussed in the policy analysis literature, albeit not explicitly in relation to policy mixes but rather to 'policies' Policy coherence, which is often used synonymously with policy consistency, generally refers to several policy instruments in a mix that support each other in the achievement of policy objectives (Howlett and Rayner, 2007). The literature often distinguishes between a state and a process perspective of policy coherence. The former characterizes the state of a policy mix at a given point in time, i.e. whether the policy mix is coherent or consistent. The latter refers to coherence of the policy formulation and planning process within and between administrative bodies (den Hertog and Stroß, 2011). This latter coherence definition goes beyond characterizing interactions of policy instruments, considering policy processes.

Policy processes are a third aspect with relevance for policy mixes, although – again – often not discussed in this context. Analysis of policy processes is a prerequisite for understanding how substantive policy outcomes, such as policy instruments, arise and for enhancing them (Foxon and Pearson, 2007). In this regard, policy processes are closely related to policy instruments and are one determinant of their effectiveness and efficiency. Policy processes refer to political problem-solving processes that aim to find solutions to societal problems. In this regard they are interactive and continuous and involve feedback loops. The government is the main actor in these processes, taking deliberate, authoritative and interrelated decisions. With a plethora of actors besides the government involved, such as interest groups and firms, these processes comprise power, agency and politics (Howlett et al., 2009). Policy processes can be analyzed by the so-called policy cycle, namely problem identification, agenda setting, policy formulation, legitimization and adoption, implementation, evaluation, policy adaptation, and succession or termination (Dunn, 2004; Dye, 2008). As such, policy processes can be seen as learning processes in which problems are repeatedly analyzed and solutions to these problems are experimented with (Howlett et al., 2009). Policy processes can be characterized by their style, i.e. their nature or the way policy instruments are formulated and implemented (Richardson, 1982). Considering the policy style might be useful when analyzing policy processes since it can exert considerable influence on the processes' outcomes and their effects (Jänicke et al., 2000).

Existing policy mix studies have important limitations. First, they are often limited to policy instrument combinations and their interactions (del Río González, 2006), neglecting other policy mix components, such as a strategic element and the role of policy processes in the mix (Howlett and Rayner, 2007). The former, although hardly addressed in the policy analysis literature, may be particularly important since it introduces a long-term perspective to policy mixes, which can give vital guidance to target actors (Jänicke, 2009; Rogge et al., 2011b). The neglect of such policy mix components might lead to an insufficient understanding of policy mixes and their effects and potentially result in fragmentary policy recommendations. In addition and related to the former point, the policy mix literature does not account for the complexity of policy mixes (Flanagan et al., 2011). Finally, studies lack a common understanding of policy mixes, particularly with respect to their definition and scope, and their terminology (Flanagan et al., 2011). This might render comparisons and assessments of policy mix studies difficult and thus may generate ambiguous findings and policy recommendations.

Innovation and technological innovation systems

Innovation can be defined as "the implementation of a new or significantly improved product (good or service), or process, a new marketing method, or a new organizational method in business practices, workplace organization or external relations" (OECD, 2005, p. 46). Innovations can be studied at different levels, including the micro level, such as that of the firm, and the meso level, such as that of the innovation system. For the former, innovation is looked at in individual firms, while for the latter the system surrounding and stimulating innovation is analyzed, which includes firms as one kind of actors. Considering these two levels enables differentiated views on innovation.

Given the crucial importance of firms as innovators (Edquist, 2005), studying innovation at the firm level appears indispensable. Firms can engage in different kinds of innovation activities, which constitute the steps towards bringing an invention to the market. The most important ones of these activities are research, development and demonstration (RD&D), as well as several adoption activities (OECD, 2005). While adoption refers to firms' investments in new or significantly improved technologies, RD&D covers basic laboratory research, testing of the new technology in small-scale pilot projects and demonstrating its functioning by initially implementing it at a larger scale.

Innovation is a social and interactive learning process – rather than through isolated individuals innovation often comes about with the help of networks. This is why innovation is often looked at with a systems approach that considers a variety of factors contributing to innovation (Edquist, 2005). In this regard, the innovation systems approach is a holistic approach that encompasses a wide array of innovation determinants, emphasizing interdependence and non-linearity of the innovation process. Due to their joint importance for innovation, an innovation system is defined to consist of the components actors, organizations and institutions, and the relations between them (Carlsson, 1997; Coenen and Díaz López, 2010). These relations, which can be captured by networks, are characterized by reciprocity and feedback loops. In addition to these components, the vital resource in innovation systems is knowledge, and a crucial activity is learning (Edquist, 2005).

Several kinds of innovation systems are distinguished in the literature. They are differentiated by space, such as national and regional innovation systems (e.g. Lundvall, 1992), or by technology, such as sectoral and technological innovation systems (Carlsson and Stankiewicz, 1991; Malerba, 2004). For studying innovation at the level of the innovation system in the case of emerging RET, the technological innovation systems (TIS) approach is often applied. A TIS denotes a set of actors and institutions that influence the direction and rate of technological change in a specific technological field (Hekkert and Negro, 2009; Markard and Truffer, 2008a). In relation to the other innovation systems approaches a TIS can be regional, national or international and a technology can cut across various industrial sectors (Carlsson and Stankiewicz, 1991). The most striking feature of the TIS approach is that it is usually applied to *emerging* systems. These systems have different characteristics than mature ones, e.g. the configuration of actors and institutions changes over time as the system develops (Carlsson, 1997). Since a technology delineates the system, it is possible to study changes in the system's components that are related to technology development. This enables an understanding of what happens in the system, ultimately allowing for targeted interventions to change system activities in the desired direction.

With the help of the TIS approach, technologies and the surrounding systems with their structural components including actors, networks, institutions and infrastructure (Edquist, 2005) are analyzed in terms of several system functions (Bergek, Jacobsson, Carlsson, Lindmark, & Rickne, 2008; Hekkert & Negro, 2009). Thereby structures and functions are closely related. On the one hand, the structural components and their capacities to stimulate innovation are crucial to the functioning of the innovation system, i.e. the functioning of the system's activities and processes (Wieczorek and Hekkert, 2012). On the other hand, functions evaluate the structural components regarding their effects on the innovation process. In this regard functions are intermediate variables between structure and system performance, or – in other words – it is via functions that structural components contribute to the development, use and diffusion of innovations (Jacobsson and Bergek, 2011).

By analyzing TIS functions, strengths and barriers of the system are identified. Barriers – also labeled system failures or systemic problems – can be defined as "all factors that block the operation and the development of innovation systems" (Negro, Alkemade, & Hekkert, 2012; p.3838). The barriers are often responsible for the slow diffusion of the studied young technology and thus the system's poor performance (Bergek et al., 2008; Tigabu et al., 2013). Based on a detailed analysis of such barriers, TIS studies usually derive recommendations for policy intervention of how to address these problems and thereby improve system functioning.

Policy mix effects on innovation

A prerequisite for designing policy mixes that successfully foster innovation in RET – both at a micro and an innovation system level – is a better understanding of the effects these policy mixes have on innovation. Various studies exist that deal with the issue of policy intervention to foster innovation in RET and environmental technologies more generally. These studies can be categorized according to their policy and innovation foci. Most studies analyze the effects of several aspects of single policy instruments on innovation at a micro level, including specific innovation activities or types such as invention and diffusion at the firm level. Policy instrument aspects considered in such studies comprise instrument type, field and design features. Typical are studies that examine the innovation impact of several policy instrument types or fields (e.g. Jaffe & Stavins, 1995; Nesta, Vona, & Nicolli, 2014), such as market pull and technology push (Nemet, 2009) or feed-in tariffs and quota systems (del Río and Bleda, 2012; Johnstone et al., 2010) in terms of instrument types, and environmental and innovation policy instruments in terms of instrument fields (Aalbers et al., 2013). Fewer studies consider instrument design features including stringency or flexibility (Hascic et al., 2009; Leitner et al., 2010). Besides the policy instrument focus, there are some studies that analyze the effects of interactions of various policy instruments on innovation at a micro level (e.g. Del Río, 2009).

Regarding innovation at the TIS level, the policy mix may impact TIS functioning as well as TIS performance in terms of the use and diffusion of an emerging technology. Although policy mixes have played a role in TIS analyses, there is a very limited number of studies having explored the effects of policy mix elements on TIS. Similarly as studies at a micro level of innovation, these studies mostly analyze the role of several single policy instruments (Vasseur and Kemp, 2011), exploring their effects on TIS functions (Kivimaa and Virkamäki, 2013; McDowall et al., 2013). Hardly any studies go beyond these single instrument considerations and take a more encompassing policy perspective, e.g. focusing on policy processes and the dynamics they spark in TIS (Chung, 2013; Hoppmann et al., 2014).

There remain essential gaps in this empirical literature of policy mix effects on innovation at a firm and a TIS level. To begin with, due to the broadness of the policy challenge (i.e. multiple failures), emerging RET are usually fostered with policy mixes whose effects exceed those of distinct policy instruments. Therefore, empirical studies on innovation effects of 'policies' at the firm and the innovation system levels should not only consider such policy instruments or design features but rather more encompassing policy mixes including their internal fit, overarching characteristics and policy processes. However, in empirical studies on policies' innovation effects such policy mixes have been rarely looked at in a systematic way. In addition, the analysis of the role of the policy mix in TIS should be strengthened since such policy mixes are of fundamental importance for the steering of emerging TIS. That is, not only should TIS be analyzed regarding their strengths and weaknesses and should recommendations for targeted policy intervention be derived, as often done in current TIS studies, but the actual effects of existing technology-specific policy mixes on TIS should be better understood. This would contribute to a better general understanding of TIS and additionally enrich the analytical basis for deducing policy advice. Ultimately, it is a prerequisite for designing policy mixes that appropriately foster innovation and thus the development of a TIS.

1.3. Research questions and research case

This thesis addresses the literature gaps identified above by the following main research questions:

1. How can policy mixes for innovation be conceptualized?
2. What is the impact of the conceptualized policy mix on innovation in offshore wind in Germany?

To explore the second research question the case of offshore wind in Germany is chosen based on the following reasons. Offshore wind is an emerging renewable energy technology with great potentials. This is due to higher and steadier wind speeds than onshore and its large-scale nature, both of which result in greater yields (IEA, 2009). Together with the limited growth potential of onshore wind in Europe due to competing land use (Roland Berger Strategy Consultants, 2013) and public acceptance issues, this justifies that offshore wind can essentially contribute to achieving renewable energy targets. Offshore wind also provides for considerable employment and economic growth opportunities (pwc and wab, 2012). For instance, about 170,000 jobs are expected in the European offshore wind sector by 2020 (40% of all wind energy jobs), and about 300,000 by 2030 (62% of all wind energy jobs) (EWEA, 2011a). Therefore, an important role of offshore wind is foreseen in Europe, including in the German energy transition (Fraunhofer IWES, 2013): The country originally aimed at ten GW of installed capacity until 2020 and 25 GW until 2030 (Bundesregierung, 2002), which was a stable target for about ten years but was adjusted downwards to 6.5 GW and 15 GW, respectively, by the new coalition in 2013 (CDU et al., 2013).

Despite its potentials the offshore wind technology still faces a number of challenges (Bruns et al., 2009). One of these is the high technological requirements, calling for greater turbines with higher capacities compared to onshore wind. Related to that, huge and heavy single components pose logistical challenges, e.g. they require special ships. The complex and heterogeneous undergrounds at sea pose high requirements to foundations, so that new foundation concepts are needed – several concepts are being tested. Lastly, since in Germany offshore wind parks are located at long distances from the coast due to nature protection areas and tourism concerns, accessibility to these parks is expensive and costs for operation and maintenance are higher than elsewhere. In order to keep these costs moderate, high reliability of plants is needed (Fraunhofer IWES, 2012).

Regarding the policy mix for offshore wind, Germany represents a rich empirical case in which various policy mix components are present. These include a policy strategy in the form of an ambitious long-term target and a complex instrument mix, as well as apparently high policy mix credibility and stability (at least until the lowering of the long-term installed capacity target in 2013). Furthermore, despite the pronounced goal of achieving 6.5 GW of installed capacity by 2020 and 15 GW by 2030 (CDU et al., 2013), only about 1 GW were installed at the end of 2014 (EWEA, 2015). This might suggest the existence of systemic problems, which hindered technology development and diffusion. It therefore appears worthwhile to better understand the role of the policy mix in this, e.g. of potential policy mix inconsistencies. Studying these policy mix effects both at a firm and an innovation system level might thereby enable an even deeper understanding of these effects, namely within firms as key innovators and at a broader system level. Besides this and more generally, Germany represents a global example for successful development and diffusion of renewable energy technologies, from which much can be learned.

Regarding the current situation of offshore wind in Germany, despite only 1 GW of installed capacity at the end of 2014, the German market is growing fast. In 2014, 0.53 GW did start operation (EWEA, 2015), and more than eight GW were in the pipeline (EWEA, 2014a), so it is expected to be the second largest European market after the UK by 2020 (pwc and wab, 2012). Due to its dynamic development, diverse players have entered the German offshore wind sector, among them turbine manufacturers, project planners (e.g. utilities, smaller project developers), port operators, suppliers for different components, e.g. substructures, vessels, electrical infrastructure, as well as grid operators and financial investors.

The second research question on the impact of the policy mix on innovation in offshore wind in Germany is to be seen as an overarching question and is therefore divided into two sub questions, reflecting the levels of innovation at which the impact of the policy mix will be analyzed:

2a. How does the policy mix affect corporate innovation activities in offshore wind in Germany?

2b. Which role does the policy mix play for the technological innovation system of offshore wind in Germany?

The latter question (2b) is further subdivided so that the role of the policy mix for the technological innovation system will be analyzed in the following two ways:

2b.1) What is the impact of the policy mix on the German offshore wind TIS and how do TIS developments influence the evolution of the policy mix?

2b.2) What are the effects of policy processes on the German off-shore wind TIS?

1.3. Chapters of the thesis

In the following the main chapters of this thesis (chapters 2 to 5) will be introduced focusing on their objectives, methods applied, their main findings and theoretical contribution. A more detailed discussion of the findings and contributions will be presented in the conclusion section (chapter 6), where the research questions will be answered.

Chapter 2: Conceptualizing the policy mix

Studies analyzing policies for fostering innovation in renewable energy and environmental technologies more generally have pointed to the need to combine several policy instruments in policy mixes (IEA, 2011c; Matthes, 2010a). This is due to multiple failures occurring in the context of such innovation, which require multi-faceted policy intervention. Yet existing policy mix studies are limited in their coverage of the policy mix, too narrowly focusing on singular aspects such as interactions or policy processes. The consequence might be an insufficient understanding of policy mixes and their effects, potentially leading to fragmentary policy recommendations. Furthermore, there is no common understanding of policy mixes regarding their definition, terminology and scope.

In order to better understand policy mixes and their effects and to make policy mix studies comparable based on a common terminology, the singular aspects should be brought together and defined in a comprehensive policy mix concept. This chapter therefore aims at developing an encompassing conceptualization of the policy mix for studying policy intervention to foster technological change, and illustrates the concept for the example of the German energy transition. In doing so, an extensive literature review was conducted: more than 100 studies mainly from the fields of innovation studies, environmental economics and policy analysis were collected in a literature database and analyzed regarding their policy mix content. Where needed studies from other research fields were consulted, such as from strategic management for the strategic component of policy mixes. Based on insights from these studies, the main building blocks of a more comprehensive policy mix were identified and combined in an encompassing concept. These building blocks comprise (i) elements, i.e. the policy strategy and the instrument mix, (ii) policy processes and (iii) policy mix characteristics including consistency, coherence, credibility and comprehensiveness. They can be delineated by several dimensions, such as policy field, geography and time.

The chapter makes two major contributions to the literature. First, it addresses important research gaps by providing an extended concept of the policy mix that considers the complexity and dynamics of real-world policy mixes and that introduces a uniform terminology. Second, the proposed concept constitutes an integrating analytical framework for empirical research, i.e. it is to serve as practical tool for conducting empirical policy analyses, helping in operationalizing the notion "policy mix". As such it may also help in more clearly defining the boundaries of a policy mix study regarding the study's scope and unit of analysis. Ultimately, the concept may contribute to increased insights on the role of policy mixes for sustainability transitions.

Chapter 3: Analyzing policy mix effects on corporate innovation activities

Most studies that analyze the innovation impact of policies in the broader field of environmental technologies are limited to the effects of single policy instruments, neglecting effects of other policy mix components. However, for a better understanding of innovation impacts of real-world policy mixes, such a single instrument perspective is not sufficient.

This chapter therefore empirically applies the previously developed policy mix concept for the case of offshore wind in Germany. It analyzes how the policy mix with its policy strategy, instrument mix and characteristics including consistency, credibility, comprehensiveness and stability influences corporate innovation at the firm level. The firm-level innovation activities studied comprise research, development & demonstration (RD&D) and adoption of the technology. The chapter puts a particular focus on the innovation effects of the consistency of the policy strategy and instrument mix since it is expected to be a crucial characteristic at the policy mix level. Besides considering effects of interacting policy instruments as done in some existing studies, consistency also captures the interplay and fit of the policy strategy and of policy instruments with the policy strategy, which is important due to the relevance of the policy strategy for the instrument mix.

Methodologically, multiple company case studies were conducted. Based on desktop research and exploratory interviews for gaining insights into the German offshore wind sector and its policy mix, in-depth interviews with company representatives having expertise in firms' innovation strategies and in the offshore wind policy mix were done. The interviews were transcribed and coded with the qualitative data analysis software Atlas.ti. Building on the coded interviews, the role of the policy mix for innovation was first analyzed for each individual case and then overall on the basis of cross-case comparisons.

A main finding is that the feed-in tariff level and the perceived consistency and credibility of the German offshore wind policy mix have been vital innovation drivers. Specifically, the consistent and stable policy strategy with its long-term targets, and the consistency of the instrument mix with this policy strategy appear crucial to RD&D. In contrast, adoption decisions largely depend on a comprehensive and consistent instrument mix. Finally, a high level of credibility can partly offset negative effects of inconsistencies in the mix.

The major theoretical contribution of the chapter is that by using an overarching policy mix concept, it enables a deeper understanding of the link between the policy mix and corporate innovation activities than previous studies. That is, it does not only provide insights into innovation effects of the policy strategy and instrument mix but also of so far largely neglected yet influential policy mix characteristics. Due to the impact that the studied policy mix components exert on corporate innovation, the chapter underlines the importance of considering comprehensive policy mixes in such empirical analyses. Finally, the chapter derives more substantiated policy recommendations, which build on a better understanding of the policy mix and of firms' strategies. These recommendations might ultimately contribute to an accelerated energy transition.

Chapter 4: Analyzing policy mix-TIS-interdependencies

When studying the role of 'policies' for innovation in renewable energy technologies, two important aspects should be considered. First, it is useful to analyze these technologies in the context of their surrounding innovation systems, using the technological innovation systems approach. Second, due to multiple failures not just single policy instruments are required for fostering these technologies but a comprehensive policy mix. For a better understanding of the impact that such a policy mix has on these technologies, the approaches of the policy mix and of technological innovation systems (TIS) should be brought together, e.g. by analyzing how TIS and the policy mix influence each other. While existing studies are limited to single policy instruments and their influence on TIS, a comprehensive policy mix perspective is still lacking in such analyses.

This chapter addresses this gap, examining interdependencies in the evolutions of the policy mix and the TIS. That is, effects of the policy mix on the TIS are studied as well as how developments in the TIS influence the evolution of the policy mix. Regarding the former link, impacts of the policy strategy, the instrument mix and policy-making and implementation processes on TIS functioning and performance are examined. Regarding the latter link, the influence mainly of systemic problems on the alteration of policy mix components, such as the introduction of a new policy implementation, is analyzed. In contrast to the previous chapter, in which innovation at the firm level is studied, such an innovation system perspective enables a broader innovation view that considers other activities besides corporate innovation, such as basic knowledge development and infrastructure build-up.

A mixed-method approach was applied. In a first step, for getting an overview of the evolution of the German offshore wind TIS over time, its functioning between 1993 and 2013 was analyzed with an event history analysis. In addition, policy documents were screened for insights into policy mix evolution. The second and main data collection step consisted of expert interviews with diverse actors in the TIS, including central policy makers and industry representatives, to gain deeper insights into the TIS conditions under which the policy mix was put in place and to explore the role that the policy mix played for TIS evolution. Based mainly on these interviews and on the information from the event history analysis, the interdependencies between the policy mix and TIS evolutions were analyzed.

Tight interlinkages were found, reflecting continuous interactions between observed problems in the TIS, the articulation of these problems and the subsequent alteration of the policy mix in place. In this cycle the policy mix did not only positively influence TIS developments but also contributed to the emergence of new or to the reinforcement of existing systemic problems. Subsequently alterations in the policy mix were required to solve these new problems. Thus, the systemic problems and their attempted solution in turn shaped the evolution of the policy mix with its many technology-specific and some generic elements.

The main theoretical contribution of the chapter is that it constitutes a first step incorporating a comprehensive policy mix concept into the TIS approach. In doing so, it allows for a more differentiated understanding of the role of policy mix elements and processes – rather than only of single policy instruments – for TIS functioning and performance. It thereby lays a foundation for more detailed policy recommendations. Furthermore, the chapter sheds light on the close interdependencies between the TIS and the policy mix over time, thus contributing to a better comprehension of the dynamics occurring in TIS.

Chapter 5: Unpacking policy processes in TIS

Studies analyzing policy and TIS in an energy transition context have largely focused on where policy intervention is needed and on suggesting appropriate policy instruments for curing identified systemic problems. In these studies a policy instrument focus has prevailed, while other policy mix components, particularly policy processes, have been largely disregarded. Yet their analysis might enrich TIS studies by insights into so far neglected factors shaping TIS functioning and performance, and thereby contribute to a better understanding of TIS in general. While the former chapters of this thesis have rather focused on policy mix elements, this chapter zooms into policy processes, which can be defined as the political problem-solving processes among constrained social actors in the search for solutions to societal problems. The objective of this chapter therefore is to uncover policy processes in TIS by analyzing how their style, i.e. their nature, influences TIS functioning and performance. Two exemplary policy-making processes are selected that address systemic problems hindering TIS development. These systemic problems are the insufficient level of support of the offshore wind feed-in tariff in the 2004 Renewable Energy Act (EEG), and great delays in grid accesses after 2009.

The methodology applied relies on a qualitative approach consisting of interviews and supplementary document analysis. Expert interviews with diverse actors in the TIS, such as central policy makers and industry representatives, were conducted to explore the policy processes in focus and their effects on the TIS. The interview data were complemented and cross-checked with document data shedding light on particular steps in and the style of the policy processes, such as industry position papers and draft laws. The role that the style of the policy processes played for the TIS was then analyzed mainly based on insights from the expert interviews.

Both positive and negative impacts of the policy style on the TIS were found. For example, the muddling through character apparent in one of the policy processes negatively influenced entrepreneurial activities, knowledge development and finally technology diffusion. However, the participatory nature of both processes had a positive impact both on TIS functioning and performance.

This chapter contributes to the literature by shedding light on so far largely neglected policy processes in TIS. It demonstrates the importance of considering such processes by illustrating their impact on TIS functions and performance. In addition, studying policy processes in TIS enables insights into how well an innovation system is organized in terms of its institutions and – as part of that – into the kind of interaction of policy makers with the rest of the innovation system. The chapter thus constitutes a further step (additional to the previous chapter) incorporating the policy mix concept into the TIS approach.

Overview of chapters

Figure 1 illustrates how these four chapters are related to each other. Chapter 2 constitutes the conceptual basis for the subsequent empirical chapters (chapters 3 to 5), developing a policy mix concept for empirical analyses in the broader field of technological change in renewable energy technologies. Chapters 3 to 5 build on this policy mix concept, exploring the role of the policy mix and particular components on innovation for the case of offshore wind in Germany. In doing so, chapter 3 focuses at the firm level, while chapters 4 and 5 examine the role of the policy mix at the level of the technological innovation system. Regarding their policy mix foci, chapter 3 considers policy mix elements (policy strategy and instrument mix) and characteristics, thereby particularly focusing on the characteristic consistency. Chapter 4 considers several policy mix components including the policy strategy, policy instruments and policy processes, while chapter 5 exclusively zooms into policy processes.

Subsequently the above introduced chapters (chapters 2 to 5) are presented. The thesis ends with a conclusion (chapter 6) answering the research questions, deriving implications for policy makers and stating the overall contributions. In addition, it suggests avenues for future research.

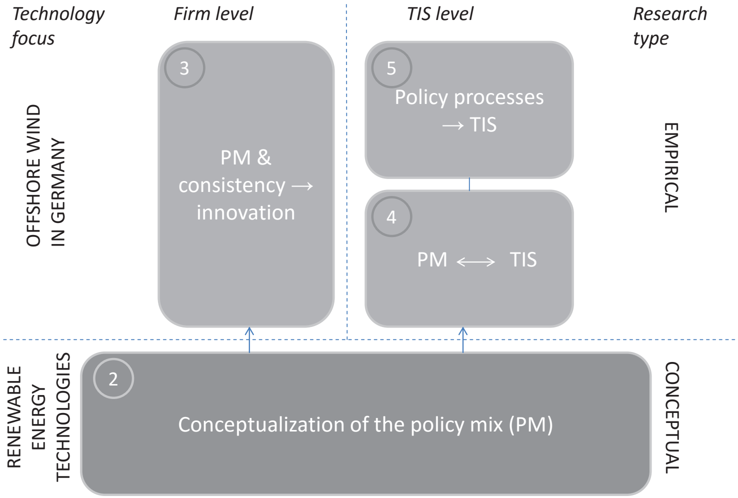

FIGURE 1: Overview of the main chapters of this thesis

Chapter 2

Policy mixes for sustainability transitions: an extended concept and framework for analysis

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2.1. Introduction

One of the main challenges in the emerging field of sustainability transitions is to improve our understanding of the policies and politics of transitions, such as for the move towards a decarbonized energy system (Markard et al. 2012). One important requirement for such a transition is the redirection and acceleration of technological change towards sustainability objectives. However, in this context technological change, often characterized by its three major stages of invention, innovation and diffusion (del Río González 2009b), is faced with multiple market, system and institutional failures and thus requires multi-faceted policy interventions (Lehmann 2010; Twomey 2012; Weber, Rohracher 2012). Responding to this challenge, in recent years scholars and practitioners in fields particularly relevant to eco-innovation (Kemp 2011; Rennings 2000) have called for a policy mix which combines several policy instruments (IEA 2011b; Nauwelaers et al. 2009; OECD 2007). However, policy mix studies tend to be limited to examining instrument interactions (del Río González 2006; IEA 2011a) or the policy processes associated with designing such mixes (Howlett, Rayner 2007). Furthermore, the terminology applied in these studies is often ambiguous, particularly regarding the desired characteristics of a policy mix[1].

This limited scope and ambiguous terminology of existing policy mix studies have two major consequences for the analysis of policy mixes and their impacts. First, the narrow scope of policy mix concepts may cause researchers to neglect important policy mix elements or processes in their analyses. This may lead to an insufficient understanding of the role of policy mixes for sustainability transitions, potentially resulting in fragmentary and oversimplified policy recommendations on how to redirect and accelerate technological change. Second, the lack of a uniform terminology could lead to apparently ambiguous findings and may render policy mix analyses difficult to assess, compare and synthesize. Ultimately, these obstacles to integrating our insights on the link between policy and innovation may further reduce the substance and impact of resulting policy advice.

In this study we address the identified lack of a comprehensive, uniformly defined policy mix concept for analyzing the link between policy and technological change, thereby heeding Flanagan et al.'s (2011)(2011) call for a reconceptualization of the policy mix for innovation. As a prerequisite of such empirical analysis, we take a first step in identifying and defining the key elements, processes, characteristics and dimensions of such an extended policy mix concept. For this, we review and synthesize the literature on innovation studies,

1 For instance, given the limitations of the EU emissions trading system, Matthes (2010) (p.6) calls for a "comprehensive, effective, economically efficient, robust, politically achievable, and inclusive climate policy mix." Regarding climate innovations in the power sector Schmidt et al. (2012a) (p.476) stress the need for a "consistent and effective policy mix which is congruent to long-term targets." Likewise, OECD (2007) (p. 22) recommends an increase of "the coherence of the instrument mix" for environmental policy and Nauwelaers et al. (2009) (p.11) underline the "need for coherence, coordination, and effectiveness of policy mixes" for R&D.

environmental economics, policy analysis and strategic management. In doing so, we aim at deriving a policy mix concept that assists in a more systematic understanding of real-world policy mixes and serves as an integrating framework for empirical analyses addressing the role of policy mixes for technological change. Thereby, such an interdisciplinary analytical framework should enhance our understanding of the role of policy mixes for sustainability transitions and thus enable more precise policy recommendations.

Throughout the paper we illustrate the proposed policy mix concept using the example of the decarbonization of the German energy system, which requires accelerated development and diffusion of renewable power generation technologies (RPGTs) to realize the aspired system transition. The associated policy mix represents a good example with its feed-in law and several other policy mix elements as well as lively policy debates as to the best way to achieve the "Energiewende" (Agora Energiewende 2012).

The remainder of the paper is structured as follows. In section 2.2 we review the literature on policy mixes and their characteristics and derive requirements for an extended policy mix concept. Based on this, in section 2.3 we present the three building blocks of the proposed policy mix concept: elements (section 2.3.1), policy processes (section 2.3.2) and characteristics (section 2.3.3). In section 2.3.4 we introduce relevant dimensions for delineating policy mixes, while section 2.3.5 synthesizes the proposed policy mix concept. Finally, in section 2.4 we discuss how the extended policy mix concept may be used as a framework for analysis for investigating the link between policy mixes and technological change (section 2.4.1), and how to address the associated challenges of such empirical analysis, including boundary setting and operationalizing the policy mix (section 2.4.2). Section 2.5 derives policy implications and concludes the paper.

2.2. Literature review

2.2.1. Policy mix

A growing number of studies in various scientific fields use the term policy mix, e.g. Lehmann (2010) in environmental economics, Nauwelaers et al. (2009) and de Heide (2011) in innovation studies, and Howlett and Rayner (2007) in the field of policy analysis[2]. In its most basic form, studies implicitly or explicitly define a policy mix as the combination of several policy instruments (Lehmann 2012; Matthes 2010). However, as stressed by Flanagan et al. (2011), a policy mix encompasses more than just a combination of policy instruments; it also includes the processes by which such instruments emerge and interact. As a consequence, studies focusing solely on the interaction of instruments should, more precisely, refer to the

2 A review of the origins of the term in economic policy and its subsequent uptake in the fields of environmental and later also innovation policy can be found in Flanagan et al. (2011).

term 'instrument mix' (see section 2.3.1.3)[3]. Table 2 gives an overview of some policy mix definitions, with the more elaborate ones mainly originating from innovation studies and the policy analysis literature.

Three general features emerge from these definitions: First, they typically include the ultimate objective(s) of the policy mix, either in an abstract form (Kern, Howlett 2009) or more typically as a specific objective of a certain policy field, such as innovation (Boekholt 2010; Guy et al. 2009; Nauwelaers et al. 2009) or biodiversity (Ring, Schröter-Schlaack 2011). Second, interaction is a central feature of the existing policy mix definitions (Boekholt 2010; de Heide 2011; Nauwelaers et al. 2009). It has been studied most extensively in the climate and energy fields, where the focus is often on its influence on the effectiveness and efficiency of instruments in the mix (del Río González 2009a; 2010; IEA 2011b; Sorrell et al. 2003). Third, some of the definitions point to the dynamic nature of the policy mix, referring to it as having "evolved" (Ring, Schröter-Schlaack 2011) and "developed incrementally over many years" (Kern, Howlett 2009). This reflects that instruments and their meanings may change over time, causing interactions between them to change (IEA 2011b; Sorrell et al. 2003).

TABLE 2: Definitions of the term *policy mix* in the literature

Source	Definition
Guy et al. (2009) (p.1)	"An R&D and Innovation Policy Mix can be defined as that set of government policies which, by design or fortune, has direct or indirect impacts on the development of an R&D and innovation system."
Kern and Howlett (2009) (p.395)	"Policy mixes are complex arrangements of multiple goals and means which, in many cases, have developed incrementally over many years."
Nauwelaers et al. (2009) (p.3)	"A policy mix is defined as: The combination of policy instruments, which interact to influence the quantity and quality of R&D investments in public and private sectors."
Boekholt (2010) (p.353)	"A policy mix can be defined as the combination of policy instruments, which interact to influence the quantity and quality of R&D investments in public and private sectors."
De Heide (2011) (p.2)	"A policy mix is the combined set of interacting policy instruments of a country addressing R&D and innovation."
Ring and Schröter-Schlaack (2011)	"A policy mix is a combination of policy instruments which has evolved to influence the quantity and quality of biodiversity conservation and ecosystem service provision in public and private sectors."

Yet, in the context of sustainability transitions a policy mix concept is needed which goes beyond this narrow scope – interacting instruments aimed at achieving objectives in a dynamic setting – at least in three respects. First, aside from capturing its dynamic nature,

3 This is done, for example, by OECD (2007), Braathen (2007) and Murphy et al. (2012). Similarly, Borrás and Edquist (2013) argue for a distinction between instrument mix and policy mix, while others use the term 'policy mix' interchangeably with 'instrument mix' (Ring, Schröter-Schlaack 2011).

an extended concept should consider more of the *complexity* of real-world policy mixes, thereby going beyond combinations of policy instruments and their interactions (Flanagan et al. 2011). Second, it needs to more explicitly incorporate *policy processes* “by which policies emerge, interact and have effects” (Flanagan et al. (2011), p.702) since such processes and related politics help explain the evolution of policy mixes, but also the resulting effects (Foxon, Pearson 2007; 2008). Third, a policy mix concept for sustainability transitions ought to include a *strategic component*. This tends to be neglected despite early works of Jänicke on the role of strategic approaches in environmental policy (Jänicke 1998; 2009), the necessity of long time horizons for sustainability transitions (Markard et al. 2012) and recent empirical evidence on the importance of long-term climate targets for companies’ innovation strategies (Rogge et al. 2011b; 2011c; Schmidt et al. 2012b).

2.2.2. Characteristics of policy mixes

To describe the nature and performance of policy mixes it is useful to differentiate between policy mix characteristics and assessment criteria (OECD 2003a; Sorrell et al. 2003). Terms belonging to the latter group represent well-established ex-ante and ex-post assessment criteria applied in impact assessments and evaluations of single policy instruments, such as effectiveness, efficiency, equity or feasibility (del Rio et al. 2012; IRENA 2012). In contrast, the former group comprises terms specifically used for characterizing the policy mix, such as consistency, coherence, credibility or comprehensiveness (Foxon, Pearson 2008; Howlett, Rayner 2007; Kern, Howlett 2009; Majone 1997; Matthes 2010). These characteristics may impact the performance of a policy mix in terms of the standard assessment criteria, particularly regarding effectiveness and efficiency.

However, most policy mix studies refer to these often ambiguously defined characteristics without clarifying what is actually meant. We will illustrate this ambiguity for the frequently used but particularly heterogeneously defined terms *consistency* and *coherence* (Den Hertog, Stroß 2011; Picciotto 2005). Based on a review of the – predominantly policy analysis – literature on these terms we identify three important points to be taken into account when establishing a more uniform terminology.

First, consistency and coherence are either seen as *identical or different characteristics*. The former suggests coherence is synonymous with consistency (Carbone 2008; Hoebink 2004; Matthews 2011). As a result, coherence is often simply defined using the term consistency (Hydén 1999; Picciotto et al. 2004), but there is no uniform definition[4]. In contrast, the latter distinguishes consistency and coherence as different characteristics (Howlett, Rayner

4 While some base their definition on the absence of contradictions and non-conflicting signals (Forster, Stokke 1999; Van Bommel, Kuindersma 2008), others refer to the consistency or coherence among policies (Bigsten 2007; Di Francesco 2001; OECD 1996), while still others speak of consistency or coherence between objectives and instruments (Fukasaku, Hirata 1995; Picciotto 2005).

2007; Mickwitz et al. 2009a; OECD 2001), but again there is no agreement on the exact nature of this difference. However, the majority of these studies assert that coherence is more encompassing than consistency (Jones 2002; OECD 2003a). That is, in its most basic form, consistency is seen as the absence of contradictions (Den Hertog, Stroß 2011; Gauttier 2004), while coherence calls for an achievement of synergy or positive connections (Missiroli 2001; Tietje 1997)[5].

Second, the literature differentiates between a *state and process perspective* of consistency and coherence, i.e. between what is being achieved and how it is achieved (Carbone 2008), but again this is not treated uniformly. A first set of studies addresses the state of affairs at a certain point in time only (Duraiappah, Bhardwaj 2007; Fukasaku, Hirata 1995; Hoebink 2004). A second set instead captures the process perspective (Jones 2002; Lockhart 2005; OECD 2003a), often concentrating on the organizational setup to attain consistency/ coherence. A third set of studies mentions – either implicitly or explicitly – both state and process perspectives, but uses the same term – typically coherence – for both (Den Hertog, Stroß 2011; Forster, Stokke 1999; McLean Hilker 2004).

Third, some studies focus on *tools* for enhancing consistency and coherence (Ashoff 2005; OECD 1996; 2003a), a discussion which is closely linked to the literature on policy coordination[6] and integration[7] (Mickwitz et al. 2009a; Van Bommel, Kuindersma 2008). However, as before, there is no common understanding of the terms consistency and coherence and how they relate to other concepts, such as coordination. One reason for this lack of a uniform terminology may be the often largely separated contributions addressing distinct policy fields, such as development policy (EU 2005; 2010; Weston, Pierre-Antoine 2003), climate policy (Kern, Howlett 2009; Mickwitz et al. 2009b) and eco-innovation policy (Reid, Miedzinski 2008; Ruud, Larsen 2004).

To better deal with such diversity in meaning and the resulting difficulties in integrating findings across studies, an extended policy mix concept needs to propose uniform definitions of these terms that fulfill the following two requirements: First, these definitions need to clearly specify whether they refer to the state or process perspective of the policy mix, which might best be accomplished by separate terms for each of these perspectives. Second, at a minimum they should allow for the differentiation of a weak and strong form to

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5 An alternative view was developed by Howlett et al. who speak of consistency of instruments and coherence of goals (Howlett, Rayner 2007) and also introduce congruence among instruments and goals as a third category (Kern, Howlett 2009).

6 Policy coordination is a formal policy process aiming to get “the various institutional and managerial systems, which formulate policy, to work together” (OECD 2003a, p. 9). Subsets of policy coordination are cooperation and collaboration (Bouckaert et al. 2010).

7 Environmental policy integration means “the incorporation of environmental objectives into all stages of policy making in non-environmental policy sectors [..] accompanied by an attempt to aggregate presumed environmental consequences into an overall evaluation of policy, and a commitment to minimize contradictions between environmental and sectoral policies” (Lafferty, Hovden 2003, p. 9).

capture the distinction between the absence of contradictions and actual synergies within a policy mix.

2.3. Building blocks of the policy mix concept

As derived in the literature review, an extended policy mix concept for sustainability transitions needs to address three basic requirements: first, the inclusion of a *strategic component,* second, the incorporation of associated *policy processes*, and third, the consideration of c*haracteristics* of policy mixes. In capturing this complexity of actual policy mixes it should also pay attention to their dynamic nature. Finally, to resolve concerns over ambiguous terminology, it needs to suggest precise definitions of key terms.

Based on these requirements, we define the policy mix as a combination of the three building blocks elements, processes and characteristics, which can be specified using different dimensions. *Elements* comprise the (i) policy strategy with its objectives and principal plans for achieving them and (ii) the instrument mix with its interacting policy instruments. The content of these elements is an outcome of *policy processes.* Both elements and processes can be described by their *characteristics*, including the consistency of elements, the coherence of processes, as well as the credibility and comprehensiveness of a policy mix. Finally, the policy mix can be delineated by several dimensions, including policy field, governance level, geography and time.

2.3.1. Building block 1: Elements

2.3.1.1. Policy strategy

The importance of a long-term strategic orientation and strategic policy frameworks has been increasingly underscored in the literature addressing sustainability transitions (Foxon, Pearson 2008; Quitzow 2015a; Weber, Rohracher 2012) and policy-triggered environmental technological change (Rogge et al. 2011c; Schmidt et al. 2012b). We therefore incorporate policy strategy as one of the elements in the policy mix concept and draw on the strategic management literature to derive a common definition for the content of a policy strategy. This literature highlights that strategy consists of a combination of interdependent ends (goals) and means (policies) to achieve the ends (Andrews 1987; Miles, Snow 1978; Mintzberg 1999; Porter 1980).

Building on Andrews (1987) and Porter (1980), we thus define policy strategy as a combination of policy objectives and the principal plans for achieving them. That is, the definition puts an emphasis on the output – the ends and means – of the strategy process, while the adaptive process of formulating, implementing and revising objectives and plans is captured by the processes building block (see 2.3.2). We will discuss these two main components of objectives and plans in turn, while recognizing that they are closely interlinked.

The first component of the policy strategy definition concerns *policy objectives* associated with sustainability transitions. These objectives tend to be substantiated by long-term *targets* with quantified ambition levels (Rennings et al. 2003; Schmidt et al. 2012b) and may be based on visions of the future (del Río et al. 2010; Kemp, Rotmans 2005)[8 9]. For example, one of the policy objectives of the EU is the reduction of greenhouse gas (GHG) emissions. This is concretized by a 20% GHG reduction target for 2020 and 40% for 2030, aiming at arriving at numbers in line with the internationally agreed target of 2°C (EU 2013)[10]. In addition to environmental objectives, the policy strategy may also include social and economic issues (Daly, Farley 2010), such as the support of growth, competitiveness and jobs (EU 2013). Besides content-oriented objectives, a policy strategy can also contain process and learning objectives, which may be particularly relevant in the context of sustainability transitions (Kemp 2007; Rotmans et al. 2001), e.g. in terms of the build-up or enhancement of the strategic capacity of governments (Quitzow 2015).

The second component of the strategy definition addresses the *principal plans* for achieving these objectives. Such plans outline the general path that governments propose to take for the attainment of their objectives and include framework conventions, guidelines, strategic action plans and roadmaps[11]. In communicating not only the ends but also the intended means to achieve these, the policy strategy gives direction to actions and decisions (Grant 2005). An example of principal plans at the EU level is the Strategic Energy Technology (SET) Plan, while at the national level the German Energy Concept provides a key example.

The long-term perspective inherent in the policy strategy (Hillman, Hitt 1999) can play a fundamental role in providing actors with needed guidance in their search and can thus support one of the functions of innovation systems (Hekkert et al. 2007). For example, research has shown the vital role of ambitious and stable long-term climate targets in

8 In making this distinction between objectives and targets we follow Tuominen and Himanen (2007, p. 390) who define a policy objective as “what the policy is trying to achieve, the overall goal; often quite abstract and qualitative” and a policy target as “more specific and quantitative than an objective [..] (e.g. 10% less emissions of air pollutants within 5 years). The target points out a clear sense of direction for policy measures.”

9 Targets can be characterized by a number of factors, including their ambition level, their type (e.g. specific, absolute), their governance level (e.g. EU, national), their scope (e.g. headline target, sub-target), their time horizon (e.g. long-term, interim), or their legal nature (e.g. binding, aspirational, voluntary), see EU (2013) and Philibert and Pershing (2001).

10 This target (20% GHG reduction until 2020 compared to 1990) is one of the three EU headline targets (20-20-20 targets) which also include a 20% share for renewable energy sources in the energy consumed in the EU (EU 2008a) and 20% savings in energy consumption compared to projections for 2020 (EU 2008b).

11 An alternative analytical lense is provided by Quitzow (2011, 2015), which includes existing policy instruments and their design in the definition of the content of a policy strategy.

steering R&D activities of companies in the power sector (Rogge et al. 2011b; 2011c; Schmidt et al. 2012b). However, the same research has also pointed out that this strategic element of the policy mix on its own is not sufficient to change companies' innovation strategies but needs to be operationalized through concrete policy instruments.

2.3.1.2. Instruments

As the second element in the policy mix, policy instruments constitute the concrete tools to achieve overarching objectives. More precisely, they can be seen as tools (Salamon 2002) or techniques of governance (Howlett 2005) that address policy problems (Pal 2006). They are introduced by a governing body (Sorrell et al. 2003) in order to achieve policy objectives (Howlett, Rayner 2007), thereby translating plans of action (de Heide 2011). Examples of policy instruments include the German feed-in tariffs incorporated in the Renewable Energy Act (EEG) and the EU Emissions Trading System (ETS).

A number of alternative terms are used, such as implementing measures (EU 2013), programs (Komor, Bazilian 2005), policies (IRENA 2012), or policies and measures (UNFCCC 2011). For simplicity, we use the term 'instrument' in the policy mix concept, with the clear understanding that it encompasses these alternative terms. However, as the term 'policy' is very broad and used differently across disciplines (Dye 2008; Fischer, Preonas 2010), we prefer not using it synonymously for 'instrument'.

Policy instruments are typically associated with specific *goals*. That is, while the policy strategy contains objectives which tend to be specified by long-term targets, we use the term 'goal' to characterize the intended effect of instruments that contribute to achieving overarching policy objectives. In addition, two key attributes of policy instruments are particularly relevant for innovation, namely instrument *type* and instrument *design feature*.

Instrument type

The type of an instrument has been identified as a major determinant of environmental innovation, both in theoretical (Jaffe et al. 2002; Popp et al. 2009; Requate 2005) and empirical studies (Hašcic et al. 2009; Hemmelskamp 1999; Johnstone et al. 2010). First attempts at a combined typology of environmental and innovation policy instrument types tend to lack either a differentiated set of innovation (Rennings et al. 2008) or environmental policy types (Nauwelaers et al. 2009). Therefore, in Table 3 we propose a more balanced 3x3 matrix typology that combines three instrument types (economic instruments, regulation and information) with three instrument purposes (technology push, demand pull and systemic concerns). It may be most noteworthy that we include a systemic purpose of instruments by which we refer to "instruments that support functions operating at system level" (Smits, Kuhlmann 2004, p. 25)[12]. Since this matrix is an oversimplification of reality, and as such not free of overlaps[13], we qualify both instrument purpose and type with the word 'primary'. For each of the nine possible type-purpose-combinations, Table 3 includes some selected examples of instruments relevant for technological change.

TABLE 3: Type-purpose instrument typology (with instrument examples)

	PRIMARY PURPOSE		
PRIMARY TYPE	**Technology push**	**Demand pull**	**Systemic**
Economic instruments	RD&D* grants and loans, tax incentives, state equity assistance	Subsidies, feed-in tariffs, trading systems, taxes, levies, deposit-refund-systems, public procurement, export credit guarantees	Tax and subsidy reforms, infrastructure provision, cooperative RD&D grants
Regulation	Patent law, intellectual property rights	Technology / performance standards, prohibition of products / practices, application constraints	Market design, grid access guarantee, priority feed-in, environmental liability law
Information	Professional training and qualification, entrepreneurship training, scientific workshops	Training on new technologies, rating and labelling programs, public information campaigns	Education system, thematic meetings, public debates, cooperative RD&D* programs, clusters

* RD&D = Research, development and demonstration

Source: Own elaboration (based on Del Río, 2009; Edler & Georghiou, 2007; Hemmelskamp, 1999; IEA, 2011b; Mowery, 1995; Rammer, 2009; Rennings et al., 2008; Smits & Kuhlmann, 2004; Sterner, 2003; Wieczorek & Hekkert, 2012)

Instrument design features

In the environmental economics literature it has been increasingly pointed out that a policy instrument's design features may actually be more influential for innovation than the instrument type (Kemp, Pontoglio 2011; Vollebergh 2007). Therefore, an increasing number of studies explicitly consider them when analyzing policy instruments and their innovation effects (Ashford et al. 1985; Blazejczak et al. 1999; Norberg-Bohm 1999). In addition, design features may also impact an instrument's effectiveness and efficiency and may be a prerequisite for interaction analyses (del Río González 2009a).

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12 Smits and Kuhlmann (2004, p. 25) distinguish between five systemic functions: "management of interfaces, building and organizing systems, providing a platform for learning and experimenting, provision of strategic intelligence and demand articulation."

13 For example, a trading system, such as the EU ETS, is primarily viewed as a demand-pull instrument, but the change in relative prices not only affects diffusion but also innovation (Jaffe et al. 2002), making it reasonable to classify it as an economic instrument serving a system-wide purpose. However, empirical evidence suggests that the primary effect occurs in the adoption of technologies, not on RD&D (Rogge et al. 2011c; Schmidt et al. 2012b), thus making it meaningful to classify trading schemes as economic instruments that primarily serve demand-pull purposes.

Design features can be differentiated by abstract and descriptive features. *Descriptive design features*, such as an instrument's legal form[14], its target actors, and its duration, summarize the content of a policy instrument (del Río 2012), which can serve as a first step in identifying how a policy instrument performs regarding abstract design features. A number of *abstract design features* have been proposed in the literature (Hašcic et al. 2009; Kemp, Pontoglio 2011)[15], but there is no universally accepted list. In the context of sustainability transitions we argue that at least the following six may be important to consider: stringency, level of support, predictability, flexibility, differentiation and depth.

First, *stringency* addresses the ambition level of an instrument and is typically associated with regulatory and economic instruments, such as emissions standards or emissions trading. It can refer both to an instrument's goal and its design, with the individually perceived stringency ultimately determined by the characteristics of the instrument's target actor, such as its technology portfolio (Rogge 2010). Although definitions and operationalizations of stringency vary across studies, findings point to a positive impact of stringency on innovation (Ashford et al. 1985; Frondel et al. 2007; Rogge et al. 2011c; 2011a; Schmidt et al. 2012b).

Second, *level of support* captures the magnitude of positive incentives provided by a policy instrument, which may be particularly relevant for instruments providing financial incentives. A prime example is the level of feed-in tariffs, which aim at increasing the return on investments in renewable power generation technologies (Steinhilber et al. 2011). Another example is the volume of RD&D support, e.g. for fostering research and development activities for niche technologies.

Third, *predictability,* having gained attention particularly in relation to the EU ETS and a post-Kyoto international climate agreement (Engau, Hoffmann 2009; Hoffmann et al. 2008), "captures the degree of certainty associated with a policy instrument and its future development. This concerns the instrument's overall direction, detailed rules, and timing" (Rogge et al. 2011c, p. 515). As such it ultimately addresses the effect of a policy instrument on investor uncertainty (Hašcic et al. 2009), which may be particularly important for long-lived capital-intensive investments and RD&D decisions. For example, the German EEG increases its predictability by granting support to investors for 20 years.

Fourth, *flexibility* captures the extent to which innovators are allowed to freely choose their preferred way of achieving compliance with an instrument (Kivimaa, Mickwitz 2006;

14 The legal form determines, for example, the binding character of an instrument, which can range from voluntary agreements to compulsory measures.

15 Not all of the abstract design features found in the literature concern instruments only, but also include aspects relevant for policy making and implementation, such as continuous improvement (Kivimaa, Mickwitz 2006) and enforcement (Kemp 1997), as well as for the overall policy mix, such as credibility (Kemp, Pontoglio 2011).

Norberg-Bohm 1999). Johnstone and Hašcic (2009, p. 1) find that for "a given level of policy stringency, countries with more flexible environmental policies are more likely to generate innovations which are diffused widely and are more likely to benefit from innovations generated elsewhere". A prime example in this regard is the EU ETS which allows firms to freely choose between various compliance options.

A fifth abstract design feature concerns the *differentiation* specified in policy instruments (Kemp, Pontoglio 2011), e.g. with regard to industrial sector, size of the plant, technology or geographical location[16]. Sixth, the *depth* of the policy instrument addresses the range of its innovation incentives, that is whether its incentives extend all the way to potential solutions with zero emissions (Hašcic et al. 2009).

The interwoven nature of design features requires them to be mutually balanced (Kemp 2007). For example, empirical studies recommend a gradual tightening of the stringency in a predictable manner, while at the same time providing enough flexibility to allow for the exploration of new technological developments (Kivimaa 2007).

2.3.1.3. Instrument mix

Moving from single instruments to their combination brings us to the instrument mix, which we conceptualize as being only a part of the overarching policy mix. This calls for a distinction between instrument mix and policy mix, with the latter encompassing the former. Regarding the instruments in this mix it may be useful to distinguish between core (or cornerstone) instruments and complementary (or supplementary) instruments of an instrument mix (IEA 2011b; Matthes 2010; Schmidt et al. 2012b). For the example of the instrument mix for renewable energies in Germany, the core instrument would be the EEG with its feed-in tariffs, which is complemented by other instruments such as the KfW renewable energy program.

At the heart of the concept of instrument mixes are *interactions* between the instruments, which signify "that the influence of one policy instrument is modified by the co-existence of other [instruments]" (Nauwelaers et al. 2009, p.4). This influence originates from the direct or indirect effect that the operation or outcomes of instruments have on each other (Oikonomou, Jepma 2008; Sorrell et al. 2003). Clearly, these interdependencies of instruments largely influence the combined effect of the instrument mix and thus the achievement of policy objectives (Flanagan et al. 2011). It is for this reason that interactions of policy instruments represent a central component of any policy mix concept.

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16 In the innovation policy literature this feature is also referred to as the "specificity of a policy measure" which serves as indicator as to whether an instrument "quite precisely describes the research target or whether this is rather open" (Cantner, Pyka 2001, p. 764).

However, as pointed out by Gunningham and Grabosky (1998), without considering the particular context in which interactions occur, only tentative conclusions on instrument interactions can be reached, thus calling for empirical analyses. Such analyses ought to understand the mechanisms and consequences of policy interactions, which requires considering a number of aspects, including the scope of the interacting instruments, the nature of their goals, their timing, and operation and implementation processes (Sorrell et al. 2003). This suggests that interaction outcomes are not only determined by the instrument mix but also shaped by the overarching policy mix.

Thus far, interactions have been predominantly dealt with in the environmental domain, particularly on climate and energy issues (del Río González 2009a; Gunningham, Grabosky 1998; Sorrell et al. 2003). More recently, innovation studies have also started to highlight interactions (Flanagan et al. 2011; Guerzoni, Raiteri 2015; Nauwelaers et al. 2009). For example, Flanagan et al. 2011 differentiate between four types of interactions, including interactions between the same instruments across different dimensions (see section 2.3.4), and similarly between different instruments either targeting the same or different actors / groups involved in the same process, or targeting different processes in a broader system. These studies acknowledge the need to avoid negative interactions and to strive for positive or complementary interaction outcomes.

2.3.2. Building block 2: Policy processes

Rather than looking only at the content of the policy strategy and instrument mix with its interacting instruments, we now turn our attention to the policy making process, or *policy process* for short (Dunn 2004; Dye 2008). It is these processes that determine the elements of the policy mix and thus how both the strategy and corresponding instruments change over time. In addition, policy processes may also impact technological change by shaping policy mix characteristics. Given their importance these processes constitute another building block of the proposed policy mix concept (Howlett, Rayner 2007; Kay 2006; Majone 1976).

Since there is no uniform definition of the policy making process, we build on Howlett et al. (2009) and Sabatier and Weible (2014) and refer to it as political problem-solving process among constrained social actors in the search for solutions to societal problems – with the government as primary agent taking conscious, deliberate, authoritative and often interrelated decisions. As such, these interactive and continuous reconciliation processes with various feedback loops involve power, agency and politics. Clearly, this is of high relevance in the context of sustainability transitions with their complex and messy policy processes with a plethora of involved actors and their conflicting interests and ideas (Meadowcroft 2009; Stirling 2014). Finally, policy processes are shaped by socio-economic conditions, infrastructure and biophysical conditions, but also by culture and institutions (Sabatier, Weible 2014), and can thus differ significantly across space and time.

Policy processes cover all stages of the policy cycle, including problem identification, agenda setting, policy formulation, legitimization and adoption, implementation, evaluation or assessment, policy adaptation, succession and termination (Dunn 2004; Dye 2008; Schubert, Bandelow 2009). As such, the policy making process can be seen "as a cycle of problem-solving attempts, which result in *'policy learning'* through the repeated analysis of problems and experimentation with solutions" (Howlett et al. 2009, p. 3). This ongoing and reactive nature of policy processes both shapes the setting and adjustment of the policy strategy as well as the (re)design of instruments in the mix.

Because of the fundamental importance of policy implementation in determining the effectiveness and efficiency of a policy instrument, we follow others in differentiating policy processes into policy making and policy implementation (Richardson 1982). Regarding *policy making*, we stress two aspects: First, due to the dynamic, multifaceted and uncertain nature of technological change and sustainability transitions, policy adaptation and thus policy learning is a crucial feature of policy making processes (Allen et al. 2011; Bennett, Howlett 1992; Boekholt 2010; Kemp et al. 2007; Loorbach 2007). To facilitate such interactive processes, the monitoring and evaluation of the impacts of policy mixes are of fundamental importance (Kemp 2011). Also, participatory processes of envisioning, negotiating, learning and experimenting can strengthen policy learning (Frantzeskaki et al. 2012). Second, policy making is a highly political process characterized by resistance to change, particularly from actors with vested interests (Unruh 2002). In that sense, the adoption of a policy strategy with clear objectives but without the simultaneous adoption of a set of instruments can be understood as an attempt of setting the agenda for upcoming changes in the instrument mix. However, given the political nature of policy making processes it may remain difficult to radically adjust the instrument mix even if new policy objectives are in place. This may be one reason why new instruments supporting niches may be added to those supporting existing regimes instead of replacing them (Kern, Howlett 2009)[17].

By *policy implementation* we mean "the arrangements by authorities and other actors for putting policy instruments into action" (Nilsson et al. 2012, figure 1), that is, for executing and enforcing them (Sabatier, Mazmanian 1981), implying that policy implementation is particularly relevant to the instrument mix. Complex and insufficient implementation structures but also political resistance at sub-ordinate governance levels may lead to implementation difficulties such that ultimately a policy instrument may not tap its full potential. Such difficulties may partly be overcome by an appropriate crafting of policy instruments (May 2003; Mazmanian, Sabatier 1981), including the provision of sufficient

17 Arguably, policy making may often be more affected by such politics than policy implementation.

funding and staff for implementation, thereby illustrating the close link between policy making and implementation.

Table 4 illustrates the evolution of the German policy mix for renewable power generation technologies by linking actors and policy-making processes, ranging from the promotion of initial support programs by advocacy groups and the parliament to the adoption and first amendments of the German Renewable Energy Act (EEG).

TABLE 4: Broad overview of key policy processes describing the evolution of the German policy mix for renewable energies (until 2004)

Time	Involved actors	Policy processes
Aftermath of oil crises and Chernobyl	Renewables advocacy groups, parliament	Promotion of initial support programs for wind and solar power, e.g. 1,000 roofs program
Late 1980s to 1990	Renewables advocacy associations	Proposal of Feed-in Law (StrEG), predecessor of Renewable Energy Act (EEG)
1990	German Bundestag	Adoption of StrEG in all-party consensus
	Ministry of Economic Affairs, big utilities	Opposition to StrEG
Mid 1990s	German Länder, municipal utilities	Support for renewables through specific local programs
2000	German Bundestag	Accelerating the fast adoption of the first EEG
2000 to 2004	Government opposition, utilities, associations, interest groups	Different degrees of disagreement on drafting first EEG amendment

Source: Own compilation (based on Jacobsson & Lauber, 2006; Wüstenhagen & Bilharz, 2006)

Finally, we highlight the role of the *style* of policy processes. More precisely, we refer to the policy making and implementation style, i.e. the “standard operating procedures for making and implementing policies” (Richardson 1982, p.2). The policy style captures, for example, the typical kind of goal setting or flexibility in instrument application (Blazejczak et al. 1999; Jänicke et al. 2000). It may directly and indirectly influence the policy mix, e.g. regarding its credibility or the design and implementation of policy instruments and thus may play an important role in how the overall policy mix affects innovation.

2.3.3. Building block 3: Characteristics

2.3.3.1. Consistency of elements

We suggest that *consistency* captures how well the elements of the policy mix are aligned with each over, thereby contributing to the achievement of policy objectives. It may range from the absence of contradictions to the existence of synergies within and between the elements of the policy mix.

We highlight two key features of this consistency definition. First, it focuses on the *state of the elements* of the policy mix at any given point in time, i.e. its content. In this regard, the development of the alignment of the elements of the policy mix over time is captured by the term temporal consistency. Second, it may be most useful to understand consistency in relative terms, i.e. differentiating between the degree of consistency and its variation across dimensions, such as time, geography or governance level. A consistent policy mix at a minimum needs to be free of contradictions or conflicts (Forster, Stokke 1999), as this may impair the achievement of objectives (Ashoff 2005; Hoebink 2004; McLean Hilker 2004). If on top of such weak consistency complementarities, mutual support and synergies exist we refer to this as strong consistency.

We distinguish between consistency of the policy strategy, consistency of the instrument mix, and consistency of the instrument mix with the policy strategy. First, consistency of the *policy strategy* incorporates the alignment of policy objectives (Mickwitz et al. 2009a; OECD 2003a), which suggests that these can be achieved simultaneously without any significant trade-offs. This is important since conflicting objectives are a major source of tension between the instruments in a policy mix (Flanagan et al. 2011). Examples are whether climate targets are consistent with energy security or competitiveness targets, or whether interim targets are consistent with long-term targets. In addition, it captures whether principal plans, i.e. framework conventions, guidelines, strategic action plans and roadmaps, are free of contradictions or mutually supportive. This first level of consistency also captures whether these plans are consistent with policy objectives. An example of this is the German Energy Concept's (2010) confirmation of the German 40% GHG emissions reduction target by 2020 as originally specified in 2002.

The second level of consistency concerns the *instrument mix* and can be assessed through interaction analysis. The instruments in an instrument mix are consistent when they reinforce rather than undermine each other in the pursuit of policy objectives (Howlett, Rayner 2013). "They are inconsistent when they work against each other and are counterproductive" (Kern, Howlett 2009, p.396). Therefore, strong instrument mix consistency is associated with positive interactions, weak instrument mix consistency is characterized by neutral interactions, while instrument mix inconsistency is captured by negative interactions (del Río González 2009a; 2010; IEA 2011b; Sorrell et al. 2003).

Finally, third level policy mix consistency addresses the *interplay of the instrument mix and the policy strategy*. This overall policy mix consistency is characterized by the ability of the policy strategy and the instrument mix to work together in a unidirectional or mutually supportive fashion (Howlett, Rayner 2013), thereby contributing to the achievement of policy objectives. Thus, a higher degree of first- and second-level consistency positively influences the degree of third-level consistency. This implies that a consistent policy strategy is implemented by a consistent instrument mix encompassing instruments with design features capable of reaching the objectives. For example, the instrument mix operationalizing the German Energiewende is currently perceived as inconsistent with its ambitious targets (ARD 2013; WDR 2013). Ultimately, consistency at these three levels may be one determinant of the performance of a policy mix, particularly regarding its effectiveness and efficiency.

2.3.3.2. Coherence of processes

To characterize policy processes we use the term *coherence*, thereby following studies that focus on the process dimension (Den Hertog, Stroß 2011; 2002; OECD 2001; 2003a; 2003b). Building on Jones (2002) we suggest defining policy coherence as referring to synergistic and systematic policy making and implementation processes contributing – either directly or indirectly – towards the achievement of policy objectives. Such more synergistic and systematic policy processes may be achieved through a number of structural and procedural mechanisms, such as strategic planning, coordinating structures and communication networks (Ashoff 2005; den Hertog et al. 2004; OECD 1996; 2001).

We highlight three key features of this definition. First, it addresses the coherence of policy processes *across different policy fields and governance levels*. These processes shape all elements of the policy mix, thereby underlining that neither the policy strategy nor instruments are seen as given. Second, it points to the need of systematic capabilities of policy makers (Jacobsson, Bergek 2011). That is, coherence of policy making and implementation requires advanced organizational capacities, including, for example, the ability to assemble related knowledge from diverse sources, to build networks with all relevant actors, or to engage with multiple stakeholders (Quitzow 2011; 2015a). Third, we differentiate between a *direct and indirect effect* of coherence. Its direct effect refers to how coherence influences the behavior of actors and thus the performance of a policy mix, as measured by standard assessment criteria. For example, we propose a positive direct link between coherence and the effectiveness of a policy mix. In contrast, the indirect effect addresses how coherence contributes to shaping the policy mix elements and their consistency, thereby indirectly affecting the performance of a policy mix. For this we presume a positive link, meaning that greater coherence is expected to be associated with greater consistency.

Two major tools for improving policy coherence are *policy integration* (OECD 2003a; Underdal 1980) and *coordination* (Bouckaert et al. 2010; Magro et al. 2015; OECD 1996)[18]. The former can improve policy coherence by enabling a more holistic thinking across different policy sectors, at the same time involving more holistic processes. In contrast, the latter can strengthen coherence by aligning the tasks and efforts of public sector organizations (Bouckaert et al. 2010), e.g. in enhancing information flows through formal mechanisms

18 While some studies view coherence as equivalent to integration and coordination (Duraiappah, Bhardwaj 2007; Geerlings, Stead 2003), we follow others in seeing them as distinct formalized tools for improving policy coherence (Carbone 2008; Di Francesco 2001; McLean Hilker 2004; OECD 2003a).

(OECD 1996). For example, the establishment of an integrated energy and climate policy department, as accomplished in the UK and Denmark, seems to be a promising approach of structural coordination for overcoming the recurring conflict of jurisdictions between the German Federal Departments for the Environment (BMU) and Economics (BMWi), which may have hampered the realization of the German Energiewende (Rave et al. 2013).

In conclusion, we want to stress that it may be impossible to actually achieve complete coherence and consistency (Carbone 2008; Hoebink 2004; McLean Hilker 2004). Reasons for this may include the complexity of the systems and associated sustainability challenges we are faced with, including path dependence and lock-in, resistance of regime actors, conflicting interests and tensions, and fragmentation of policy making (Meadowcroft 2007; Unruh 2002). Therefore, "the aim is to make progress towards maximum coherence within the limited resources available" (McLean Hilker 2004), thereby also striving to maximize policy mix consistency. Yet, ultimately neither coherence nor consistency should be seen as goal in itself but rather as means for improving the performance of a policy mix regarding the standard assessment criteria, particularly effectiveness and efficiency.

2.3.3.3. Credibility

In addition to consistency and coherence, credibility may also be relevant for describing the nature of policy mixes for sustainability transitions. Such policy credibility is rooted in macroeconomics and monetary policy and refers to the challenges that short time horizons (electoral cycles) pose for policy makers' credibility (Kydland, Prescott 1977). However, while the term appears frequently in current debates on climate policy, its underlying meaning remains rather vague. Therefore, we define credibility as the extent to which the policy mix is believable and reliable (Newell, Goldsmith 2001), both overall and regarding its elements and processes.

Credibility may be influenced by a range of factors, such as the commitment from political leadership, the operationalization of targets by a consistent instrument mix or the delegation of competencies to independent agencies. For example, for the case of solar PV in Germany a content analysis of the industry journal Photon (1996-2012) suggests that the most relevant determinants of the perceived degree of credibility were the stability and temporal consistency of the policy mix, and the commitment from political leadership, followed by the consistency of the instrument mix and the support level of policy instruments (Bödeker, Rogge 2014).

We argue that the credibility of the policy mix may play an important role in the achievement of policy objectives and thus in determining the effectiveness of the mix (Gilardi 2002; Majone 1997).

2.3.3.4. Comprehensiveness

The *comprehensiveness* of the policy mix captures how extensive and exhaustive its elements are and the degree to which its processes are based on extensive decision-making (Atuahene-Gima, Murray 2004; Miller 2008).

That is, comprehensiveness of the elements of the policy mix implies that the policy mix is constituted of both a policy strategy with its objectives and principal plans and at least one instrument in the instrument mix operationalizing the policy strategy. The comprehensiveness of this instrument mix is determined by the degree to which the instrument mix addresses all market, system and institutional failures, including barriers and bottlenecks (Lehmann 2012; Sorrell 2004; Sovacool 2009; Weber, Rohracher 2012). As such, a comprehensive instrument mix may address all three instrument purposes of technology-push, demand-pull and systemic concerns.

By contrast, the comprehensiveness of policy processes can be influenced by their structure, rigor and thoroughness (Atuahene-Gima, Murray 2004). As with the other characteristics, the comprehensiveness of a policy mix may impact its performance regarding standard assessment criteria.

2.3.4. Dimensions

All three building blocks of the policy mix concept can be specified along a number of dimensions, including the policy field, governance level, geography, and time. These dimensions capture the space in which interactions can occur (Flanagan et al. 2011) by pointing to the origin of the different components of the policy mix.

The first dimension *policy field* refers to the policy domain, such as energy, environmental, climate, innovation, technology, science, industrial and transition policy (van den Bergh et al. 2007). For instance, a policy strategy aiming at the promotion of renewable power generation technologies does not have to originate from the field of climate or energy policy but instead could be based on industrial policy, e.g. depending on the national circumstances. Analyzing policy mixes across policy fields matters because internal and external inconsistencies and incoherencies within and across policy fields could render these mixes ineffective (Huttunen et al. 2014).

For the second dimension *governance level* we focus on the distinction between vertical and horizontal governance, a distinction typically made in studies on policy coherence and consistency (Carbone 2008; den Hertog et al. 2004; Pal 2006). The vertical level differentiates, for example, between the EU and its member states as well as between international, federal or local levels. It further distinguishes between government departments and implementing agencies. For example, in the first and second EU ETS trading phase, policy making has occurred both at the level of the EU and the member states, while its implementation has predominantly taken place at the member state level. In contrast, the horizontal level allows for differentiating between different political or administrative entities at the same vertical governance level, such as federal departments of different policy fields. An example is the German Energiewende, in which six federal departments have been involved.

Third, closely related to this abstract space of governance level is the *geography* dimension, constituting the space from which the policy mix originates. The inclusion of this dimension is in line with the increasing attention to the geographical perspective in transition studies (Coenen et al. 2012; Raven et al. 2012; Späth, Rohracher 2012). An example of this is a regional policy strategy and instruments targeted towards a certain geographical region (Navarro et al. 2014), such as funding initiatives of specific cities or regions aiming at promoting green industrial clusters.

Finally, *time* is another crucial dimension in the policy mix concept, capturing its dynamic nature. That is, a policy mix develops over time in terms of its elements, processes and characteristics. First, the *elements* of the policy mix change over time, which we illustrate using the example of the evolution of the elements of the German policy mix for renewable energies from 2000-2013. As can be seen in Figure 2 particularly the instrument mix has changed over the years, with new instruments having been added, existing ones amended but only few ones terminated. Policy instruments may not only change in terms of their contents, ideally resulting in continuous improvement (Kivimaa 2007), but also in terms of their effects as they are interpreted against changing rationales (Flanagan et al. 2011) and changing contexts. Similarly and resulting from changing instruments, interactions are not stable over time either, which may cause the instrument mix to drift out of alignment (IEA 2011b; Sorrell et al. 2003). Second, policy *processes* may also change over time (Flanagan et al. 2011). For example, adaptive policy making allows for adjusting the policy mix as "the world changes and new information becomes available" (Walker et al. 2001, p.283)., thereby enabling policy learning for transitions (Loorbach 2007; Rotmans et al. 2001). Finally, *characteristics* can change over time. For example, the adherence to long-term targets beyond electoral cycles and thus the stability of targets may be one factor influencing policy mix credibility. Also, large unexpected changes in policy instruments may lead to temporal inconsistency of the instrument mix and thus to a loss of credibility (White et al. 2013). Another example concerns increases of coherence due to a move away from unscheduled ad-hoc changes to advanced planning, prior announcements and stakeholder participation in the light of envisaged changes to the policy mix.

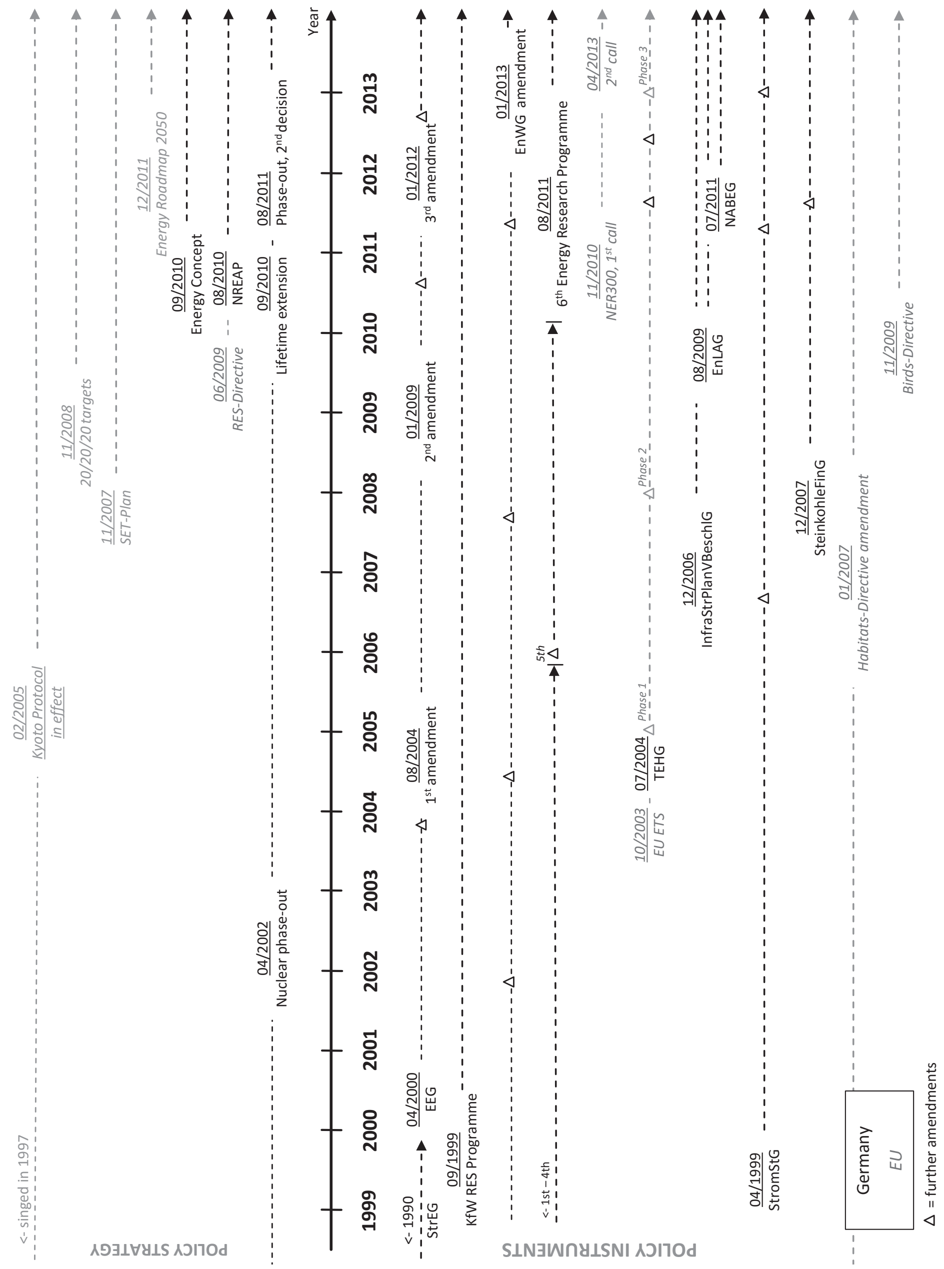

FIGURE 2: Development of the elements of the policy mix for renewable energies in Germany over time[19]

19 See Appendix 2 for an explanation of the depicted elements of the policy mix (policy strategy and instrument mix).

2.3.5. Synopsis

Having introduced the three building blocks and the dimensions, we now integrate them into an extended policy mix concept (see Figure 3).

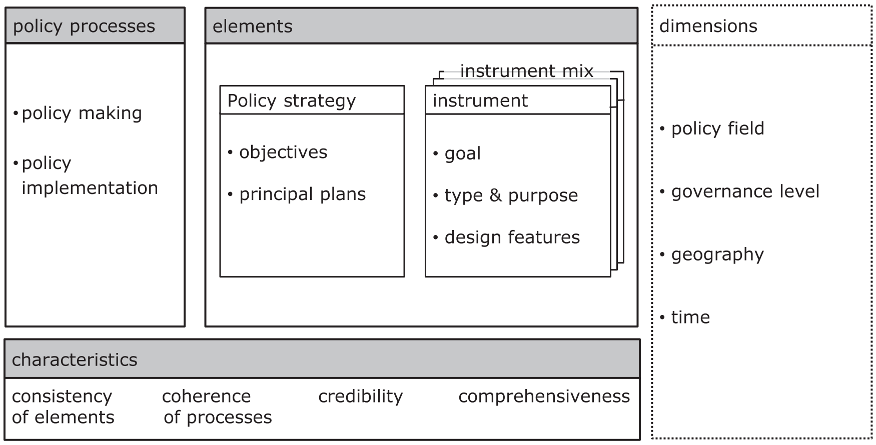

FIGURE 3: Building blocks of the extended policy mix concept

First, the *elements (E)* are at the core of the policy mix concept and refer to the content of the policy mix, including (i) the instrument mix – with interacting policy instruments characterized by their goals, type and design features – and (ii) the policy strategy – with its objectives (including long-term targets) and principal plans (section 2.3.1).

Second, in incorporating the *policy processes (P)* of policy making and implementation the concept includes political problem-solving processes among constrained social actors in the search for solutions to societal problems (section 2.3.2). These policy processes determine the policy mix elements.

Third, overarching *characteristics (C)* describe the policy mix. While consistency refers to the alignment of the elements of the policy mix, the term coherence relates to synergic and systematic policy processes. In addition, credibility captures the extent to which the policy mix is believable and reliable, while comprehensiveness describes how extensive and exhaustive it is. These policy mix characteristics may be important determinants for the performance of the policy mix regarding standard assessment criteria, such as its effectiveness.

Finally, the dimensions (D) can serve to specify the elements, processes and characteristics of a policy mix. For example, a study could consider the temporal consistency of the policy mix (D: time) or its horizontal coherence (D: governance level).

2.4. Application of the policy mix concept

2.4.1. Towards an analytical framework for evaluating policy mixes

The main intention of this paper is to derive a policy mix concept that serves as interdisciplinary analytical framework for studying the link between policy and technological change in the context of sustainability transitions. In the following we therefore outline how the three building blocks of the policy mix concept relate to each other and, based on this, derive key implications for how the concept can be used for evaluating policy mix impacts on technological change. Figure 4 illustrates these linkages with numbered arrows.

For redirecting and accelerating technological change towards sustainability objectives not only the instrument mix with its interacting instruments (1) but also the policy strategy (2) is important to consider. That is, their impact on technological change is likely to be a joint one due to the combined effect of the elements of a policy mix (3). While the policy strategy, such as the EU 2020 climate and energy targets, may provide some long-term orientation it is how such targets are translated into concrete instruments – at potentially different governance levels – which may ultimately help to explain the redirection and acceleration of technological change (Reichardt, Rogge 2014).

In addition, policy mix analysis should go beyond analyzing how these elements of the policy mix come about and why they change (4) but should also investigate how the resulting strategies and/or instruments impact technological change (4+3). Such a combined analysis of policy processes and elements enables highlighting the impact of politics and power not only on targets and instruments but also on innovation. By considering the political realities such an integrated impact analysis may also enable more realistic policy recommendations.

A closer look at the processes of policy making and implementation may even reveal a direct link between such policy processes and technological change (5). We indicate the bi-directionality of this link between technological change and policy making using a double-sided arrow. That is, the innovation impact of policy mixes can have repercussions for the evolution of the policy mix as it may have to be adjusted due to technological developments (Hoppmann et al. 2014). Such patterns of the co-evolution of the policy mix and technological change can only be revealed through dynamic analyses, for example regarding the joint development of technological innovation systems and policy mixes for emerging green technologies (Reichardt et al. 2016).

Finally, policy mix characteristics may be crucial for assessing the effectiveness of policy mixes in redirecting and accelerating technological change. The extent to which the proposed characteristics are relevant in this regard needs to be uncovered (6). Such an analysis requires a detailed understanding of policy mix elements (7) and policy processes (8) as these may determine policy mix characteristics. For example, a stable and ambitious policy strategy backed up by attractive demand-pull instruments may signal a strong political will and hence lead to high credibility. Similarly, controversial public debates and political discussions may lower such credibility. In this context research should also investigate the interplay between different characteristics, such as between the consistency of the policy mix and its credibility.

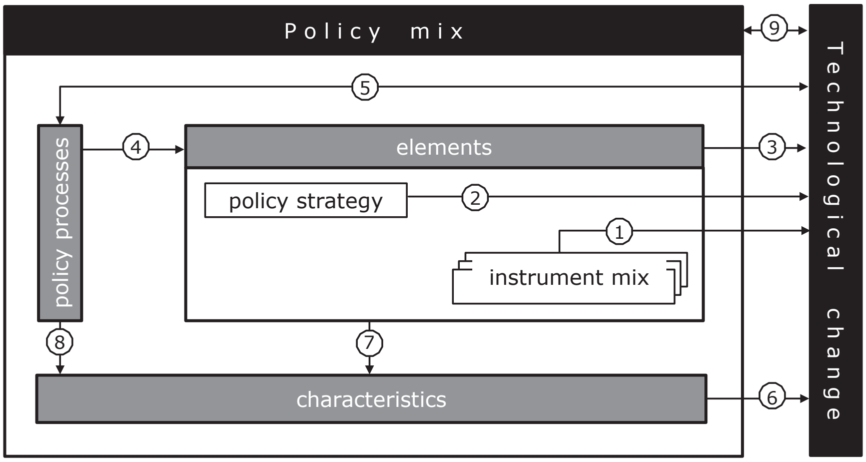

FIGURE 4: Framework for analyzing the link between the policy mix and technological change

In conclusion, such extended policy mix analysis may significantly enhance our understanding of the complex link between policy and technological change and their co-evolution (9). For this, studies can attempt to capture the complex interplay in a comprehensive manner (Bödeker, Rogge 2014), but can also reduce the complexity by focusing on just some of the linkages. Meta-studies can then utilize the policy mix concept as integrating analytical framework to synthesize these partial contributions to further advance our understanding of how technological change can be redirected and accelerated towards sustainability objectives. Thereby, this line of policy mix research – which includes but also goes well beyond the analysis of instrument interactions – may generate an improved basis for more nuanced policy recommendations aimed at redirecting and accelerating technological change as key requirement of sustainability transitions.

2.4.2. Challenges of empirical policy mix analyses

Applying the extended policy mix concept as analytical framework for investigating the link between real-world policy mixes and technological change poses several practical challenges for policy analysts. In the following we discuss two key challenges, namely boundary setting (section 2.4.2.1) and operationalization (section 2.4.2.2).

2.4.2.1. Boundary setting

One key challenge of any policy mix study concerns the task of setting its boundaries, thereby determining the complexity of the studied policy mix as well as its observable impact. As usual, such boundary setting is dependent on the concrete research question and research case, and therefore the boundaries of different policy mix studies can vary substantially. In the following we will discuss boundary setting in terms of the policy mix to be studied – its scope – and in terms of the analysis of the impact of the policy mix – the study's unit of analysis.

Regarding the *scope of the policy mix* analysts have to decide whether it is sufficient to focus on the policy mix creating the protected space for an emerging sustainable technology or whether they also need to pay attention to the policy mix of the encompassing regime, including, for example, subsidies for competing technologies[20]. In line with Kivimaa and Kern (2016) we suggest that research on policy mixes for sustainability transitions should include the latter, thereby calling for greater attention to policies (de)stabilizing unsustainable regimes, such as, for example the existence and stringency of political carbon constraints. In addition, researchers need to decide whether they only provide a static snapshot of a policy mix at a given point in time, or offer a dynamic perspective by capturing its development over time (see below).

Of course, the specification of the system boundaries in terms of the scope of the policy mix to be studied also determines the alleged feasibility of achieving policy mix consistency and coherence. For example, a study of the policy mix regarding renewable energies could focus on the niche for one specific technology (e.g. wind), widen its scope to all renewable energy technologies or assume a holistic energy sector perspective. Given conflicting interests and tensions between niches (e.g. onshore wind vs. offshore wind vs. solar PV) and regimes (e.g. renewable energies vs. fossil fuels), the wider the boundaries are set and thus the greater the scope of the policy mix, the greater the challenges for consistency and coherence, as indicated by the arrow in Figure 5 However, widening the system boundaries may allow for a more holistic perspective of the problem – both in terms of policies and politics – and may thereby enable a better achievement of policy objectives.[21]

Apart from the scope of the policy mix to be studied researchers also need to decide on the appropriate boundaries for the analysis of the impact of the policy mix on technological change, i.e. on the *unit of analysis*. Such a decision should be based on a detailed understanding of the relevant innovation system for the technology or sector in question, including, among others, its past development and the current techno-economic maturity of the technology, the sectoral pattern of innovation and the relevant

20 For example, Quitzow (2015) analyzes the technology-specific policy mix for solar PV in India.

21 For example, a recent study on aligning policies for a low-carbon economy included, among others, not only climate and innovation policies but also tax and trade policies (OECD/IEA/NEA/ITF 2015).

actors and networks (Hekkert et al. 2007; Malerba 2004; Pavitt 1984). For example, a study on the policy mix for renewable power generation technologies should expect a supplier-dominated pattern of innovation and thus include technology providers and their innovation activities in the analysis (Rogge et al. 2011c). Another example concerns the relevant actors (e.g. authorities, companies, consumers) and their networks (e.g. industry associations and non-governmental organizations) to be included in the analysis of policy processes (Markard et al. 2015). One possible criterion for their inclusion or exclusion may be their degree of influence and power in decision making. Similarly, researchers need to decide on the geographical confines of the impact analysis. For the example of the German energy transition and the policy mix promoting solar PV the increasingly global innovation system would imply to not only investigate innovation effects within Germany, but also the interplay with the resulting technological and structural change in foreign countries, such as in China (Quitzow 2015b). A final example concerns the timing of the impact, with today's policy mix determining tomorrow's technological change, which in turn may have repercussions for future changes in the policy mix. This co-evolution of impacts and policy mix can only be unpacked by a dynamic analysis covering decades rather than years, while a static analysis of a certain year provides in-depth insights into the current link between the policy mix and technological change.

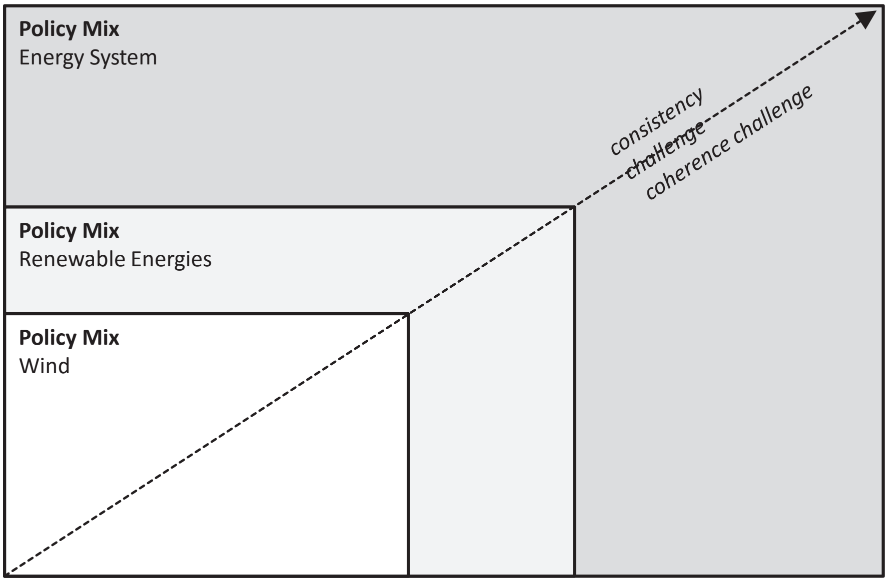

FIGURE 5: Link between policy mix boundaries and consistency/coherence

To conclude, boundary setting is by no means a straightforward exercise, and the initially set boundaries may change as the analysis proceeds. Given its analytical consequences, boundary setting should be seen as an important iterative task, which requires continuous attention.

2.4.2.2. Operationalizing the policy mix

After an initial delineation of the scope of the policy mix under study a second key challenge concerns the capturing of the relevant real-world policy mix.

The operationalization of the *instrument mix* requires the identification of key instruments and their design features. As starting point research can draw on data bases of policy instruments, such as the IEA policies and measures data bases for renewable energies or energy efficiency (IEA 2012). Analysts may also refer to the original laws, acts, governmental strategies and other public documents, particularly for extracting information on the design features of selected instruments. One example is the German Renewable Energy Sources Act (EEG) as core instrument of the *Energiewende*, which, among others, established technology-specific feed-in tariffs. These provide one proxy for the level of support, which – due to several regular and irregular amendments – have changed over time. Another example concerns the EU Emission Trading System (EU ETS) whose stringency can be operationalized, for example, by tracking carbon prices published by the relevant stock exchanges.[22] Often, however, the specification of design features will not be as straightforward but require further analysis, as these cannot always be directly derived from publicly available documents and data bases. Further analysis may also be needed for identifying instrument interactions. For example, in order to study interactions between technology push and systemic instruments public R&D funding needs to be separated into these two categories, as done by Cantner et al. (2016) for the case of public R&D funding for wind and solar PV in Germany.

Apart from capturing the relevant instrument mix our extended policy mix concept points to the need to also consider the *policy strategy*, and thus long-term targets and principal plans. Targets can be operationalized based on figures included in strategic policy documents. For example, in terms of the German energy transition these data could be extracted from the German Monitoring reports published on a yearly basis (BMWi 2015). Such quantitative targets could then, for example, be integrated in a policy mix index, as was done by Hess and Mai (2014) who developed a policy mix index including not only feed-in tariffs and emissions trading but also renewable electricity targets as part of Asian countries' policy strategies. Of course, dynamic analysis will need to pay attention to changes in long-term targets over time, such as an increase or decrease in ambition levels. In contrast to the fairly straightforward measurement of long-term targets, the details typically included in the associated principal plans are likely more difficult to be operationalized and made comparable across countries, and may thus require more sophisticated analysis but also major simplifications. One avenue may be obtaining expert judgments on the quality of a given principal plan, e.g. in terms of its credibility or comprehensiveness (see below).

22 Botta and Kozluk (2014) provide an example of available options and difficulties for operationalizing the stringency of environmental policy across OECD countries.

For the analysis of *policy processes* researchers can draw on the standard methods and variables for operationalizing these processes used within the study of public policy (Howlett et al. 2009; Sabatier, Weible 2014). Operationalizing them could, among others, draw on a content analysis of media coverage and could be further supplemented by interviews with involved policy makers and other stakeholders. By doing so, analysts could track, for example, the debate about the suggested retrospective adjustment of previously guaranteed feed-in tariffs received by plant operators in Germany initiated by the Federal Minister of the Environment at the beginning of 2013 (Spiegel Online 2013a). This would allow for analyzing, among others, whether this heavily debated and later withdrawn suggestion had a detrimental effect on innovation, e.g. by casting doubt on the predictability of the EEG and the credibility of the policy strategy (Spiegel Online 2013c), thereby enabling insights on the direct link between policy processes and technological change.

This leads us to the need for operationalizing policy mix *characteristics*, such as the above mentioned credibility, which may pose one of the greatest analytical challenge as official databases or documents typically do not capture such characteristics. Rather, their operationalization may require original data collection and interpretation. Two main routes for capturing policy mix characteristics may exist: the first one is the derivation of these characteristics from the analysis of policy mix elements; the second one pursues the collection of perceptions of innovators or other stakeholders regarding these characteristics. An example for the former is the observation of renewable energies having come under the auspices of the German environmental department in October 2002 (BMU 2013). This structural change could be interpreted as increase of the coherence of policy making as it may, for example, have eased the integrated consideration of demand-pull, technology-push and some of the systemic concerns relevant for the transition to renewable energies. An example for the latter is the conduction of a survey asking companies about their judgment on the credibility of the *Energiewende* policy mix.[23] Such direct questions appear particularly suitable for eliciting innovators' perceptions on the current level of credibility, whereas changes of these perceptions over time may be more difficult to capture, unless such surveys are regularly repeated.[24]

Overall, this implies that studies applying the extended policy mix concept are likely to require the development, testing and further refinement of novel ways of operationalizing relevant policy mix components. Only then will future policy mix research be able to provide answers to the questions raised by the analytical framework proposed in this paper (see section 2.4.1).

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23 A possible question for the case of the German *Energiewende* could, for example, ask respondents for their opinion regarding a number of statements on the policy mix for renewable energies in Germany, such as regarding the existence of a broad consensus across all political parties, the clarity of the political vision, the stability of the political will or the unambiguity of political signals – measured, e.g. with a Likert scale ranging from "very low" to "very high".

24 Besides the importance of analyzing policy mixes and their impacts, detailed policy instrument evaluations remain indispensable as well.

2.5. Conclusion

This paper on policy mixes for sustainability transitions contributes to the literature on the link between policy and technological change in two major ways. First, it advocates an *extended concept* of the policy mix that takes into account the complexity and dynamics of real-world policy mixes and provides a uniform terminology applicable across academic disciplines, thereby enabling interdisciplinary research. Specifically, the concept stresses that a policy mix goes beyond the combination of interacting instruments – the instrument mix – but also includes a policy strategy, policy processes and characteristics. Second, the paper provides an *integrating analytical framework* which may aid empirical research by pointing to previously neglected aspects to be considered in empirical policy mix studies. Such studies are faced with multiple analytical challenges, among them the setting of the boundaries for the considered policy mix and its impact, for which the paper proposes some analytical guidelines. Thereby, the paper aims to pave the way for increasing our insights on the role of policy mixes for sustainability transitions.

We derive three main policy implications. First, the paper underlines the importance of *thinking in terms of policy mixes* for redirecting and accelerating technological change towards sustainability objectives, and it provides an analytical framework helpful in assuming such a broader and systematic perspective. More precisely, it highlights the need for policy makers to consider instrument mixes and instrument interactions along with the policy strategy with its long-term orientation as equally important elements of a policy mix. It also stresses that policy processes may directly influence innovation and emphasizes the relevance of characteristics such as credibility.

Second, policy makers are advised to work on *improving both the consistency of the elements of the policy mix and the coherence of policy processes*. Of course, and particularly in times of fundamental societal transitions, a certain degree of inconsistencies and incoherence may be expected due to the complexities involved in addressing sustainability challenges, conflicting objectives and mutually exclusive interests, for example between niche and regime actors. Yet, given the relevance of consistency and coherence for the performance of policy mixes in terms of assessment criteria, such as its effectiveness in redirecting innovation, policy makers are advised to intentionally and continuously strive for their enhancement.

Third, the paper stresses the necessity to assume a *system perspective in policy making.* For example, an instrument mix should not only address demand pull or technology push instruments but should cover all concerns, including systemic ones. In addition, policy makers should also scan the existing instrument mix for instruments inconsistent with a given policy strategy, including from different policy fields, which therefore may have to be adjusted or phased out. Such an analysis requires systemic capabilities, which could be supported through coherent policy processes and further developed through policy learning.

We see two main limitations of the policy mix concept proposed in this paper. First, since it has been developed for technological change, it may not be directly applicable to non-technological innovations. Second, some of the components of the concept lack well-established indicators, which may complicate their investigation in empirical studies.

In conclusion, this paper calls for unpacking the link between policy mixes and technological change in the context of sustainability transitions, for which we envisage four main areas of future research. First, empirical studies should analyze the interplay within and between the three building blocks of the policy mix and how such interplay affects the effectiveness of policy mixes in redirecting and accelerating innovation towards sustainability objectives. In doing so, studies will need to find new or improved ways of operationalizing the policy mix. Second, the nature of policy processes – including the underlying politics – and their direct and indirect influence on the performance of policy mixes regarding innovation and sustainability transitions should be explored in more depth. Third, empirical research should investigate the determinants and relevance of policy mix characteristics, such as credibility, for innovation. Finally, the integration of the policy mix concept with other research approaches, such as the technological innovation system approach, may further sharpen the analytical clarity and policy advice of such approaches in the context of sustainability challenges.

Chapter 3

How the policy mix impacts innovation: findings from company case studies on offshore wind in Germany

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3.1. Introduction

Given the sustainability challenges that face humankind, researchers and policy makers alike have proposed a number of routes leading to a greening of the economy (Grin et al., 2010; UNEP, 2011). One prominent example is the challenge of limiting climate change, calling for a decarbonization of the economy (IPCC, 2013, 2011). In this regard, the transition of the energy system towards renewable power generation technologies plays a key role, requiring the redirection and acceleration of technological change (IEA, 2009; van den Bergh et al., 2011). Policies incentivizing such technological innovation and related cost reductions are crucial – particularly for emerging renewable energy technologies (del Río, 2012; IEA, 2008b).

Research analyzing the link between policies and innovation in environmental technologies has thus far mostly focused on the innovation impact of single policy instruments (Kemp and Pontoglio, 2011). These studies can be differentiated into those analyzing the innovation impact of the instrument type (e.g. Hoppmann et al., 2013; Rennings et al., 2008) and of instruments' design features (del Río, 2012; Hascic et al., 2009). Some recent studies go beyond such a focus on instruments by considering the effects of particular policy mix aspects, such as policy coherence and long-term targets (Huttunen et al., 2014; Schmidt et al., 2012). Studies at a system level analyze the impact of policies on the performance of technological innovation systems (TIS) for selected renewable energy technologies (Foxon et al., 2005; McDowall et al., 2013). However, most of these studies either only account for policy instruments or, if they consider other policy aspects, this rarely follows a comprehensive policy mix approach.

Yet, in the broader climate and energy policy as well as innovation policy literature increasing attention is paid on the importance of analyzing policy mixes (Matthes, 2010; Nauwelaers et al., 2009; Rogge and Reichardt, 2015, 2013[25]). The rationale behind this is the multiple market, system and institutional failures in place requiring multi-faceted policy intervention (IEA, 2011c; Lehmann, 2010a; OECD, 2007). In addition, policy mix concepts help to better capture the complex multi-level and multi-actor realities of 'real-world' policy mixes and their changes over time (Flanagan et al., 2011). The strength of using a policy mix concept from the outset of a study lies in its explicit and systematic recognition of aspects exceeding single instruments, such as interactions of instruments, the relevance of a policy strategy with long-term targets, and the importance of overarching policy mix characteristics such as consistency, comprehensiveness, credibility and stability (Boekholt, 2010; del Río, 2012; Flanagan et al., 2011; Rogge and Reichardt, 2015).

25 Rogge and Reichardt (2015) represents an updated and shortened version of their 2013 working paper, the 2013 version including – among others – a comprehensive annex with overviews of definitions used across different studies for defining policy mixes and their components.

However, there is a lack of empirical studies of the innovation effects of policies that use a comprehensive policy mix concept as starting point for their analyses. In this paper we take a first step in this direction by analyzing how a policy mix impacts corporate innovation activities regarding emerging renewable energy technologies, including both research, development and demonstration (RD&D) and adoption. In doing so we consider both elements and the so far understudied characteristics of the policy mix, as specified by Rogge and Reichardt (2015). That is, in our analysis we include the policy strategy with its long-term targets, interacting instruments and the consistency, credibility, comprehensiveness and stability of the policy mix (for definitions see section 3.2). While we acknowledge that these elements and characteristics are shaped by policy making and implementation processes, which can also have a direct effect on innovation, we do not explicitly include policy processes in our analysis since this would exceed the scope of this paper. Instead we put a particular focus on the consistency of the elements of a policy mix and for this build upon studies analyzing interactions between policy instruments (del Río, 2010). However, we extend these by considering the absence of contradictions and the existence of synergies at three levels: first, within the policy strategy, second, within the instrument mix, and third, between policy strategy and instrument mix. Following the literature on the determinants of eco-innovation we also consider the innovation impact of other firm-external and firm-internal factors (del Río González, 2009; Frondel et al., 2008). Overall our analysis enables a better understanding of the role of real policy mixes for innovation, thereby going beyond the existing literature on the innovation impact of single policy instruments. Based on this we derive policy recommendations providing more differentiated advice to policy makers.

To explore how policy mixes affect innovation, we study the case of offshore wind in Germany for two main reasons: First, the policy mix for offshore wind in Germany – which also encompasses some relevant EU policy mix components – represents a rich empirical case in which an ambitious long-term target and a complex instrument mix with apparent inconsistencies are present (BMWi and BMU, 2010). However, despite being the only renewable power generation technology in Germany with an explicit policy strategy and corresponding high political commitment backing it up, the actual diffusion of the technology is lagging behind, suggesting there may be important lessons to be learned for policy mix design. Second, given the large technological potentials of offshore wind (Roland Berger Strategy Consultants, 2013) and the increasing global interest in making it a key element of countries' energy transition plans (EWEA, 2011a), a more thorough and systematic understanding of how to support this emerging technology is of great interest to policy makers around the world. In order to understand how the policy mix has impacted innovation in this emerging technology, we choose firms as our unit of analysis and apply a qualitative case study approach. Our main data source are interviews with several power generators and technology providers active in the German offshore wind market, supplemented with secondary data, such as company reports and public statistics. The remainder of the paper is structured as follows: we first explain the research framework (section 3.2) before turning to a description of the research case (section 3.3) and methodology (section 3.4). Section 3.5 presents the main findings for firms' innovation activities regarding adoption and RD&D. Finally, in section 3.6 we discuss some major findings and derive implications for policy makers.

3.2. Research framework

The literature that discusses factors driving environmental technological change considers a variety of innovation determinants, with environmental policy featuring as a key determinant (del Río González, 2009). For instance, environmental policy and its stringency have been shown to be highly influential for innovation (Frondel et al., 2008; Taylor et al., 2005). Our paper contributes to this literature by studying how a broader policy mix impacts environmental innovation at a firm level. Based on the Oslo Manual (OECD, 2005) and in line with Rogge et al. (2011), we define these corporate innovation activities as consisting of adoption as well as research, development and demonstration (RD&D). That is, by adoption we refer to firms' investments in new or significantly improved technologies, and by RD&D we mean basic laboratory research, testing of the new technology in small-scale pilot projects and demonstrating its functioning by initially implementing it at a larger scale.

In contrast to many earlier studies, our policy variable does not consist of single policy instruments or specific design features only, but applies the policy mix concept proposed by Rogge and Reichardt (2015) as an analytical framework for a more comprehensive policy analysis. Figure 6 shows a representation of this concept comprising elements and overarching policy mix characteristics.

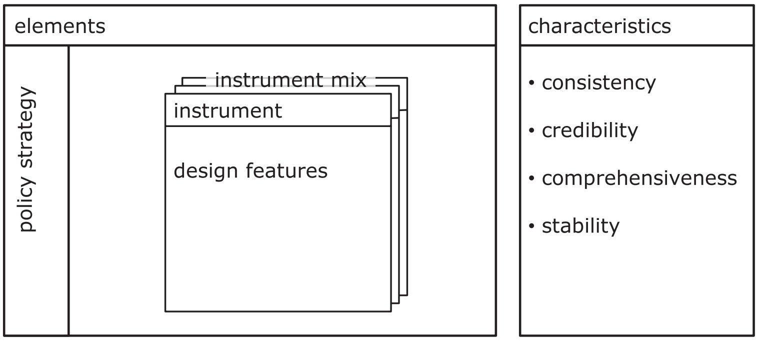

FIGURE 6: Policy mix concept applied in this study (adapted from Rogge and Reichardt (2015))

Elements include the policy strategy and instrument mix. The policy strategy refers to policy objectives and principal plans to achieve these, while the instrument mix is the combination of interacting policy instruments characterized by their design features, such as the level of support. *Characteristics* describe the nature of a policy mix and may also be important determinants for policy mix performance. They may include consistency, credibility, comprehensiveness and stability. Consistency captures the alignment of policy mix elements with each other and as such contributes to achieving policy objectives. It thus comprises three levels: First-level consistency refers to the consistency of the policy strategy, second-level consistency means consistency of the instrument mix according to the nature of the instruments' interactions, and third-level consistency refers to the consistency of the policy strategy with the instrument mix. Credibility captures how believable and reliable the policy mix is, while comprehensiveness addresses how extensive and exhaustive the policy mix elements are. Finally, stability describes the long-term certainty of the policy mix.[26]

Apart from policy as one innovation determinant several other firm-external and firm-internal factors have been included in the literature, with varying effects and importance for innovation (Horbach et al., 2012). For instance, Horbach et al. (2012) conclude that different types of eco-innovation are driven by different factors which are, however, mostly firm-external, such as current and expected regulation or prices of energy and raw materials. Therefore, while focusing on the link between the policy mix and innovation, we also account for other firm-external and firm-internal innovation determinants (Rehfeld et al., 2007), namely context factors and firm characteristics.

For context factors, following other studies we distinguish between market factors, technology characteristics and public acceptance (Rogge et al., 2011; Schmidt et al., 2012). Market factors comprise, for instance, supply and demand for resources, components and products and their prices, as well as market structure (del Río González, 2005; Kesidou and Demirel, 2012)on the other hand, underlines other important determinants of eco-innovations, mainly the supply-side factors such as firms\u2019 organisational capabilities and demand-side mechanisms, such as customer requirements and societal requirements on corporate social responsibility (CSR. Furthermore, we include technology characteristics to capture the variation of techno-economic features across technologies. Examples include a technology's scale, state of development and thus its maturity, and competitiveness, or its location and necessary enabling infrastructures (del Río González, 2009, 2005). We also incorporate public acceptance as a context factor (Schmidt et al., 2012), thereby considering the perception of the technology by society and through this its perceived legitimacy (Hekkert et al., 2007). For example, public resistance could arise owing to financial burdens imposed on consumers or taxpayers due to initial high costs or potentially negative environmental impacts associated with a technology (O'Keeffe and Haggett, 2012).

As for firm characteristics, following the literature we include four such characteristics in our research framework (del Río González, 2009; Schmidt et al., 2012). A firm's technology

26 These definitions follow Rogge and Reichardt (2015) with the exception of stability, which was only included in Rogge and Reichardt (2013).

portfolio, which reflects its technological capabilities, can play a role in whether a firm becomes active in a new technology or not (Christensen and Rosenbloom, 1995). A firm's strategy "defines the range of business the company is to pursue" (Andrews, 1987, p. 13) and might thus play a crucial role in guiding its innovation activities. The value chain position can influence the kind of innovation activities a firm carries out, e.g. if it conducts more RD&D or rather adopts a new technology (Mazzanti and Zoboli, 2006; Taylor, 2008). Finally, the size of a firm has been shown to affect the direction and rate of its innovation activities, although with ambiguous findings (Acs and Audretsch, 1988; Shefer and Frenkel, 2005).

Figure 7 summarizes our research framework, indicating the main link between the policy mix and corporate innovation by the thick grey arrow.[27]

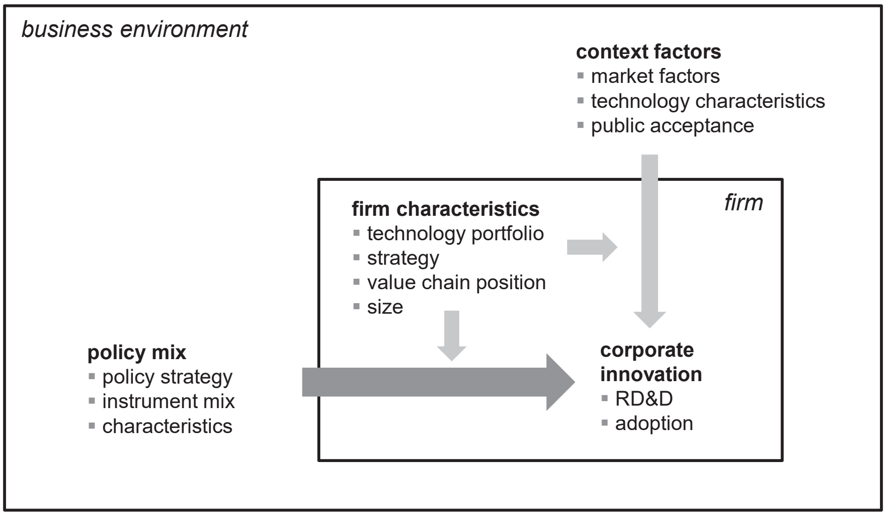

FIGURE 7: Research framework for studying the role of the policy mix for corporate innovation

3.3. Research case

As a research case we chose offshore wind in Germany for its multi-faceted policy mix with an ambitious policy strategy and relatively complex instrument mix. Such a policy mix provides a particularly useful example for empirically studying its impact on innovation. In addition, existing studies on offshore wind do not treat the policy mix in a systematic fashion, but either focus on costs and the investment environment in general (Praessler and Schaechtele, 2012; van der Zwaan et al., 2012) or on specific aspects of the policy framework, such as support schemes and planning tools (Green and Vasilakos, 2011; Smit et al., 2007).

27 This figure only depicts those links our study focuses upon. However, there may also be other possible relationships, such as effects between context factors and the policy mix. Note that the down left corner of the figure refers to the policy mix concept as depicted in Figure 6.

The boundaries we set for our research are summarized in Table 5. For instance, we focus on the policy mix relevant for offshore wind (technology) in Germany (geography), containing both national and relevant EU policy mix components (governance level; see Table 7). Furthermore, we analyze policy mix effects on corporate innovation focusing on the period between 2011 and 2013 (time).

TABLE 5: Boundaries of our empirical policy mix study

Dimension	Specification for our study of offshore wind in Germany
Policy field	Energy, climate, RD&D
Geography	Germany
Governance level	National, EU
Technology	Offshore wind
Sector	Power
Innovation phase	RD&D, adoption
Actor	Firms (technology providers, firm characteristics)
Value chain	Turbine development & manufacturing, power generation
Time	2011-2013

Source: Own elaboration (following dimensions proposed in Rogge and Reichardt (2015)

3.3.1. The offshore wind technology

Offshore wind is a technology with large potential. Higher and steadier energy yields offshore, i.e. up to 4,000 full load hours per year compared to 2,000-2,500 full-load hours onshore (EWEA, 2009a), and limited potential for onshore growth in Europe are important reasons for its great growth prospects (Praessler and Schaechtele, 2012)[28]. However, the technology is also confronted with difficulties. One is that offshore wind faces more challenging conditions than its onshore counterpart (IEA, 2009). For example, the marine environment with its salt water and higher wind speeds intensifies corrosion and puts higher demands on turbine materials. Thus, in view of the relatively low capacities currently installed in the EU and Germany compared to their ambitious 2020 targets (see Table 6), offshore wind is still rather immature (EWEA, 2011a). Relatedly, offshore wind costs to date are comparatively high, ranging between 12.8 and 14.2 ct/ kWh in Germany (Fichtner and Prognos, 2013). However, costs are expected to fall to 9 ct/ kWh by 2020 (see Table 6). The offshore wind cost structure is more evenly spread across the supply chain than onshore costs, with the turbine still representing the biggest share. Key savings can be achieved not only by utilizing bigger turbines but also through improved foundation concepts, economies of scale in foundation production, and more mature operation and maintenance concepts (Roland Berger Strategy Consultants, 2013).

28 Until 2030, between 12% and 17% of EU electricity consumption is predicted to come from offshore wind (EWEA, 2009a).

TABLE 6: Installed capacity and electricity production costs of offshore wind

		2012	2020 (planned)
Installed capacity (in GW)	EU	5.3	40
	Germany	0.28	10
Electricity production costs (ct/ kWh)	Global average	11-18	9

Source: Own compilation based on EWEA (2011), Fichtner & Prognos (2013), Roland Berger (2013)

Despite these challenges, an attractive German offshore wind market has emerged and is set to become one of the largest ones in Europe, with about nine GW of capacity being installed or in the pipeline (Fraunhofer IWES, 2012). The number of industry players along the whole value chain that have entered this market illustrates its attractiveness; they range from operators of offshore wind ports to service providers for operation and maintenance of farms (KPMG, 2010). On the supply side, technology providers that construct offshore wind turbines represent a central actor, with currently four (mostly German) firms active in the German market (see appendix 3.1(1)). On the demand side, farm owners exhibit a high diversity with a multitude of heterogeneous, predominantly German players (see appendix 3.1(2)). In terms of capacity installed, large incumbents currently dominate the German market.

3.3.2. The policy mix for offshore wind in Germany

The German market is governed by a policy mix that has thus far reflected a strong political will to promote offshore wind. Table 7 gives an overview of the main components of this mix, including the policy strategy with its objectives and principal plans and the instrument mix with demand pull, technology push and systemic instruments, both at an EU and the German national level. In the following, we highlight the most important elements of this policy mix for offshore wind.

Probably the most relevant component of the policy strategy is the German long-term target for offshore wind, an objective which aims at 10 GW of installed capacity by 2020 and 25 GW by 2030 (Bundesregierung, 2002). The core instrument of the instrument mix has been the demand pull instrument Renewable Energy Sources Act (EEG). This law specifies the levels of offshore wind-specific feed-in tariffs (FIT) (see below). Another central instrument is the Energy Economy Law (EnWG), a systemic instrument which regulates the grid access for offshore wind farms. The demand pull instrument KfW Offshore Wind Program, which grants loans at market conditions for early offshore wind farms, and technology push instruments in the form of several RD&D support programs supplement the instrument mix.

One core instrument of the offshore wind policy mix is the EEG, which has been in place since 2000 and has been amended several times. The EEG version from 2012 – effective during the time of our interviews – lets investors choose between an initial remuneration of 15 ct/ kWh for twelve years and 19 ct/ kWh for eight years (compression model). These and further design features of the offshore wind feed-in tariff are depicted in Table 8. It is interesting to note that installations in nature conservation areas have been excluded from these tariffs since 2004.

TABLE 7: Key policy mix elements for offshore wind in Germany as of 2013 (differentiated by governance level EU vs. Germany (DE))

			EU	DE
POLICY STRATEGY	**Objectives (Long-term targets)**	**Offshore wind**	No technology-specific target[29]	By 2020: 10 GW capacity By 2030: 25 GW capacity
		Renewables	20% renewables in energy consumption by 2020	18% renewables in energy consumption by 2020
			Renewables Directive (DIR 2009/28/EC)	
		Climate	20% GHG emissions reduction by 2020*	30-40% GHG emissions reduction by 2020*
	Principal plans		Energy Roadmap 2050	Energy Concept
			Strategic Energy Technology (SET) Plan	National Renewable Energy Action Plan (NREAP)
INSTRUMENT MIX	**Demand pull**		EU Emission Trading System (EU ETS)	Renewable Energy Sources Act (EEG)
				KfW Offshore Wind Program
	Technology push		New Entrants' Reserve (NER 300)	RD&D support programs
			European Energy Program for Recovery (EEPR)	
	Systemic			Energy Economy Law (EnWG)

Source: own compilation; * compared to 1990 levels

Another vital instrument is the Energy Economy Law (EnWG), which regulates details of the grid connection and operation for offshore wind farms and – most importantly – since 2006 has obliged transmission system operators (TSOs) to build and operate the grid connection lines for farms. Several EnWG amendments have been implemented, the latest one in 2012 addressing the problem of delayed grid access facing many of the early German farms. It changes the former provision that the grid connection be operation-ready when the farm is ready to operate by newly requiring operators to negotiate a fixed date for this with the TSO. This date becomes mandatory 30 months before its expiry. If the TSO then cannot adhere to it, a liability clause ensures that the farm operator is compensated financially for each day the farm stands idle and thus cannot feed in electricity. In addition, the EnWG 2012 obliges TSOs to put forward a yearly offshore grid development plan containing details on the location, timing and size of grid connection lines.

29 However, the potential of offshore wind has been estimated to be 40 GW by 2020 (EWEA 2011).

3

TABLE 8: Key design features of the German feed-in tariff for offshore wind (EEG 2012)

Component	Design features
Initial remuneration (since 2009)	15 ct/ kWh, payable for 12 years
Elevated initial remuneration ("compression model", since 2012)	Alternative to initial remuneration for plants starting operation before 2018: 19 ct/ kWh, payable for 8 years
Basic remuneration	3.5 ct/ kWh, payable after initial or elevated remuneration for further 8 or 12 years (until 20 years of FIT are completed)
Remuneration extension (since 2004)	Initial remuneration is extended in time for plants: • > 12 nautical miles from shore: for each full additional nautical mile by 0.5 months • > 20 meters of water depth: for each additional meter by 1.7 months
Degression	Starting in 2018 yearly 7% degression in FIT for plants starting operation in 2013 or later

Source: Own compilation based on EEG (2009, 2012)

3

3.4. Method

To answer our research question, we chose a qualitative research design involving multiple company case studies (George and Bennett, 2005; Gerring, 2007; Yin, 2009). This approach enables an in-depth study of the phenomenon and thorough exploration of its causes and consequences, thereby allowing for detailed insights into how and why the policy mix impacts firms' innovation activities. In addition, it is suitable for research settings in which only few actors are involved and which consequently do not lend themselves to a large-scale survey. In line with similar studies (Hoffmann, 2007; Hoppmann et al., 2013) our focus is on companies since they tend to be key players for innovation and addressees of many policy mix components.

In order to gain a better understanding of the offshore wind sector, we initially performed desktop research analyzing publicly available information such as magazine articles and firm websites (see appendix 3.1). As the policy mix concept by Rogge and Reichardt (2015) has not been empirically applied before, we then conducted exploratory interviews in order to gauge how to best operationalize the concept's key variables. That is, we tested with which vocabulary and questions the policy mix and its components could most appropriately be addressed in interviews with corporate actors. For this purpose we interviewed ten experts of companies involved in offshore wind in Germany between August and October 2011. The result of these interviews with power generators and technology providers was our semi-structured interview guide, which formed the basis for our ensuing case study interviews.

Subsequently, we started our case study research phase in which we studied six companies. We chose our firm sample in such a way as to capture major actors in the value chain who are active both in RD&D and adoption. Hence, we selected turbine technology providers

(TPs) and power generators (PGs) for the following reasons: First, the turbine constitutes the single most costly technology component with the potential for cost reductions from RD&D (see section 3.3.1). Second, power generators have thus far been crucial actors for adoption, currently responsible for constructing and operating the majority of offshore wind farms in Germany (see appendix 3.1). In order to allow for theoretical and literal replication and to ensure external validity, we relied on a theoretical sample which incorporates at least two firms for each of the two firm types (see Table 9). In addition, for PGs we included both large and small companies that construct and / or operate offshore wind farms in Germany.

TABLE 9: Overview of the firm sample and interviews

Category		**Power generators**				**∑**	**Technology providers**		**∑**	**Total**
		A	B	C	D		E	F		
Firm size	Large	x	x			**2**	x		**1**	**3**
	Medium/ small			x	x	**2**		X	**1**	**3**
Interviews	Number	1	1	2	2	**6**	1	2	**3**	**9**
	Interviewee functions	Head energy policy	Head business development	Head energy policy, project manager	Head renewables, member managing board		Head business development	Head OW development, R&D manager		

For the case study data collection we proceeded in three steps. First, to gain deeper insights into the firms in our target group and their offshore wind activities, we conducted background research on them, analyzing their websites, annual reports and press articles in the databases Genios and Lexis Nexis starting in 2005. Second, based on this we tailored the semi-structured interview guide to the specificities of individual firms. That is we included the specific innovation activities of firms in order to be able to address specific innovation projects. As a third step we conducted our main interviews with company representatives between January and March 2013. We chose such a short interview period to control for the fast-changing policy mix for offshore wind, thereby ensuring that within the interview period no major policy mix changes occurred. With the exception of two interviews, these were jointly conducted by two interviewers and lasted around 73 minutes on average. Reflecting our focus on firms' innovation strategies and how they are impacted by the policy mix, we chose as interviewees firm employees with offshore wind expertise who typically held RD&D, strategy or project management functions. Depending on firm organization we thus conducted one to two telephone interviews per company, which were recorded and subsequently transcribed. In the interviews we first explored a firm's innovation activities. We then started our question block on the policy mix with an open question on the effect of the policy mix on innovation, so as to allow the interviewee to mention any target or instrument regardless of policy field or governance level.[30] Only then did we ask about the relevance of specific policy mix components for a firm's innovation activities – with a focus on consistency. Finally, we investigated the importance of context factors and firm characteristics for understanding firms' innovation activities (see appendix 3.2).

We analyzed our case study interviews using the qualitative data analysis software Atlas.ti and proceeded in five steps. First, we developed a code list covering all components of our research framework (as depicted in Figure 7). We refined this list during the coding of the first interviews, which was done by two researchers to control for intercoder reliability. Second, after the code list was finalized and a common understanding of all codes ensured, one researcher coded all interview transcripts according to this list.[31] Third, based on this coding we analyzed the role of the different policy mix components, including the three levels of consistency, for corporate innovation activities. In our search for causal links between the policy mix and innovation, we also explored the role of context factors and firm characteristics for each individual firm and triangulated our interview findings with insights from our background research. Fourth, we compared our findings for single company cases among all power generators – later also proceeding in the same manner for technology providers – thereby looking for common patterns and reasons for differences among firms, such as a firm's size or technology portfolio. For instance, if a firm did not mention a certain policy mix effect, which, however, had been stressed by other firms, we tried to find an explanation based on differences in firm characteristics. Only if such an explanation could be identified did we consider this effect as unambiguous finding. Finally, we contrasted our findings for power generators with those for technology providers, searching for commonalities and differences between these two groups. Emerging patterns were cross-checked with all cases with a view for conflicting evidence, in which case we continued to search for alternative explanations. Based on this procedure we derived the main findings supported by our case studies, i.e. common patterns enabling us to explain the influence of the policy mix on adoption and RD&D activities.

30 Interestingly, despite the open nature of the initial policy mix question respondents did not mention instruments from more general policy fields, such as general tax policies, but rather focused on policy fields directly relevant to offshore wind. This specificity was also the case when discussing perceived inconsistencies in the instrument mix.

31 The initial coding was done by two researchers in an iterative process in which the researchers separately coded an interview passage, then contrasted and compared their coding, and based on this jointly clarified the meaning of each code and refined the code list. This procedure was repeated until a final code list emerged and coding differences were negligible. Therefore, the final coding of the interviews was performed by one researcher only.

3.5. Results

In the following we present our main findings on how corporate adoption and RD&D activities were influenced by the policy mix (sections 3.5.1 and 3.5.2, respectively). We start with the policy mix elements policy strategy and instrument mix and then turn to policy mix characteristics, also considering the interplay of these components. In addition, we point to the influence of the most important context factors and firm characteristics at the end of each subsection. We depict our main results with supporting illustrative interview quotes in Table 10 and Table 11. Each subsection starts with a brief description of the main corporate adoption and RD&D activities that the interviewed firms performed.

3.5.1. Effects on adoption

Power generators in our sample have constructed and operate offshore wind farms in Germany. Their turbines have been developed and sold by technology providers: *"We function essentially as the operator of the farm, responsible for construction and management and the supply of electricity."* (PG)

Our interviews suggest that the **policy strategy** – in terms of the characteristics of the German long-term targets for offshore wind and renewables – played a reinforcing role in power generators' adoption activities. They perceived these targets as consistent, credible, stable over time and ambitious, and as such the targets strengthened their adoption activities in addition to other policy mix components. This is captured by one power generator: *"[The long-term targets for offshore wind and renewables] naturally motivate the decision behind every project."*

However, the **instrument mix** played a much more important role for firms' adoption activities. Both power generators and technology providers clearly perceived the EEG with its feed-in tariff for each kWh electricity fed into the grid as the most crucial policy instrument for adoption (see {1} in Table 10), as one power generator explains *"The EEG is the decisive factor in our decisions on whether to construct a wind farm."* Two main design features have been key to this realization (see {2} in Table 10): First, the feed-in tariff reached an investment-triggering level of support with the increased tariffs introduced in 2009. This was further intensified by the compression model in 2012, as illustrated by one power generator: *"The EEG amendment [2009] brought the surety of earning sufficient money from the projects. From that point on, one could say that it was possible to run financially viable projects."* The second central design feature is the feed-in tariff's long-term predictability, i.e. 20 years of guaranteed remuneration. The positive repercussions of this feed-in tariff for sales of offshore turbines (and all other associated components and services) are described by one technology provider in these terms: *"How much can be sold is very important for us as a plant manufacturer. This forecast naturally depends very strongly on feed-in revenues."*

Another central instrument in the instrument mix facilitating adoption was the EnWG's requirement that grid operators build and operate the grid connection of offshore wind farms, as this power generator states: *"From an economic perspective [the most important policy instruments] are the EEG and the grid connection [the EnWG]."* Additional instruments complement the mix, such as the KfW program which grants low-interest loans for the first ten farms in Germany. Introduced in 2011 as a response to financial bottlenecks in the aftermath of the financial crisis, it was an important instrument for project-financed farms, as explained by one technology provider: *"Startup financing is naturally extremely important for project-financed farms."*

In combination with the instrument mix and its vital importance, several **policy mix characteristics** turned out to be central determinants of firms' adoption activities. Most importantly, consistency or the fit of the instrument mix, i.e. second-level consistency, appears to have been a prerequisite for adoption (see {3} in Table 10). This is most clearly evidenced by the detrimental effect of instrument mix inconsistencies in the form of negative interactions between the EEG and the EnWG that became apparent in 2012 (see {4} in Table 10). In response to these inconsistencies power generators have put their final investment decisions for new farms in Germany on hold: *"For new building decisions [...] at present we have no framework that allows us to decide on new investments in construction."* (PG) The immediate negative implications for sales and thus manufacturing of offshore wind turbines are stated by one technology provider: *"We will now [...] finish production according to the contract and then stop for a while".* (TP)

This inconsistency can be traced back to the ineffectiveness of the EnWG regulation in addressing the bottleneck of grid access, which simultaneously rendered the current EEG with its compression model ineffective, as illustrated by this power generator: *"For example, the compression model in the EEG is expiring. Never mind the fact that many projects are substantially behind schedule from the many changes and delays in the grid and through the awarding of grid connections. That still doesn't go together."* More specifically, although the 2012 EnWG amendment introduced significant changes for grid access (see section 3.3.2), several projects would continue to face grid access delays, since this new regulation takes some time to become effective. Some offshore wind investors were thus likely to miss the temporally limited validity of the feed-in tariff compression model, which is running out in 2017 and which several of today's investors seem to require for making investment decisions for new farms. A power generator illustrates this problem: *"If you don't make the commissioning deadline [the end of the compression model in 2017], the compensation scheme is useless to you. Since the rate of remuneration is nevertheless the lower one."*

Our interviews indicate that in addition to consistency, comprehensiveness of the instrument mix, i.e. the existence of these other instruments, has been a prerequisite for adoption (see {3} in Table 10). That is, only in combination did the policy instruments appear to be able to overcome the most important market and system failures and any other bottlenecks, despite the central importance of the EEG. The significance of this comprehensiveness is illustrated by one power generator: *"It doesn't help to have a great permit if you don't have enough financing or any chance of a grid connection. These all build on each other and you need every part".*

TABLE 10: Key findings and *illustrative quotes* regarding adoption of offshore wind

Findings on how the policy mix affects adoption of offshore wind	***Exemplary quotes***
{1} Feed-in law with its feed-in tariff is the most important instrument driving adoption.	*"[The role of the policy mix in OW (offshore wind) innovation:] In one word: essential. Or fundamentally enabling, since without the feed-in tariffs there would be no offshore wind projects in Germany." (PG)*
{2} Investment-triggering level of support and its high predictability are the most crucial feed-in law design features driving adoption.	*"They [the feed-in credits] must reach a certain level so that the investment is worthwhile. The currently announced levels are very good and enable exactly the sort of the dynamic that we now see in the German market." (TP)* *"What we see in terms of the volume of offshore wind is that we have to get far more involved with project financing than we thought. So it was important in the last EEG amendment [2012] to make further improvements. This succeeded in part because the compression model was introduced." (TP)* *"What we in the German system would point out from the perspective of a builder and operator is naturally the security that the EEG represents. That is a very big advantage." (PG)*
{3} A comprehensive and consistent instrument mix facilitates adoption.	*"As stated, the grid connection is important in order to be able to feed in power at all, and naturally so that the financing, as it is currently stipulated, can work. In this respect, these two things are interdependent." (PG)* *"The EEG embedded in an appropriate policy framework is decisive." (PG)*
{4} Inconsistencies between the feed-in law and the grid access regulation hinder further adoption.	*"But we now had the situation that the EEG had been solved but not the EnWG. And you can't plan a wind farm when you don't have a grid connection. And having a grid connection is useless when you don't know what the remuneration looks like. Both of these are essential." (PG)* *"So this has to do with the fact […] that we don't know when we will get a grid connection. And if we are uncertain whether we will slip out of the compression model […], naturally that has significant economic repercussions. And since at the moment we are not taking this risk, we have said that we will further develop the projects, but that at the present time we cannot make the investment decision." (PG)* *"We have to […] reevaluate the schedule for our upcoming projects. We could say […] we'll start construction on the project at such and such a time. But that doesn't help us, since we don't know whether we'll get a grid connection by then. That means we'll have to [...] wait until we get the […] grid connection plan so that we can plan. At the moment we're somewhat at the mercy of this." (PG)*
{5} A credible policy mix facilitates adoption.	*"Then the EEG, the EnWG with the grid access provision – these were really important instruments. But also a certain level of trust that this would not suddenly be changed." (PG)* *"Without this commitment of the government the offshore market would not exist in this form, this is very clear." (TP)*

We finally find an important role of credibility, which appears to have been key for adoption (see {5} in Table 10). That is, if power generators and technology providers perceived a credible political will in favor of offshore wind, they were very likely to start their adoption activities, as stated by one power generator: *"In view of the then relatively rudimentary state of knowledge on costs and risks, the political will to do it was naturally the deciding factor."* Yet this high credibility achieved until early 2013 was decreased by the recent political debate about how to lower soaring electricity costs for consumers, the so-called electricity price brake discussion[32], which has been detrimental to innovation. Thus, in addition to second-level inconsistencies between the EEG and the EnWG, this discussion has further impeded adoption (and ultimately also RD&D).

The observed adoption activities were also driven by factors beyond the policy mix. First, regarding firm characteristics, the firms' growth strategies, their renewable energy goals and the propensity of large power generators to invest in large-scale power generation technologies (building on their capabilities in managing such projects) were essential drivers for adoption: *"Offshore is a very good fit for us. These are large, complex projects which we as classic power plant operators and builders know how to handle." (PG)* In addition, a firm's size helps explain which markets firms focus on: larger firms were often active in other countries, and smaller and locally rooted power generators as well as smaller technology providers seemed to focus on Germany as the home market. A further driver for adoption was the high availability of offshore wind projects and the close fit with large utilities' capabilities that are enabled by their large scale.

3.5.2. Effects on research, development and demonstration

Technology providers in our sample have at least one commercial offshore turbine type in their portfolio. They have been instrumental in developing, testing and improving turbines, with a current focus on improving their reliability and reducing costs, as this technology provider points out: *"Becoming more standardized, lower-priced, faster, more automated […] these are areas we are working hard on."* In contrast, power generators have focused on optimizing the construction and operation of their offshore wind farms, and in so doing they aimed for cost reductions: *"There is a lot of emphasis put on how to optimize the operation of such a wind farm […] As before, our focus is on how to further lower offshore's costs." (PG)* Several actors have also jointly pursued RD&D. The most prominent example is the cooperation of early entrants in the German test farm alpha ventus, in which three power generators have been testing twelve 5 MW turbines supplied by two technology providers.

Our interviews indicate that the **policy strategy,** particularly the long-term target for offshore wind, was one factor stimulating both firm types' RD&D. The ambitiousness of this target

32 The electricity price brake discussion, initiated by former environment minister Peter Altmaier in early 2013, suggested a retrospective reduction of tariffs for renewable energy technologies (Spiegel Online, 2013).

was interpreted as a sign of a growing market, as stated by one power generator: *"[Political long-term targets] for us mean that over the next decade a market will be developed that will make it worthwhile to develop innovations."* These market expectations triggered by long-term targets then positively influenced RD&D, as explained by this technology provider: *"If [these targets] are no longer there, so to speak, or if they are not updated, then naturally the pressure to innovate is smaller."*

An important complement to the policy strategy as part of the **instrument mix** has been the German feed-in tariff – a demand pull instrument – with its sufficiently high level of support: *"[...] but without such an impulse from the EEG [...] this [that the installations would improve, run more] would not be possible." (TP)* In addition, technology push instruments, such as financial RD&D support, seem to have had an impact on RD&D activities. They appear to have been especially important for technology providers in early phases of technology development and currently seem to play a supplementary role to demand pull support by guiding or deepening some RD&D projects, as one technology provider points out: *"[R&D funding programs] support the process and can also accelerate it."*

3

Regarding **policy mix characteristics**, consistency of the policy strategy, i.e. of the long-term targets for offshore wind and for renewable energies in general, has been a key driver for RD&D in offshore wind. Furthermore, the stability of the offshore wind long-term target has likely played an important role (see {1} in Table 11): *„Since we regularly check whether we're on the right track, [we look] at what has changed in the [LTT] framework, and we can say that basically it is still stable. Then naturally we stand by the decision [to be active in offshore wind]" (PG).* A further crucial RD&D driver has been the actual or expected consistency of the policy strategy with the instrument mix: Technology providers stressed that the offshore wind long-term target alone was not sufficient but needed to be operationalized in a consistent manner by policy instruments, primarily by a sufficient level of demand pull support (see {2} in Table 11. In addition the second-level inconsistency, i.e. the negative interaction between the EnWG and the EEG, which caused a decline in technology providers' sales, has been perceived as a barrier to RD&D (see {3} in Table 11): *"Naturally we want to further develop our current technology. But without knowing how long grid access delays by TSO TenneT will go on, our decisions on whether to further develop our turbines—almost all of which entail costs—will be postponed." (TP)* Yet the high credibility of the policy mix has partly compensated for the lack of consistency (see {4} in Table 11): Although these second-level inconsistencies negatively affected RD&D activities, firms continued at least some RD&D since they still perceived the overarching policy mix as credible, believing in the resolution of the inconsistencies: *"Since we now have a divergence between the EnWG and EEG rules, I'm sure that this topic will receive political attention… I think the will is there."* (PG) Similarly, we find signs of compensation between credibility and comprehensiveness (see {4} in Table 11): Actors invested in RD&D despite the policy mix's initial lack of comprehensiveness because they trusted policy makers' commitment to solve problems. This was the case for the perceived high level of credibility that helped stimulate offshore wind project development activities early on in technology development even though the instrument mix lacked some important instruments, such as a technology-specific feed-in tariff. This is aptly put by one technology provider: *"Also the commitment [...] even just through statements, and even when no proper business rules have been established yet, such commitment has a huge influence on all activities, on our investments and especially the investments of our customers."*

TABLE 11: Key findings and *illustrative quotes* regarding RD&D in offshore wind

Findings on how the policy mix affects RD&D in offshore wind	***Exemplary quotes***
{1} Consistent, credible and stable technology-specific policy strategy with ambitious long-term target stimulates firms' RD&D.	*"Renewable energy targets have their place here, otherwise the policy framework is not consistent and the OW LTT [long-term target] is not credible; it would be strange to have only an OW LTT without renewable energy targets." (PG)*
	„Since we regularly check whether we're on the right track, [we look] at what has changed in the [LTT] framework, and we can say that basically it is still stable. Then naturally we stand by the decision [to be active in offshore wind]" (PG)
{2} Consistent operationalization of the policy strategy particularly by sufficiently high level of demand pull support has indirect positive effect on RD&D.	*"One thing is definitely support [FIT] for our customers, since that's the only way they can build wind parks and in that way we sell wind turbines. So that's indirect support." (TP)*
	"The [onshore] plants improved and more got put into operation […] I expect the same for offshore wind in the next years, but without an impulse from the EEG […] that would not be possible." (TP)
{3} Inconsistencies between feed-in law and grid access regulation hinder RD&D.	*"At present we can't make any large innovations, since we have a drop-off in orders. In Germany, since the first TenneT letter of 11/07/2011, there have been practically no more orders in the offshore sector." (TP)*
	"We have not stopped innovating [because of TenneT's grid-access delays], but the pace has slackened somewhat" (TP)
{4} High policy mix credibility alleviates the negative effects of inconsistencies or lack of comprehensiveness.	*"The hope is there, of course. We see the willingness of the stakeholders to work on this issue – we do notice that." (TP)*
	"This brings us back to the point that the national government wants to have offshore wind and will therefore find a solution to the offshore grid issue. And against this background one has a certain level of trust [...]" (PG)

Besides the policy mix, several context factors and firm characteristics help explain corporate RD&D activities. For context factors, a major motivation for TPs' RD&D activities was the excellent market prospects for offshore wind, which were, however, mainly brought about by the policy mix. In this, the high demand for the offshore wind technology seems to have had a positive influence on the level and direction of RD&D activities. Furthermore, the immaturity of the technology was a strong innovation driver for both TPs and PGs. For German firms, this included the far out offshore location and related high costs, as illustrated by this technology provider: *"We are trying [...] to create a standard product, since our ultimate objective is to bring down the cost of offshore wind."*

As for firm characteristics, these high costs are reflected in PGs' cost reduction goals that drove their RD&D activities, as this PG states: *"We have identified specific measures that help us to reduce costs here as well [...] in order to be able to continue to realize wind farms in the future."* Similarly, TPs' strategies aiming at technology leadership, growth or cost reductions were key drivers for RD&D activities, as one technology provider points out *"that innovation for us is [strategically] extremely important. Our entire business is built on it."* Also, existing onshore wind technological capabilities benefited TPs' offshore wind RD&D activities.

3.6. Discussion and conclusion

This study has provided insights into how the policy mix has influenced corporate innovation activities in the emerging technology of offshore wind in Germany.

Summarizing our findings, we want to highlight two main points. First, the long-term target for offshore wind and its consistency with overall renewable energy targets appear particularly central to RD&D investments. In contrast, the instrument mix and the fit of policy instruments such as the EEG and the EnWG are particularly relevant for adoption. In this regard the most important policy instrument in the mix is the feed-in tariff and its sufficient level of support and high predictability. Second, we find a compensation effect of the generally high level of policy mix credibility, implying that a lack of the otherwise central characteristics consistency and comprehensiveness of the policy mix has only limited negative consequences for RD&D and the initial interest in adoption. This is exemplified by technology providers' continuation of some RD&D activities despite inconsistencies between the EEG and EnWG policy instruments.

Given the decisive roles of consistency and credibility for offshore wind innovation, we will focus our discussion on their significance. First, we find that a certain level of policy mix consistency is central for corporate innovation activities. This importance of consistency might be due to the fact that corporate actors consider the whole policy mix when thinking about investments into a technology, which they did, for instance, with the EEG and EnWG. Therefore not only single instruments need to be appropriately designed but due to interaction effects they need to fit together to provide clear investment incentives. This implies that analyzing interacting policy instruments and also the policy strategy enables crucial insights into otherwise neglected policy effects caused by interactions.

Second, the perceived high credibility of the political framework and thus the belief of actors in the political will to continue promoting the emerging offshore wind technology seems to create expectations of a favorable future policy mix. On the one hand, this is an important investment condition given the plethora of uncertainties about future developments in the offshore wind sector, including regarding the policy mix. On the other hand, such expectations might explain the aforementioned compensation effect of credibility. That is, if the policy mix is credible, it does not need to be fully consistent or address all bottlenecks – at least temporarily – since actors expect that policy makers will eventually remove these flaws.

Based on our findings on how the policy mix impacts corporate innovation in offshore wind in Germany, we propose some general lessons for other countries aiming to advance the technology.[33] First, it may be particularly useful to establish a technology-specific long-term target early on, and to ensure that it is ambitious, credible, stable and consistent with the overarching climate and renewable energy strategy. This is supported by earlier studies favoring technology-specific support over technology-neutral measures for bringing new technologies to the market (Azar and Sandén, 2011). Second, aside from introducing a predictable demand pull instrument with a sufficiently high level of support, policy makers should strive for a comprehensive instrument mix that also addresses other market failures and barriers. Third, a credible political commitment is a central characteristic of an effective policy mix for offshore wind, where trust needs to be built over time through multiple mechanisms but can also quickly be destroyed by pure political discussions.

Considering our findings for offshore wind in Germany, we recommend tackling several current challenges if the technology is to play a central role in the energy transition. The delays in grid access and associated inability of many investors to meet the 2017 deadline for the feed-in tariff compression model call for two main policy responses. First, the negative interaction between the EnWG and the EEG ought to be resolved, e.g. by extending the compression model by the grid access delay time or introducing an alternative model with comparable investment incentives, which also considers these delays.[34] Second, the effectiveness of the new EnWG addressing the grid access delays should be monitored and, if necessary, alternative solutions should be considered. The second challenge relates to the currently still relatively high costs of the offshore wind technology, which are increasingly being criticized. We argue that this debate would benefit from a more dynamic perspective that accounts for cost reductions stimulated by technological innovation. We suggest several routes that may potentially enhance long-term cost reductions. The credibility of the German offshore wind policy mix should not be prematurely put at risk, as happened through the discussions on the 'electricity price brake'. Efforts should now be targeted at regaining trust and confirming the commitment of the German government to offshore wind. Also, the implicit cost-reduction objective could be made more explicit in the offshore wind policy strategy to provide clear guidance for companies' innovation strategies. Finally, policy makers could also consider a more systemic policy style, so as to allow for the

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33 An important caveat, which is however outside the scope of this paper, is the general decision about which renewable energy technologies are most suited to accomplishing the energy transition (Midttun, 2012), considering for example technology and geographical potentials and costs (Agora Energiewende, 2013).

34 Meanwhile, this issue has been addressed by policy makers, i.e. the new grand coalition in their coalition agreement foresees an extension of the EEG compression model by two additional years.

anticipation of required policy actions, thereby ensuring continued policy mix consistency. The resulting proactive adjustments of the policy mix could contribute to speeding up the rate of innovation and thus the materialization of cost reductions.

While our study focuses on offshore wind, our results go beyond this research case in at least two respects. On the one hand, the findings might be transferable to other emerging renewable energy technologies and potentially also other green technologies. This is because such emerging technologies have comparable characteristics such as lack of cost-competitiveness and initial high technological uncertainties (IEA, 2011a). In addition, all these technologies are confronted with multiple market, system and institutional failures (Weber & Rohracher, 2012) and as niche technologies embedded in established regimes may need an initial phase of shielding, nurturing and empowering in protective spaces (Smith and Raven, 2012)defined as a protective space for path-breaking innovations. Surprisingly, the concept of protection has not been systematically interrogated. Our analysis identifies effective protection as having three properties in wider transition processes: shielding, nurturing and empowerment. Empowerment is considered the least developed in current niche literature. It can be understood as either processes that make niche innovations competitive within unchanged selection environments (fit-and-conform. On the other hand, our research with its focus on the impact of the policy mix on technological change may contribute to a better understanding of the role of the policy mix for the envisaged energy transition, thereby supplementing studies focusing on other fundamental material, organizational and socio-cultural changes (Markard et al., 2012).

By providing the first empirical application of the policy mix concept proposed by Rogge and Reichardt (2015), this study makes three key contributions. First, it allows for a deeper understanding of the link between the policy mix and corporate innovation activities for an exemplary emerging renewable energy technology. Second, it provides insights into innovation effects not only of policy mix elements but also of their characteristics, including their consistency and thus their interplay. Third, it derives more substantiated policy recommendations grounded in a better understanding of firms' strategies, which might ultimately contribute to an accelerated energy transition.

However, it is not free from limitations and thus calls for further research. First, future studies should extend our focus on corporate actors by assuming a more systemic perspective that analyzes the interplay between the policy mix and the technological innovation system, thereby also incorporating perceptions of other actors such as policy makers. Second, future policy mix research should continue to unpack the role of policy mix characteristics and also of policy mix processes for innovation, and in doing so account for the underlying politics. Finally, the effect of the policy mix on innovation in other technologies, sectors and countries should be analyzed and compared.

Chapter 4

Analyzing policy mix-TIS interdependencies: The case of offshore wind in Germany

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4.1. Introduction

In order to prevent the costly consequences of climate change, a decarbonization of the energy system is needed. This transition requires the development and diffusion of low-carbon energy technologies, such as technologies based on renewable energies. However, without policy intervention these technologies will not be developed and will not diffuse at a rate and scale required for such a radical transition. A major reason for this is multiple failures in place, which require not just single policy instruments but rather a policy mix to address them (Lehmann, 2010a; Weber and Rohracher, 2012). Besides comprising several interacting policy instruments, such policy mixes more recently have been highlighted to also include a policy strategy, policy processes and overarching policy mix characteristics (Flanagan et al., 2011; Rogge and Reichardt, 2013.

Emerging technologies, such as renewable energy technologies, are not only influenced by a policy mix but actually are impacted and shaped by an entire system, a so-called technological innovation system (TIS). Scholars on technological innovation systems study the evolution of such technologies as the outcome of complex interaction processes between actors, institutions (hard and soft rules) and physical artifacts (e.g. Negro, Suurs, & Hekkert, 2008; Suurs, Hekkert, Kieboom, & Smits, 2010). This includes the analysis of the structure of the innovation system as well as its functioning (Bergek et al., 2008; Hekkert et al., 2007). In doing so, system failures or systemic problems are identified and, based on these, recommendations for specific policy interventions are derived.

While the literature on TIS has helped policy makers by developing the framework necessary for analyzing where policy intervention is needed and has offered a toolbox for such policy intervention (Bergek et al., 2008; Wieczorek and Hekkert, 2012), a more thorough understanding of the actual interlinkages between policies and the TIS they are embedded in, as well as a more differentiated treatment of policies are still largely lacking. There exist some TIS studies that analyze the role of policies to improve innovation system functioning, yet they are mostly limited to policy instruments. A recent example is Kivimaa and Virkamäki (2013), which analyzes the impact of several policy instruments on TIS functioning and in doing so detects design flaws in single policy instruments. Similarly, McDowall et al. (2013) explores how policy instruments influence system functioning, and addresses system weaknesses for the onshore wind innovation system in four countries. It concludes with lessons for a low-carbon instrument mix, e.g. the need to include systemic policy instruments alongside traditional demand pull and technology push. However, these studies do not consider features of a more encompassing policy mix, such as a policy strategy and policy processes.

In this article we incorporate a more comprehensive policy mix concept into the TIS approach by explicitly analyzing the role of a differentiated policy mix in the development of TIS. More specifically, we study the evolution of a technological innovation system and its corresponding policy mix and analyze interdependencies between the two. We thereby do not only examine the role of the policy mix for TIS functioning and performance but also investigate how particular TIS developments affect the coming about of the policy mix. By applying the policy mix concept within the TIS approach we enable a better understanding of the role of the policy mix in emerging innovation systems. Regarding the policy mix we rely on a recently proposed concept, which defines a policy mix as consisting of the four building blocks elements, processes, dimensions and characteristics (Rogge and Reichardt, 2013; see section 4.2.2). We consider all of these building blocks, i.e. the policy strategy and the instrument mix as elements, policy making and implementation as policy processes, actors as an important policy mix dimension and the influential policy mix characteristic credibility.

We explore our research question of the interdependencies between the policy mix and TIS developments for the case of offshore wind in Germany, which we chose for the following reasons. First, the policy mix promoting the development and diffusion of this technology appears particularly rich and dynamic, comprising a policy strategy and an encompassing instrument mix, which have been adjusted several times. Second, offshore wind is an emerging renewable energy technology with great technological potentials expected to play a key role in the transition of the German energy system (BMWi and BMU, 2010), but is faced with a number of difficulties. In combination, these factors make offshore wind in Germany an ideal candidate to study the role of the policy mix for the development of the TIS.

We proceed as follows: Section 4.2 reviews the literatures on TIS and on policy mixes, and derives our analytical framework, which combines these two approaches. Section 4.3 introduces the research case of offshore wind in Germany. While section 4.4 outlines our method for analyzing TIS and policy mix developments over time, section 4.5 describes these developments for the German offshore wind TIS between 1993 and 2013. Based on this description, section 4.6 discusses the interdependencies between the TIS and policy mix developments, and section 4.7 concludes.

4.2. Theoretical background

4.2.1. Technological innovation systems

The recent years have seen a fast growing literature applying the technological innovation systems framework for studying sustainable transition processes such as the transformation of the energy system (Jacobsson and Bergek, 2011; Truffer et al., 2012). A technological innovation system (TIS) can be defined as the network of actors, rules and material artifacts that influence the speed and direction of technological change in a specific technological area (Hekkert et al., 2007; Markard and Truffer, 2008a). The purpose of analyzing a TIS is to evaluate the development of a particular technological field in terms of the structures and processes that support or hamper the development and diffusion of novel technologies. The ultimate aim is to derive implications for policy makers and other actors so as to remedy ills in the functioning of such systems (Bergek et al., 2008).

The structural analysis of systems comprises mapping of its elements – actors, networks, institutions, and infrastructure – and evaluating their capacity to stimulate innovation. These structural elements, their presence or absence as well as their capacities are critical to the functioning of innovation systems (Wieczorek and Hekkert, 2012).

While different innovation systems may have similar structural elements, they may function in an entirely different way. Therefore, measuring the functioning of innovation systems constitutes another crucial step of analysis. Table 12 presents a list of key processes that need to be fulfilled for a TIS to build up and function well (Hekkert et al., 2007). These key processes are called system functions.

TABLE 12: Description of seven key system functions of a TIS

Function number	Function name	Description
F1	Experimentation and production 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.
F2	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.
F3	Knowledge exchange	The exchange of relevant knowledge between actors in the system is essential to foster learning-processes.
F4	Guidance of the search	The processes that lead to a clear development goal for the new technology based on technological expectations, articulated user demand and societal discourse enable selection, which guides the distribution of resources.
F5	Market formation	This function refers to the creation of a market for the new technology. In early phases of developments this can be a small niche market but later on a larger market is required to facilitate cost reductions and incentives for entrepreneurs to move in.
F6	Resource mobilization	The financial, human and physical resources are necessary basic inputs for all activities in the innovation system. Without these resources, other processes are hampered.
F7	Creation of legitimacy	Innovation is by definition uncertain. A certain level of legitimacy is required for actors to commit to the new technology and execute investments, take adoption decisions etc.

Source: adapted from Wieczorek et al. (2013)

Structure and functions complement each other. While functions are more evaluative in character and allow for assessing of what works well and what does not within the TIS, the structure is what needs to be adjusted to enable better system functioning and thus should be the target of policy intervention. Put differently, functions that are badly fulfilled indicate problems in the structure. By identifying where the problems are within the system, these problems can more easily be addressed by policy makers. For example, if function knowledge diffusion is weak then the cause could be related to a lack of networks in which knowledge is exchanged (Wieczorek et al., 2013). Such problems are usually called systemic problems or system failures and can be defined as "factors that negatively influence the direction and speed of innovation processes and hinder the development and functioning of innovation systems" (Wieczorek and Hekkert, 2012, p.79). Finally, the structure and functioning of a TIS have a direct influence on its performance, i.e. the development, use and diffusion of the technology under study (Bergek et al., 2008; Tigabu et al., 2013).

4.2.2. Policy mixes

Although policies are part of the institutional structures that make up a TIS and play an important role in TIS analyses, only few studies have focused on policies and their impact on the rest of the TIS (Foxon et al., 2005; Kivimaa and Virkamäki, 2013). Even fewer studies have focused on studying TIS-related policies from a policy mix perspective. At the same time the need for considering such policy mixes – both for researchers and policy makers – has been increasingly stressed in the climate, energy and innovation policy literature (Matthes, 2010; Nauwelaers et al., 2009; see Rogge and Reichardt (2013) for a detailed overview). The main argument for this need is that the necessary transformation of socio-technical systems like the energy system is slowed down by multiple market, system and institutional failures in place requiring multi-faceted policy intervention (Weber and Rohracher, 2012). Therefore we are often dealing with complex policy mixes rather than single instruments (Braathen, 2007; Lehmann, 2010a). The literature on policy mixes stresses the importance of such policy aspects as instrument design features (Kemp and Pontoglio, 2011), policy mix characteristics (Rogge and Reichardt, 2013), and policy processes (Flanagan et al., 2011). One strength of considering policy mixes in innovation system studies would be a more encompassing understanding of the role of 'policies' in the innovation system, which may ultimately enable a better understanding of these systems themselves. In this regard, applying a well-defined policy mix terminology that explicitly differentiates between policy instruments, a policy strategy, policy processes and overarching policy mix characteristics such as credibility is thought to increase the analytical clarity of empirical TIS studies (Rogge and Reichardt, 2013).

Despite these increasing calls for considering overarching policy mixes (Flanagan et al., 2011), policy mix definitions in the literature thus far have remained rather narrow and ambiguous. Addressing this problem Rogge and Reichardt (2013) propose a more comprehensive policy mix concept as tool for policy analyses, including elements, processes, dimensions and overarching characteristics. Elements consist of a policy strategy with long-term targets and principal plans, and an instrument mix with interacting policy instruments, including the instruments' type and design features. Processes comprise policy making and implementation. These processes shape the policy mix elements and might also have a direct effect on the performance of the policy mix, e.g. through signals they send out. Characteristics describe the nature of the policy mix and include policy mix consistency, coherence of policy processes, credibility, stability and comprehensiveness. For instance, credibility – as a potentially highly influential characteristic – means the extent to which the policy mix is believable at a general level and at the level of particular elements or processes. Finally, dimensions serve to specify elements, processes and characteristics, and thus the scope of a policy mix. They comprise, among others, the governance level, such as regional versus national, actors including both policy and target actors, and time, which captures the dynamic nature of policy mixes.

4.2.3. Analytical framework

In this study we take a first step incorporating the policy mix concept proposed by Rogge and Reichardt (2013) into the TIS framework by explicitly including the policy mix as one of the constituents of the structural component of 'institutions' in TIS. As the structure of the TIS for a large part determines its functioning, we can zoom in on the impact of the policy mix on TIS functioning. This implies that, on the one hand, the framework enables an analysis of the role of the policy mix with its policy strategy, the instrument mix, the processes of policy making and implementation and policy mix characteristics, for TIS functioning. On the other hand, the framework allows for studying the influence of certain TIS developments, e.g. functions and systemic problems, on the development of these policy mix components. Thereby, changes in the policy mix require interaction between policy makers and other TIS actors, i.e. politics are at play. Although we will not elaborately study such politics, we acknowledge that without these the policy mix would not change. We will therefore name relevant organizations and their roles in the context of particular problems in the TIS.

4.3. Offshore wind in Germany

Offshore wind is to play a considerable role in the German energy transition, 'Energiewende' (BMWi and BMU, 2010), in which the country aims to transform its energy sector towards more renewable energy technologies. In the context of this transition, by 2020 a share of 35 % of power consumption is envisaged to come from renewable energy technologies, which is to rise to more than 80 % by 2050. Against this background, ambitious long-term capacity targets for offshore wind were established already in 2002, namely 10 GW by 2020 and 25 GW by 2030. These targets were adjusted downwards – to become more 'realistic' – to 6.5

GW and 15 GW, respectively, by the new government in 2013 (CDU et al., 2013, see Table 13). They nonetheless concede a significant role to offshore wind, which is also visible in the rich policy mix that has emerged over the past 20 years and that continues to incentivize investments into the technology (see Figure 8).

TABLE 13: Development of installed capacity of offshore wind

		2012	2020	2030
Installed capacity (in GW)	EU	5.3	40	150
	Germany	0.28	6.5	15

Source: Own compilation based on EWEA (2011), CDU et al. (2013), EWEA (2014)

The significance of the technology is mainly due to its large technological potential. Energy yields offshore are higher and steadier, reaching up to 4,000 full-load hours per year compared to 2,000-2,500 full-load hours onshore (EWEA, 2009a). The limited spatial potential for onshore growth in Europe adds to the great growth prospects of offshore wind not just in Germany but across the EU (Praessler and Schaechtele, 2012). Thus, 40 GW capacity are estimated to be installed in EU countries by 2020 (EWEA, 2011b).

Despite its potential, the technology is confronted with difficulties. One is that offshore wind faces more challenging conditions than its onshore counterpart (IEA, 2009). For example, the marine environment with its salt water and higher wind speeds intensifies corrosion and puts higher demands on turbine materials. A particularity in Germany is the relatively long distance that offshore wind parks are located from the coast (usually at least 40 km). This is due to the near-shore nature protection area Wadden Sea in the North Sea and anticipated public acceptance problems in near-shore waters in the Baltic Sea. These particularities are a major reason for the immaturity of the technology, which is reflected in relatively low capacities currently installed in the EU and Germany compared to their ambitious 2020 targets (Table 13, EWEA, 2011). Relatedly, offshore wind costs are still comparatively high, ranging between 12.8 and 14.2 ct/ kWh in Germany (Fichtner and Prognos, 2013). However, costs are expected to fall to 9 ct/ kWh by 2020.

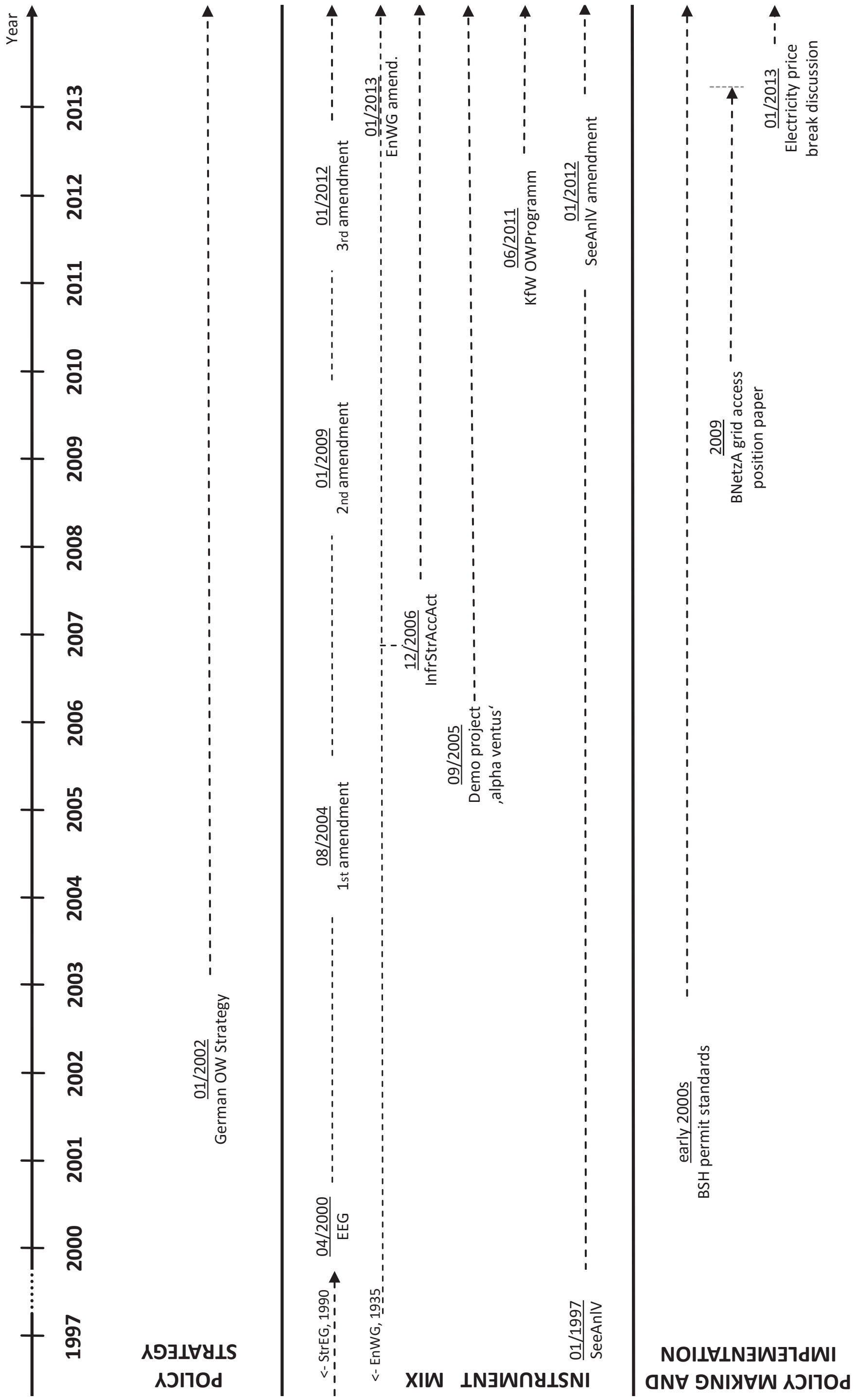

FIGURE 8: Evolution of key elements and processes of the German offshore wind policy mix

Methodology

In order to answer our research question of how the German offshore wind TIS and its corresponding policy mix evolve and influence each other, we combine event history analysis with interviews. While the event history analysis provides an overview of the evolution of the offshore wind TIS and its policy mix, i.e. of what happens, interviews create deeper insights in the interdependencies between the policy mix and the TIS. They reveal why and how the TIS and its policy mix came into being and how they influenced each others' development, thereby also shedding light on the effects of the policy mix on the TIS.

We proceeded in two main steps. First, by applying event history analysis we reconstructed the development of the German offshore wind TIS. In doing so we selected all articles on offshore wind in Germany between 1993 and 2013 from the European magazine Wind Power Monthly and extracted all relevant events[35] (Negro et al., 2007). We chronologically put these events in a database allocating each event to one of the seven TIS functions, according to functions indicators established in the literature (see, Negro et al. (2007)). Besides this, for getting insights into the evolution of policy mix components we screened related policy documents. These documents and the events constitute the basis – providing the facts – for our analysis of the evolution of the TIS and its policy mix. For clearly pointing out the policy mix terminology in the description of the TIS evolution, we indicate the policy mix components in squared brackets in section 4.5 (see appendix 4 for an overview of policy mix components and their abbreviations). Also, based on the TIS events we analyzed the system functions over time (indicated in brackets in section 4.5) and identified major systemic problems. We described the TIS development in five time periods. The end of each period was chosen on the basis of change in activities or key events, which is why not all periods are equal in length (Negro et al., 2007).

Second, between February 2013 and January 2014 we conducted 16 expert interviews to gain deeper insights into the role of policy mix components for TIS functioning and performance. We also explored why and in which way the policy mix elements were put in place in relation to TIS development. For obtaining detailed information on these issues, we selected long-standing experts in the field representing all main stakeholder groups in the TIS (see Table 14). In order to safeguard the interviewees' anonymity regarding singular statements, in section 4.5 we allocate each interviewee a name from A to P. We transcribed and coded all 16 interviews, which were conducted by telephone and lasted 85 minutes on average, using the qualitative data analysis software Atlas.ti. Our code list comprised codes for systemic problems in the TIS and for the policy mix components (policy strategy, policy instruments, policy mix characteristics, policy processes) that were put in place, often to address these systemic problems. In our analysis we combined interview data with

35 An event can be defined as 'the smallest meaningful unit in which change can be detected.' (Poole et al., 2000).

the information gathered in the event history analysis, and triangulated our findings with secondary data from publicly available reports and databases on offshore wind in Germany. Together, this allowed for a rich description of the interdependencies of the TIS and its policy mix.

TABLE 14: Overview of expert interviews

Actor type[39]	Actor name	# interviews	Interview duration	Interview date
Government	Federal Ministry for Environment (BMU)	2	117 min 87 min	07/08/13 15/01/14
	Federal Maritime and Hydrographic Agency (BSH)	2	99 min 112min	08/08/13 07/11/13
	Federal Network Agency (BNetzA)	1	50 min	13/01/14
Companies	German manufacturer of OW turbines	1	86 min	08/02/13
	German operator of OW farm	1	85 min	19/02/13
	Tennet (grid operator)	1	100 min	13/11/13
Financial organization	Reconstruction Loan Corporation (KfW)	2	30 min 58 min	28/11/13 04/12/13
Knowledge institute	Center for Wind Energy Research (ForWind)	1	40 min	27/11/13
Industry organization	Stiftung Offshore Windenergie	1	200 min	31/07/13
	Wind Energy Agency (wab)	1	78 min	26/07/13
	German Engineering Association (VDMA)	2	102 min 31 min	17/10/13 18/12/13
NGO	World Wide Fund for Nature (WWF)	1	90 min	09/08/13
SUM		**16**	**1,365 min (22.75h)**	

4.4. Development of the German offshore wind TIS and its policy mix from 1993 to 2013

In the following we describe the evolution of the German offshore wind TIS and its policy mix over the past 20 years, dividing this period in five phases.

Phase 1: Pioneers‘ era (1993-1999)

In 1993, one of the first wind conferences ‘Husum Wind Energy Days’ takes place in Husum, where a report is presented by British consultants Garrad Hassan and German classification society Germanischer Lloyd, revealing the enormous potential of offshore wind (F3;F4) (Wind Power Monthly, 1996). The interest in offshore wind in Germany continues to grow due to the positive developments of this technology in pioneer countries such as Denmark

36 Based on Wieczorek and Hekkert (Wieczorek and Hekkert, 2012).

(Interviewee A) and the rapid growth of German onshore wind (F4). As early as in 1994, first plans for offshore parks are made by small planning firms, e.g. in the Baltic Sea off the Rostock coast (F1) (Wind Power Monthly, 1994). The most important policy instrument incentivizing advancements in the (onshore) wind technology at that time is the Electricity Feed-in Law (EFL, predecessor of the EEG) from 1990, a demand-pull instrument granting fixed-premium payments for electricity from wind and other renewable energy technologies [In.dp]. Offshore wind pioneers believe that such a premium payment would eventually also be put in place for offshore wind (Interviewee E), which contributes to driving their activities (F4).

In the late 1990s, a lot of technology development occurs (F2). For instance, German-Danish wind turbine maker Nordex develops a 2.5 MW offshore turbine (Wind Power Monthly, 1999). Furthermore, many requests for projecting offshore wind farms are posed – mainly by small onshore wind planning firms such as Plambeck and PROKON Nord (Interviewee E) – including a 16 turbine project close to the huge German port of Wilhelmshaven planned by Winkra-Energie (Wind Power Monthly, 1998). It is these small, innovative technology providers of onshore wind turbines and onshore wind project developers that initiate and significantly push the development of the offshore wind technology in Germany.

Despite quite some activities in the technology, so far there is no comprehensive policy mix in place for offshore wind [PM.compr]. One example is the lack of regulation for handling offshore wind permission requests. As a response to first such requests by wind planning firms, in January 1997 the responsible transport ministry (BMVBS) sets up the Marine Facilities Ordinance (SeeAnlV) [P.impl; In.sys]. The ordinance requires that a wind farm project be approved provided that it does not impair the safety and efficiency of navigation, and is not detrimental to the marine environment (F4) (BSH, 2014, Interviewee E). However, the agency carrying out the application procedure of offshore wind farm projects in the Exclusive Economic Zone (EEZ)[37] of the German North Sea and Baltic Sea, the Federal Maritime and Hydrographic Agency (BSH), cannot hark back to any rules to apply when handling permission requests. For dealing with requests in the early 2000s, within the frame of the SeeAnlV the BSH thus autonomously sets up procedures from scratch [P.impl], and is thereby struggling to attract enough manpower to process all requests (-F6) (Wind Power Monthly, 2001a, Interviewee E).

In sum this first phase is characterized by a lot of optimism and high expectations of pioneers and entrepreneurs (F4). Things are still relatively chaotic but at the same time also very dynamic, “with a very optimistic and cooperative feel to it” (Interviewee E). There are various plans for wind parks and many technology development activities (F2). Because this is an emerging technology, a comprehensive policy mix including a standardized permit

37 Most of the German offshore wind farms are planned to be installed in the EEZ. Within the 12 nautical mile limit, i.e. the area of the territorial sea, responsibility for approval of wind farms rests with the German coastal states (BSH, 2014).

process has not yet been established [PM.compr] (-F4). The lack of a permit process is, however, addressed by the authority in charge by establishing standards for handling offshore wind permit applications (F4).

Phase 2: Early growth (2000-2004)

In April 2000, for further fostering renewable energy technologies the newly elected red-green coalition introduces the Renewable Energy Act (EEG) [P.mak; In.dp] (F5), which replaces and extends the EFL (IEA, 2013b). Transmission system operators are obliged to buy all wind kilowatt hours generated by renewable energy technologies, including wind, at a technology-specific fixed minimum price. They can spread the cost of their purchases equally across all consumers. This guaranteed technology-specific feed-in tariff (FIT) for wind power (to this point just one tariff for onshore and offshore wind) and the Sea Plant Ordinance are at that time the only policy instruments in place for offshore wind [In]. Particularly the EEG and actors' expectations of a sufficiently high FIT for offshore wind [PM.cred] trigger planning-firms' activities in the technology as well as technology development (F1; F2; F4) (Interviewee E).

In 2001, the BSH grants the first permit to the project Borkum West 1 [P.impl] (later renamed to become the demonstration project Alpha Ventus) commissioned by the planning-company PROKON Nord (F4) (Wind Power Monthly, 2001b). Further project approvals follow, such as in 2002 for the 240 MW Butendiek project (Wind Power Monthly, 2003a, 2003b).

Progress is also made with the offshore wind port infrastructure. For instance, based on a study by Olav Hohmeyer (professor of energy and resources at Flensburg University) forecasting a bright future development of offshore wind in Germany (Wind Power Monthly, 2003c), the federal state of Schleswig-Holstein grants 13 million Euros for an expansion of Husum port [In.sys] (F6), with half of the sum to be provided by the EU (F4) (Wind Power Monthly, 2003c). In addition to these infrastructure advancements, German turbine developers including Repower and Enercon drive knowledge creation by developing the first big German offshore turbines. Repower builds its 5 MW prototype in the Elbe river estuary as early as in December 2004, and at around the same time Enercon builds its E112 near-shore prototype in the Emden port (F2).

Offshore wind development enjoys remarkable cross-party political support, particularly from north German state governments that hope to enliven industrial activity and employment in the economically weak coastal regions (F4; F7) (Wind Power Monthly, 2003a). With the goal to further and more significantly advance offshore wind, in 2002 two policy makers in the Federal Environment Ministry (BMU) proactively develop a long-term action strategy for the technology – the offshore wind strategy [PS] (F4) (Bundesregierung, 2002, Interviewee B). Since this strategy is endorsed by the environment minister who brings it into the cabinet, it is officially adopted by the German government [P.mak]. It foresees to have installed 10 GW of offshore wind capacity by 2020 and 25 GW by 2030. Although it is not legally binding, the strategy creates big expectations regarding the further development of the technology, thus spurring innovative activities in the short and long term (F4).

However, large electricity utilities such as E.ON and RWE generally oppose the young offshore wind technology (-F7). They are mainly complaining about the extra cost of balancing supply and demand that they claim are inflicted on the system by such an intermittent energy source. Additional opposition comes from German environmental groups, such as Naturschutzbund (Nabu) and Bund für Umwelt und Naturschutz Deutschland (BUND) (-F7). In 2003, they launch legal procedures to stop development of the permitted offshore wind farm Butendiek in the North Sea because the project lies in a nature protection area. Also, they plan to extend their legal campaign to other offshore projects (Wind Power Monthly, 2003d).

In 2004 an amendment of the EEG comes into force [In.dp], based on an experience report that the German government regularly has to conduct (F4). Rooted in the insight that offshore wind is technologically different from onshore wind and that it features higher costs, the wind FIT is split into offshore and onshore, with the offshore tariff amounting to 9.1 ct/kWh for twelve years (and thus being higher than the onshore tariff, F5). Also, mainly due to the increasing opposition of environmental groups against offshore wind projects, a clause is included in the EEG excluding farms in nature protection areas from feed-in-tariffs (Interviewees D, L). This leads to greater acceptance of offshore wind also by nature conservationists (F7).

Summing up, in this second period the national and regional governments play a more active role. They support offshore wind with long-term guidance in the form of the offshore wind strategy and an amendment of the FIT, as well as large investment in the creation of an offshore wind industry in northern Germany (F4; F5). However, incumbent fossil fuel firms are reluctant to invest in offshore wind, and also environmental organizations protest against the location of offshore wind parks in nature protection areas (-F7).

Phase 3: Temporary Depression (2005-2006)

This period is characterized by problems with cable connections of parks, which seriously hamper offshore wind projects (-F1) (Wind Power Monthly, 2005). According to the existing grid regulation anchored in the EEG [In.sys], project planners have to plan and finance their own cable, resulting in chaotic cable planning (Interviewees A; J). Furthermore, long policy implementation procedures from the side of some federal states cause permit delays [P.impl]. These are due to, among others, nature protection conflicts when crossing the Wadden Zea (Interviewee L). Besides being ecologically detrimental, this adds to the economic non-attractiveness of offshore projects, for which the 2004 FIT has been identified as too low in the light of rising costs [In.dp] (-F5; -F6) (Interviewees A; J; M). Therefore, projects do not get going – despite many new construction permits issued by the BSH – putting the whole sector in a "somewhat depressive phase" (Interviewee E).

Since the cable connection problems for offshore wind projects – uncoordinated planning and high costs – have become so severe, affected actors such as project developers and the federal states call for a more centralized and coordinated cable planning, ideally done by the transmission system operator (TSO) and no longer by the park planners themselves. The BMU, being responsible for offshore wind[38], finally becomes active and shifts the responsibility of providing grid connections for offshore wind farms to the TSOs (F4) (Interviewee A). These changes in offshore wind grid access regulation are then implemented in the Infrastructure Planning Acceleration Act (InfrStrAccAct) at the end of 2006, which amends the Energy Economy Law[39] (EnWG) [P.mak; In.sys]. Creating positive expectations, they temporarily ease the cable connection situation.

Summing up, the main barriers in this period are delayed permits of cable connections of parks and chaotic cable planning of offshore wind projects due to inappropriate existing regulation [In.sys], which makes technology use economically unattractive (-F4; -F6). These problems are articulated by several organizations in the offshore wind TIS. The government responds to these problems and improves the organization of the cable planning [P.mak; In.sys] in order to reduce delays and costs for the park operators. By removing these barriers, activities can be continued and a growth of the German offshore wind TIS is expected.

Phase 4: Birth of test field Alpha Ventus and rapid growth (2005-2009)

In parallel to the negative events in the previous period, also significant positive developments begin to take place in the German offshore wind TIS. Industry representatives had called for an offshore wind workshop during the biannual national maritime conference in 2005. In this workshop, it is predominantly turbine manufacturers that demand establishing a test field, since offshore wind projects have still not taken off. In subsequent discussions between such technology firms and the environment ministry BMU on how to realize such a test field, the BMU suggests creating a foundation, the "Foundation Offshore Wind Energy", for further developing this project. A broad range of actors involved in offshore wind joins this foundation, which is mainly financed by the BMU. Also the BMU asks the initiators of the test field, turbine manufacturers, to participate in the project. Repower, Multibrid (now AREVA) and Enercon join to provide four turbines each that they fund by themselves (Interviewee

38 The Federal Ministry of Economic Affairs (BMWi) is actually responsible for grids, including those for offshore wind. However, due to its opposition against offshore wind the BMU often takes action in its place.

39 The EnWG originally regulated fundamental aspects of grid-bound electricity supply, such as approval obligations, grid operation and utilities' obligation to contract with consumers.

J). However, Enercon soon drops out and completely quits offshore wind, presumably due to technical problems and resentment against the technology by the company head Alois Wobben (Interviewee A). Repower and Multibrid are invited to fill the gap by delivering two extra turbines, i.e. six instead of four turbines, each, but they object operating them. Therefore, the Offshore Wind Foundation asks the three utilities EWE, E.ON and Vattenfall that – as responsible grid operators for the German North and Baltic Sea – originally only were to provide the grid access for Alpha Ventus within the operator consortium DOTI ("Deutsche Offshore-Testfeld und Infrastruktur GmbH") (Interviewee A). The three firms are willing to also operate the test farm. In this whole process the Offshore Wind Foundation plays a key role as moderator, e.g. convincing both the turbine manufacturers and utilities to participate in Alpha Ventus. In addition, the demonstration project profits from the backing of the responsible BMU. This backing well exceeds a 50 million Euros grant for a number of research projects accompanying Alpha Ventus [In.tp] (F6). It also comprises a general positive attitude and constant support for offshore wind (F4) (Interviewees A; E; J).

Despite all the Alpha Ventus preparatory activities, by the end of 2008 no offshore wind capacity is online yet. One major reason for this is the – due to rising costs – underestimated level of the 2004 FIT. In 2007, the discussion on raising the offshore wind FIT is fuelled by the mandatory EEG experience report, the basis of which form scientific studies by independent research institutes. A KPMG study from December 2007, commissioned by several firms, also points out the need for a higher FIT (F7). Thus in 2007 the grand coalition government proposes to increase the initial FIT from currently 9.1 ct/ kWh to 11-15 ct/kWh, thereby creating positive expectations and first commercial interests in German offshore wind by large utilities such as EnBW (F1; F4; F5). Following several discussions, the 2009 EEG amendment comprises a rise of the offshore wind FIT to 13 ct/kWh for the first twelve years[40], with a 'sprinter bonus' of 2 ct/kWh on top for projects that come online before 2016 [P.mak; In.dp] (EEG, 2009, Interviewee B).

Meanwhile the planning of the test field Alpha Ventus by the operator consortium DOTI continues. Due to approval problems for the big utilities E.ON and Vattenfall, the medium-sized utility EWE takes over the majority (almost 50%) of the project, thus becoming its main driver. Despite some delays mainly because of logistical challenges (Interviewees B; E), after around four years of planning the 60 MW farm starts operation in 2009 and is thus the first operational German offshore wind farm (F1; F2; F3) (Wind Power Monthly, 2010). A lot of (joint) learning has taken place during this planning-process, which the involved firms can later use for their commercial projects. The following successful operation of Alpha Ventus does not only demonstrate the feasibility of such large-scale deep-water projects with their great unknowns and risks but also sends positive signals to other entrepreneurs and investors (F4) (Interviewees B; J; M).

40 After this initial period the FIT is to fall to 3.5 ct/kWh for the remaining part of the 20 years in which it is granted.

These improvements – going operational of Alpha Ventus and the higher FIT of 2009 – lead to a big increase in trust and positive expectations in the German offshore wind sector, such as by large utilities (F4) (Wind Power Monthly, 2009a, Wind Power Monthly, 2009b). Both events can be seen as tipping point in the German offshore wind TIS, initiating the actual take-off of many projects that have been bobbing up and down so far. From now on the sector grows substantially, i.e. new – usually larger – firms enter the market, projects are being considerably advanced and actually constructed, and the responsible TSO TenneT builds the first cable connections for commercial farms (F1). It is only now – around 2008/2009 – that the big utilities enter the German offshore wind market. They do so in buying and realizing existing projects from small project developers that lack the (financial) resources to actually follow through these projects.

Overall, in this period policy makers – alerted by industry representatives – address the systemic problem of insufficient financial support instruments altering the corresponding policy instrument EEG [P.mak; In.dp] (F4; F5). Also the first test field for offshore wind starts operation. Consequently positive experiences and high expectations reinforce each other and trigger the growth of the German offshore wind TIS (F1; F4).

Phase 5: Resource crisis (2009-2013)

With more and more wind parks proceeding with their plans and taking investment decisions, some problems come more to the fore. First, regarding grid connections, the 2006 InfrStrAccAct had left open the conditions that offshore wind projects have to fulfill so that the TSO would actually start constructing a cable connection for the future farm. For deciding on this, TSO Tennet develops certain criteria. The finance commitment is one of these. However, the park planners cannot deliver it without having a grid connection. A problem of mutual dependence of the grid access and finance commitments arises, commonly referred to as the “chicken-egg-problem”. Addressing this serious bottleneck, in 2009 the regulator in charge (Federal Network Agency, BNetzA) proactively clarifies the cable connection conditions in a position paper, suggesting a clear order in which planners and TSOs should deliver proofs or contracts [P.impl] (F4) (BNetzA, 2009). After the introduction of this non-binding position paper, the situation at first eases (F6), so that the first wave of investment decisions for around three GW takes place (F1) (Interviewee A). However, due to a number of problems on the side of the responsible TSO TenneT, including technical difficulties such as with TenneT’s suppliers (due to the novelty of the technology) and financial bottlenecks due to TenneT’s relatively small size, the whole process of cable planning and implementation often takes much longer than anticipated – delays of more than a year are common. In most cases, the cable connection is not finished when the offshore wind farm is ready to start operation, thus causing high costs for the operators (Interviewees A; J; O; P).

In addition, in 2009-2010 the climax of the financial crisis is still going on when some of the first commercial projects need financing at the capital market. Due to the high uncertainties offshore projects feature, only about ten private banks grant loans of at most 30-50 million Euros for one project whose costs easily amount to 1.5 billion Euros. This means that the capital on the financial market does not suffice for these first projects (-F6). Responding to this bottleneck, the government sets up a loan program in mid 2011 [P.mak; In.sys], which is issued by the publicly owned Development Loan Corporation (KfW bank). This program grants loans at market conditions for up to ten offshore wind farms in Germany and as such potentially eases the tight financial situation[41] (F6). However, its main initial effect is probably the positive signals it sends out regarding the ongoing political will to support offshore wind (F4) (Interviewee K).

One of the key events in this phase is initiated by the TSO TenneT. With an open letter to the chancellor, in November 2011 TenneT turns to the government announcing that the firm cannot keep up with the pace of installation of transmission cables in the North Sea due to bottlenecks with its suppliers, shortage of materials and a lack of finance (-F6) (Wind Power Monthly, 2011). TenneT states that the current law regulating grid access (EnWG) should be changed towards a more overarching offshore wind grid planning (Wind Power Monthly, 2012a). So far, the EnWG stipulates that the TSO entirely finance the grid connection. Utility E.ON and other planners warn they will halt their investments if the TSOs do not speed up the construction of transmission cables (-F4) (Wind Power Monthly, 2012b).

The government addresses these resource constraints in the following ways. In a reaction to the grid problem, which has built up and worsened over several years, in December 2012 the EnWG is finally amended [P.mak; In.sys] based on an initiative by the BMWi (responsible for grids) and the BMU, and in close cooperation with affected stakeholders (F4; F6) (Interviewees A; J). It introduces a system change in grid access whose main novelty is that the TSO and the project developer negotiate a fixed date for an operation-ready grid connection, which becomes mandatory 30 months before the date's expiry (formerly the grid connection had to be ready when the farm was ready to operate). If the TSO then cannot adhere to this fixed date, a liability clause ensures that the farm operator is compensated financially for each day the farm stands idle and thus cannot feed in electricity. Also, this system change foresees more frequent appraisal of the grid access situation and adjustments in planning, thereby involving all relevant stakeholders (Stiftung Offshore Windenergie, 2012).

Furthermore, in a reaction to the acute financial resources problem and besides the KfW loan program, the German government follows the suggestions of the 2011 EEG experience

41 However, probably due to severe grid access delays hindering many projects, only few projects actually are in need of (external) capital and make thus use of this program (in 2013 only three projects have used the program) (Interviewee A).

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report and once again increases the offshore wind FIT in the 2012 EEG amendment [P.mak; In.dp]. It introduces the option of a so-called compression model, in which the initial FIT is higher (19 ct/ kWh) but is granted for a shorter period (eight instead of twelve years). Alternatively, offshore wind farm operators can still choose the basic initial tariff of 15 ct / kWh for twelve years (F4; F5) (EEG, 2012).

Both of these improvements in the instrument mix do not only signal the sustained political will with regard to advancing offshore wind in Germany and therefore create new hopes and expectations that the situation will finally improve [PM.cred] (F4). They also trigger new innovation activities by offshore wind firms, which are, however, very soon foiled.

In January 2013, the environment minister Peter Altmaier makes waves in the renewable energy sector and beyond when announcing plans for lowering soaring electricity costs for consumers – the so-called electricity price brake [P.mak] (Rheinische Post, 2013). These plans foresee cuts in FITs for renewable energy technologies, including for existing plants (Spiegel Online, 2013). Although many of Altmaier's proposals are dismissed later on, this mere discussion creates huge uncertainties among investors in offshore wind. Investors put ongoing projects on hold, such as EnBW the parks *He Dreiht* and *Hohe See*, which also has negative implications for technology suppliers (-F4). This discussion therefore immediately cushions the recent new hope that the dissolving of the grid access problem and the even higher (initial) FIT in the compression model has brought about (Interviewee O).

In sum, the problems of grid connections for parks and financial resources bottlenecks due to the financial crisis dominate this phase. These problems delay offshore wind projects and make external investors reluctant to invest in these (-F4; -F6). Reactions by the respective policy makers result in new or altered policy instruments [P.mak; In] that – in spite of being tardy – successfully address these problems and signal the strong political will to continue to support the growth of the German offshore wind TIS [PM.cred] (F4). However, the electricity price brake discussion in early 2013 [P.mak], shortly after the former problems are solved, immediately suppresses the newly created hopes and puts many activities on hold (-F4).

4.5. Discussion of dynamic policy mix-TIS interdependencies

Having outlined the evolution of the offshore wind TIS and its policy mix, in the following we will shed more light on dynamic interdependencies in this evolution (see Table 15). We will thereby consider all major components of the policy mix concept, namely the policy strategy, the instrument mix, policy processes, policy mix characteristics and actors as an important dimension of the policy mix. The development of the German offshore wind TIS and its policy mix is tightly interlinked: early TIS developments, such as entrepreneurial activities, occur, requiring some kind of policy regulation. In reaction to these activities policy mix components are therefore introduced, which enable TIS developments to continue. However, problems emerge in the TIS, and policy mix components are subsequently adjusted to address these. Once these problems appear to be resolved, TIS developments continue, but then new or reinforced problems come up. There is again an adjustment of the policy mix, and so forth. These interdependencies are a continuous cycle in which the TIS constantly influences the policy mix and vice versa, so that both continue to develop and expand.

Two key patterns of these dynamic interdependencies are, first, that early entrepreneurial activities need regulation in the form of policy mix components. These newly set up policy mix components subsequently enable TIS development to continue, as in the case of the permit standards introduced by the Maritime and Hydrographic Agency. This is an example of policy implementation – since the standards were passed by a public authority – which responded to a lack of detailed rules on how to handle permission requests. Second, policy mix components are set up or adjusted to remedy severe problems in the TIS, which occur in relation to concrete planning activities starting in the early to mid 2000s. These policy mix components alleviate problems of the time, so that TIS developments can continue. This frequently occurring main pattern applies to a number of policy mix components introduced in a later phase, including the EEG amendments, the KfW program and the EnWG amendment from 2012.

Regarding the second interdependency pattern, we find that most systemic problems are addressed through the alteration of (mal-functioning) policy instruments, particularly demand pull and systemic instruments. For problems with demand pull instruments, dominated by the EEG with its FIT, it is normally the function market formation (F5), which is not working properly, causing problems with entrepreneurial activities (F1). Once these demand-pull instruments have been adjusted, market formation (F5), entrepreneurial activities (F1) and also guidance of the search (F4) improve, though often only temporarily. Systemic instruments, particularly the grid access regulation specified in the EnWG, tend to be changed in reaction to problems with market formation (F5) or resource mobilization (F6), which together hamper entrepreneurial activities (F1). The new or altered systemic policy instruments then contribute to stimulating these functions (F1, F5) and improve the guidance of the search (F4), thus temporarily alleviating important systemic problems. What both of these interdependencies have in common is that first attempts of addressing the occurring systemic problems did not lead to a long-lasting solution, despite initial signs of problem alleviation. This is mainly a consequence of unexpected developments, such as instrument mix interactions.

Unlike in other emerging renewable energy TIS, particularly in other countries (e.g. Jacobsson, 2008; Negro et al., 2007), problems in the German offshore wind TIS have so far always been addressed, i.e. the policy mix has always been adjusted to deal with unforeseen or underestimated problems, and as a consequence the TIS developed further. Thus the question arises why barriers have continually been addressed or even overcome. A major reason for this appears to be the combination of high commitment to the technology by policy makers and industry advocacy coalitions. Thereby, the strong and stable commitment for offshore wind by the former actors translates into a high value of the policy mix characteristic credibility and is reflected in a generally strong guidance of the search (F4) (Wieczorek et al., 2013). A crucial determinant of this high credibility is the long-term target for offshore wind together with the implementation of supporting instruments underlining the political will to promote the technology. The existence of this ambitious and credible long-term target – the key policy strategy element of the offshore wind policy mix – has stimulated innovation activities over a long time, particularly knowledge development (F2) and, in contrast to other policy mix components, did not contribute to systemic problems but had a very positive influence on TIS functioning and performance. However, this high policy mix credibility can quickly be destroyed and then bring TIS developments to a hold. This can be illustrated by the electricity price brake discussion in 2013, which is part of a policy-making process. It caused huge uncertainties based on which projects were put on hold (-F1) and technology development was slowed down (-F2), even without any changes in the instrument mix.

Turning to actors as both a dimension of the policy mix and a structural component of TIS, other TIS actors besides policy makers – primarily industry actors – have a share in the (successful) continuation of the TIS and policy mix developments. This also confirms former studies stressing the importance of actors in innovation systems (Erlinghagen and Markard, 2012; Markard and Truffer, 2008b). Over time, several important actors have brought the TIS forward. Innovative and risk-taking entrepreneurs were crucial in a very early TIS phase, while subsequently single policy makers together with industry representatives organized in the Offshore Wind Foundation as well as other industry associations advocated the TIS, contributing to the design and implementation of favorable policy mix components. Finally, the entering of large utilities into the TIS, i.e. of incumbents, turned a formerly opposing actor group into offshore wind proponents (F7). The same applies to the formerly relatively passive economics ministry, and both the ministry and incumbents contributed to the take off of the TIS at around 2009. What was also fundamental for this take off was the pilot and demonstration project Alpha Ventus – a special kind of policy instrument and unique project. This project, which was called for by early entrepreneurs, pushed by the manufacturing industry association VDMA and supported by policy makers in the BMU, affected almost all TIS functions positively. For example, projects were being started or finally took off, since Alpha Ventus demonstrated the feasibility of projects in deep waters far off the shore (F1), and new knowledge on how to build and operate parks was developed (F2) and exchanged (F3).

While the patterns of development of the policy mix and TIS can be expected to continue, the reduced ambition levels of the so far stable long-term offshore wind target suggest a somewhat reduced momentum, with consequences for the future development of the German offshore wind TIS. The recent lowering particularly of the 2030 target from formerly 25 GW to 15 GW decreases market expectations and thus reduces the attractiveness of the German offshore wind market (Hamburger Abendblatt, 2014). This may negatively impact several TIS functions, such as entrepreneurial activities, and TIS performance, such as the rate of technology diffusion. In addition, the national policy mix and TIS might become less important since industry players may expand the geographical range of their markets to growing offshore wind markets abroad. Given that several other countries start to voice their interest in offshore wind, export markets could indeed counter these German growth reductions. Yet local content requests, as can be increasingly observed in the UK (Kern et al., 2014), for instance, may hamper such a Europeanization of the TIS, which may become a future concern of policy makers.

In sum, despite only touching upon the plethora of interdependencies that exist between the policy mix and TIS developments, our analysis demonstrates that all components of the policy mix interact with TIS developments. These often tight interactions are complex and do not only exist *between* the policy mix and TIS developments but also *within* each of these. For example, a policy-making element (the electricity price brake discussion) affected a policy mix characteristic (credibility), which then negatively affected some TIS functions (e.g. F1, F2). Although at first sight it seems to be policy instruments that interact most with the TIS, especially in relation with systemic problems, the role other policy mix components such as the policy mix characteristic credibility play should not be underestimated.

TABLE 15: Changes in policy mix components, how they were influenced by the TIS and their main effects on TIS functions and performance

Policy mix component	Type of policy mix component*	Year of introduction / alteration	Main involved actors	TIS influence on PM components		PM component influence on TIS	
				Underlying TIS developments for coming about of PM components	Involved TIS functions	Effects of PM components on TIS performance (technology development, use, diffusion)	Main effects on TIS functions
SeeAnlV	In.sys	1997	Entrepreneurs, BMVBS	No regulation in place for handling offshore wind permission requests	F1, F5	Enables OW[a] permits → potentially contributes to technology use	+F5
Permit standards	P.impl	early 2000s	BSH	No detailed rules for handling permission requests	F1, F5	Enables standardized permit process → potentially contributes to technology use	+F5
EEG introduction	In.dp	2000	Red-green government	First time greens in government → green party support	F4	Investment trigger and guidance → potentially drives technology use & diffusion	+F4, +F5
Offshore wind long-term target	PS	2002	Two policy makers from BMU	Early entrepreneurial activities → wish to provide guidance and thus push TIS development	F4	Stimulates subsequent innovation activities → contributes to higher technology development activities, later to technology use & diffusion	+F2, +F4, +F5
EEG amendment: OW FIT introduction	In.dp	2004	Scientists, BMU, environmental NGOs	EEG experience report: offshore more expensive than onshore wind	F5	No more FIT for parks in nature protection areas → reduced opposition by environmental NGOs	+F7
InfrStrAccAct	In.sys	2006	BMU, BMWi, farm planners	Uncoordinated cable planning, ecological and economic non-effectiveness	F5, F6	Cable connection problems ease → accelerates potential technology use and diffusion	+F5
Setting up demonstration project Alpha Ventus	In.tp, In.dp	planning start: 2005	TPs, OW Foundation, BMU	Offshore wind does not take off partly due to technical uncertainties	F1, F2	Demonstrates feasibility of offshore wind and increases credibility & expectations: big utilities enter offshore wind, projects take off → stimulates technology use and diffusion	+F1, +F2, +F3, +F4, +F5, +F7

Policy mix component	Type of policy mix component*	Year of introduction / alteration	Main involved actors	TIS influence on PM components		PM component influence on TIS	
				Underlying TIS developments for coming about of PM components	Involved TIS functions	Effects of PM components on TIS performance (technology development, use, diffusion)	Main effects on TIS functions
EEG amendment	In.dp	2009	Farm planners, industry associations, scientists, BMU	Offshore wind does not take off partly due to low FIT (relative to higher than expected costs)	F1, F5	Makes OW projects economically attractive: big utilities enter OW & projects take off → stimulates technology use and diffusion	+F1, +F5, +F6
BNetzA position paper	P.impl	2009	BNetzA, TSOs	Chicken-egg-problem in grid access → timelines of cable and farm planning are not compatible	F1, F4	Cable connection problems ease → first wave of investment decisions taken → facilitates technology use & diffusion	+F1, +F5, +F6
KfW offshore wind program	In.sys	2011	BMU, KfW	Lack of capital at financial market during financial crisis	F1, F6	Signal of persisting political will to support OW, enables start of few projects	+F1, +F4, +F5, +F6
EnWG amendment	In.sys	2012	Tennet, BMU, BMWi, OW Foundation, farm planners	Escalation of grid access problem: TenneT announces inability to connect further farms under current circumstances	F6	Relief & new hope, farm planners intend to continue planning → potentially enables continuation of technology diffusion	+F1, +F4, +F5
EEG amendment	In.dp	2012	Industry & researchers, BMU	Greater financial stimulus needed due to financial resources problem and low number of implemented projects so far	F1, F6	Potentially triggers more projects to be built	+F6
Electricity price brake discussion	P.mak	2013	Environment minister	Increasing costs of EEG for consumers	F7	Immediately brings ongoing projects to halt; stops, puts on ice or slows down OW technology development and diffusion activities	-F1, -F2, -F4, -F7

* PS = policy strategy, In,dp = demand pull instrument, In,tp = technology push instrument, In,sys = systemic policy instrument, P.impl = policy implementation, P.mak = policy making; [a]OW = offshore wind; [b]RET = renewable energy technologies

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4.6. Conclusion

In this paper we took a first step towards a more explicit and differentiated consideration of the role of policies in the development of technological innovation systems. For doing so, we applied a comprehensive policy mix concept in our analysis of the TIS of offshore wind in Germany, studying the dynamic interdependencies between the policy mix and the rest of the innovation system. We found tight interlinkages reflecting continuous interactions between observed problems in the TIS, the articulation of these problems and the subsequent alteration of the policy mix in place. In this cycle the policy mix did not only positively influence TIS developments but also contributed to the emergence of new or to the reinforcement of existing systemic problems. Alterations in the policy mix were then needed to solve these new problems. Thus, the systemic problems and their attempted solution in turn shaped the evolution of the policy mix with its many technology-specific and some generic elements. In our analysis of policy mix-TIS interdependencies we considered all components of the policy mix concept, and we found that all of them interacted with TIS developments. These rather tight and often complex interactions did not only occur between the policy mix and TIS but also within each of these.

Conceptually, our analytical framework should be seen as a first step incorporating a more comprehensive policy mix concept into the TIS approach. We show that such a more differentiated treatment of policies in TIS enables a better understanding of the role and effectiveness of policy mix elements, processes and characteristics – rather than only of single policy instruments – for TIS development and functioning. Furthermore, this differentiated policy treatment provides deeper insights into the tight interdependencies between the TIS and policy mix developments over time. Analyzing not only the one-way link of how policies affect the TIS but also the reverse link contributes to a better understanding of real dynamics occurring in TIS (see Hoppmann et al., 2013). Thereby our study underlines the need to reconsider the under-conceptualization of policies within the TIS approach, in which policies – or the policy mix – are so far hidden as one constituent of the institutions of a TIS and are at the same time used as indicator for TIS functions, such as market formation. This does not reflect their key importance particularly for emerging TIS, and is detrimental to proper evaluations of their actual effectiveness.

Based on our findings we derive four key implications for policy makers aiming to advance emerging TIS in the environmental field more generally. First, the existence of a policy strategy with an ambitious and stable technology-specific long-term target promises to be highly beneficial for stimulating TIS developments due to the market expectations it creates. Second, demand-pull instruments with design features tailored to the emerging technology, such as a feed-in tariff with a sufficient level of support, play a central role for TIS development. In addition, systemic instruments are also of crucial importance, both as initial catalyst by supporting pilot projects and as backing for enabling technologies and infrastructures. Third, a credible political commitment towards the technology is of great importance for such an emerging TIS, since it potentially acts as a main driver for continuing TIS developments in times of systemic problems. Finally, from a dynamic TIS development perspective, due to constant changes in the TIS flexible adjustments of policy mix elements appear vital for maintaining continuity in TIS development. This calls for the establishment of policy processes striking the delicate balance between providing stability and allowing for needed adjustments.

This study is not free from limitations and thus calls for future research, for which we see three main avenues. While we investigated the interdependencies between several policy mix components and the TIS over time, future studies should focus in more detail on often neglected policy processes and their role in TIS, as this may reveal additional insights into TIS dynamics. In addition, since actors greatly shape the TIS and the policy mix, analyzing agency and politics in more depth would contribute to a better understanding of TIS development. Finally, the TIS approach may benefit from a conceptual disentangling of policies, or more precisely of the policy mix, from the structures and functions of technological innovation systems.

Chapter 5

Unpacking the policy processes for addressing systemic problems in technological innovation systems: The case of offshore wind in Germany

This chapter has been submitted to *Renewable and Sustainable Energy Reviews* and is currently under review. Authors are Kristin Reichardt, Karoline S. Rogge and Simona O. Negro.

5.1. Introduction

Analyses of technological innovation systems (TIS) focus on emerging technologies often in early phases of development (e.g. Jacobsson & Bergek, 2004). Typical for these early stages is the existence of a number of failures hindering the development and diffusion of the young technologies, so that it is particularly hard for them to compete with established technologies (Carlsson and Stankiewicz, 1991). For overcoming these failures and allowing the technologies to become market-ready, government intervention is needed (Borrás and Edquist, 2013; Klein Woolthuis et al., 2005).

Against this background, the goal of TIS studies is to identify such failures or systemic problems and, based on this, suggest concrete tools for policy intervention, so as to purposefully foster the technology (Jacobsson & Bergek, 2011). There exists a considerable number of studies having completed exactly such analyses. One of the first studies of this kind is Negro et al. (2008) that analyzes the functional patterns of the biomass TIS in the Netherlands identifying corresponding system failures and suggesting policy measures for addressing them. Further studies that examine systemic problems via a functional analysis of TIS and identify areas for policy intervention include, for example, Jacobsson and Karltop (2013), van Alphen et al. (2010), and Jacobsson (2008). While the analytical framework applied in these studies has helped policy makers by analyzing where policy intervention is needed and has suggested policy instruments, studies have focused much less on associated policy processes.

In this regard, recent studies identified a need for a better conceptual understanding of institutions in TIS, including the regulatory frame (Truffer et al., 2012) and tools for the selection of policies that address system failures (Coenen and Díaz López, 2010). Related to that, the literature called for a more detailed understanding of the dynamics of policy intervention processes that result from addressing systemic problems (Hoppmann et al., 2014). These studies hint at the importance of more thoroughly examining policies in TIS, particularly policy processes. It is therefore the goal of this paper to address this gap by analyzing policy-making processes that respond to systemic problems and exploring how these processes influence TIS functioning and TIS performance in terms of technology use and diffusion (Bergek et al., 2008; Hekkert et al., 2007). In particular, we focus on the style of these policy-making processes – or policy style in short – as the policy style has been argued to be an important determinant for eco-innovation (Jänicke et al., 2000), and analyze the role of this style for the TIS. This focus on the role of the policy style allows for revealing vital information about the nature and impact of such policy processes, which in turn enables us to derive concrete policy recommendations for how to improve policy making so as to foster the development of an emerging TIS.

For our analysis we frame policy processes as part of a comprehensive policy mix concept (Rogge and Reichardt, 2015). It is these processes that shape the elements of the policy mix – that is the policy strategy and various instruments. Thereby the processes can have an indirect impact on innovation. However, it has been argued that policy processes may also directly influence innovation, yet with few empirical studies investigating this link.

We address this gap in the literature by examining the role of policy processes for technological innovation systems, taking the case of offshore wind in Germany. The main reason for choosing this case is that the German offshore wind TIS has experienced several systemic problems that were addressed by policy makers, ultimately contributing to the evolution of a complex policy mix as well as to some positive developments in terms of TIS functioning and performance (Reichardt and Rogge, 2016; Reichardt et al., 2016). Methodologically, we combine expert interviews and desktop research to analyze the policy-making processes in which two crucial systemic problems were addressed. These problems posed the greatest barriers in the TIS in recent years and were thus decisive for the further direction of the TIS. In doing so, we shed light on the direct and indirect mechanisms by which the style of these processes impacted TIS functioning and TIS performance.

In the following we will first review the literature on technological innovation systems and policy processes, with a focus on policy-making processes and their relevance for TIS functioning and performance (section 5.2). We then provide a brief overview of the research case (section 5.3), and a delineation of our methodological approach (section 5.4). Subsequently we describe the policy-making processes as well as the associated policy-making style and analyze the effects on the TIS (section 5.5). Finally, section 5.6 concludes.

5.2. Technological innovation systems and policy processes

The technological innovation systems (TIS) approach has been widely applied to the analysis of emerging technologies, among others in the field of energy technologies (Bergek, 2012; Jacobsson and Bergek, 2011; Truffer et al., 2012). The major goal of these studies is to detect system strengths and weaknesses by analyzing the structure and functions of the TIS. While structural analyses of TIS focus on describing its actors, networks and institutions and thus constitute static inquiries (Edquist, 2005), functional analyses map a range of different activities taking place in the TIS. For doing so a number of key functions are applied (Hekkert et al., 2007, Table 16). This functional analysis serves as prerequisite for explaining the performance of TIS in terms of the development and diffusion of innovations (Bergek et al., 2008; Hekkert et al., 2007). Based on the identified system strengths and problems, concrete recommendations for government intervention are given so as to improve system functioning. In doing so, studies often suggest which policy instruments might best be suited to remove the systemic problems (Simona O Negro et al., 2008; Wieczorek and Hekkert, 2012).

TABLE 16: Key functions of technological innovation systems

Function (function number)	Description
Experimentation and production by entrepreneurs (F1)	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.
Knowledge development (F2)	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.
Knowledge exchange (F3)	The exchange of relevant knowledge between actors in the system is essential to foster learning-processes.
Guidance of the search (F4)	The processes that lead to a clear development goal for the new technology based on technological expectations, articulated user demand and societal discourse enable selection, which guides the distribution of resources.
Market formation (F5)	This function refers to the creation of a market for the new technology. In early phases of developments this can be a small niche market but later on a larger market is required to facilitate cost reductions and incentives for entrepreneurs to move in.
Resource mobilization (F6)	The financial, human and physical resources are necessary basic inputs for all activities in the innovation system. Without these resources, other processes are hampered.
Creation of legitimacy (F7)	Innovation is by definition uncertain. A certain level of legitimacy is required for actors to commit to the new technology and execute investments, take adoption decisions etc.

Source: adapted from Wieczorek et al. (2013)

In terms of policy, TIS studies have so far focused on policy instruments and their role for innovation systems. That is, some studies show how policy instruments impact innovation systems (Kivimaa and Virkamäki, 2013; McDowall et al., 2013), while other studies state which policy instruments may be effective in improving TIS performance (Negro et al., 2007; van Alphen et al., 2010). Another aspect TIS studies consider with regard to policies is system building, such as how actors shape the build up of innovation systems and their institutions, including policies (Kukk et al., 2014, 2013).

However, policy processes have as yet been largely neglected in TIS studies (Coenen and Díaz López, 2010; Hillman et al., 2011), although their importance for innovation has recently been stressed, e.g. in the policy mix literature. For instance, Flanagan et al. (2011) in their call for a reconceptualization of the policy mix for innovation point out that policy processes should be an integral part of policy analyses. Rogge and Reichardt (2015) acknowledge the importance of policy processes in their policy mix concept, based on their potential influence on policy mix effectiveness, for instance regarding innovation.

The study by Chung (2013) on technology and innovation policies in Taiwan is one of the first and very few ones to focus on the analysis of policy processes in an innovation system context. It analyzes the link between the innovation policy-making process, the design of innovation policy instruments and the development of the innovation system, finding vital dependencies between these factors. However, what is still lacking is an analysis of the direct impact of policy processes on the innovation system.

In order to address this gap an important starting point is to clarify what is meant by policy processes, given the multitude of definitions that have been used (Howlett et al., 2009). Due to our focus on policy in the context of innovation we rely on Rogge and Reichardt (2015) who, in their policy mix concept for innovation, define them as "political problem-solving process among constrained social actors in the search for solutions to societal problems" (p. 13). Besides the crucial role of actors, this definition stresses an important aspect for this study, namely the fact that policy processes aim at solving (societal) problems.

Policy processes with their plethora of diverse actors with heterogeneous interests and often long time horizons are usually extremely complex (Sabatier and Weible, 2014). In order to analyze and better understand such complex processes different theories on the policy process have been developed that explain how these processes shape policy outcomes (Sabatier and Weible, 2014). However, the objective of this study is not to explain how or why certain policy outcomes, such as policy instruments, or changes in these, come about by policy processes but to study the role of such processes for the technological innovation system. We therefore need an analytical concept for capturing these policy processes, which then enables us to analyze their impact on the TIS. For this purpose the concept of policy style – first introduced by Richardson (1982) – seems appropriate since it captures the nature of policy processes, i.e. the "operating procedures for making and implementing policies" (Richardson, 1982).

In his seminal work Richardson (1982) proposes describing national policy processes by contrasting anticipatory versus reactive and consensus-oriented versus impositional policy styles. More recent studies have built on this generic policy style typology, analyzing policy styles, often of particular countries, and describing them in terms of, e.g., the degree of consensus in policy formulation, the role of expert advice or the extent to which policy making occurs unilaterally in a top-down manner (Birrell and Heenan, 2013; Cairney, 2008; Toke and Nielsen, 2015). In this paper we build upon and extend Richardson's generic typology of policy style by drawing on three approaches reflecting policy styles that can often be found in real-world policy processes and that seem to be particularly relevant in the context of emerging TIS: the science of muddling through, adaptive policy making, and participatory policy making. In combining these, we rely on a more differentiated typology serving as our analytical concept to describe the style of policy processes.

The first approach is Lindblom's (1959, 1979) *science of muddling through* or incrementalism, which purports that rational-comprehensive decision-making is hindered by constraints in intellectual and informational capacities as well as time and resources. Rather, when changing existing policy instruments administrators compare a limited number of similar alternative instruments and thus design policy in an endless process of incremental but easily reversible steps. Policy making in this manner is assumed to bring about only incremental changes compared with the status quo. Lindblom argues that a continuous sequence of incremental steps nonetheless might lead to faster policy-induced changes than any comprehensive policy-making approach. More recent studies evaluated Lindblom's approach in the light of scientific advances since it has been developed, concluding that in parts it does no longer hold to a globalized, networked and rather conflictual policy-making world, which can be described by more far-going models of the policy process with greater explanatory power. Yet its basic idea of incremental steps in policy making still applies today (Atkinson, 2011; Pal, 2011).

The second approach considered, which is in part related to the idea of incrementalism, is *adaptive policy making* (Walker et al., 2001). It assumes that policy instruments are usually designed for a certain future scenario and that in fact often another scenario occurs, so that the original instruments do not fit any more. Therefore, it is argued that policy instruments should not be tailored to a particular scenario of the future but should be able to adapt to changing circumstances. Such policy instruments should consist of components with the potential to shape the future and components that preserve the needed flexibility. That is, policy instruments should make explicit provision for learning and respond to changes over time. They should also leverage the self-organizing potential of all kinds of actors and the decentralization of governance to detect emerging policy issues and design the needed adaptations in policy instruments (Marchau et al., 2010; Swanson et al., 2010). Overall such adaptive policy-making processes are likely to be more effective than rational processes aiming for 'optimal' designs, since they can adjust to specific situations (Bankes, 2002).

5

Finally, the third approach is that of *participatory policy making*, which has been conceived as the degree of involvement of diverse stakeholders with their stakes and values in policy processes (Frantzeskaki et al., 2012; Stigson et al., 2009). This stakeholder involvement is deemed to be necessary particularly in the context of sustainability transitions – such as the German energy transition, for which the emerging offshore wind technology is playing a role – since a plethora of actors are needed for such a transition to be accomplished. Involving them in policy processes might also contribute to maintaining social equity and cohesion (Frantzeskaki et al., 2012). Participatory policy processes are likely to lead to policy instruments with designs better tailored to the particularities of target actors and which are thus more accepted by affected actors.

Based on these three approaches, which extend Richardson's seminal typology, the nature of policy-making processes can be described in terms of muddling through (which we also refer to as incrementalism), adaptiveness and participatory policy making. Analytically, we are interested in shedding light on how the policy-making style – captured by these three categories – influences the functioning and performance of a technological innovation system. Here, by functioning we refer to the seven TIS functions elaborated by Hekkert et al. (2007) while by performance we mean technology use and diffusion. By analyzing this link between policy-making style and TIS we take an important step towards incorporating policy processes as part of a broader policy mix in TIS analysis.

5.3. Research case

For our analysis we selected two policy processes in the German offshore wind TIS. In the following we explain why we chose this research case.

Regarding the TIS in focus, we chose the German offshore wind TIS for three major reasons. First there are ambitious targets in place for offshore wind in Germany, i.e. 6.5 GW of installed capacity by 2020 and 15 GW by 2030 (CDU et al., 2013), but the TIS still displays a poor performance with only 0.52 GW installed at the end of 2013 (EWEA, 2014a). This might be due both to the comparative immaturity of the technology with related high costs (Fichtner and Prognos, 2013), and to the existence of systemic problems in the TIS. Second, an encompassing policy mix has been set up, implying that policy makers may somehow have attempted to address these problems. Third, offshore wind is a technology with great technological potential and growth prospects, and could thus play an important role in a decarbonization of the energy sector, not only in Germany but also globally (e.g. EWEA, 2013). This technological potential results from the strong and steady winds at sea and correspondingly many full-load hours (4,000 compared to 2,000-2,500 onshore) as well as the technology's large scale and associated great project sizes (EWEA, 2009b). Against this background, Germany is an interesting case since it is one of the fastest growing offshore wind markets worldwide (pwc and wab, 2012), despite its currently relatively low installed capacity.

Regarding the chosen policy processes addressing systemic problems, out of five identified systemic problems (Reichardt et al., 2016) we selected those two that posed the greatest barriers in the TIS in recent years and whose resolution essentially contributed to the further development of the TIS. These problems are, first, an insufficient level of support of the feed-in tariff for offshore wind in the mid 2000s and second, heavy delays in grid access provision for parks between about 2010 and 2012. The existence of the first problem can be traced back to the mismatch between the foreseen EEG feed-in tariffs for offshore wind and actual cost developments and is therefore closely linked to the Renewable Energy Act (EEG). The second problem was mainly caused by the ineffectiveness of the grid access regulation for offshore wind parks specified in the Energy Economy Law (EnWG) and evidenced by delays in grid access to be provided by TSO TenneT. Since these two policy instruments were decisive for the existence of the systemic problems, we will shortly introduce them.

The Renewable Energy Act (EEG) has been put in place in the year 2000 with the goal to significantly increase the share of renewable energy technologies in Germany. For achieving this, it introduced – among others – technology-specific feed-in tariffs with a twenty year guaranteed payment per produced kilowatt-hour of electricity (EEG, 2000). While in the initial EEG there was only one feed-in tariff (FIT) for onshore and offshore wind, the first offshore wind-specific FIT was introduced with the 2004 EEG amendment, since higher costs were expected for offshore than for onshore plants. This offshore wind FIT was increased – according to updated cost estimations – several times in the course of the years, besides in 2004 also in 2009 and 2012 (EEG, 2012, 2009).

The grid access for parks was originally regulated in the EEG, according to which park operators were to finance the grid connection themselves (EEG, 2000). This provision was changed with the Infrastructure Planning Acceleration Act (InfrStrPlBeschlG) in 2006, becoming part of the Energy Economy Law (EnWG). It shifted the responsibility of connecting offshore wind parks to the grid from the park operators to the transmission system operators (TSOs) and prescribed that this connection had to be available when a farm was ready to start operation (InfrStrPlBeschlG, 2006). Due to several emerging problems, this grid access regulation had to be changed again, with a fundamental 'system change' occurring in 2012 (see section 5.5.1.2). An essential provision of this new system is that the operators are to negotiate a date with the TSO at which the grid access would be provided. If the TSO cannot adhere to this date, it is to financially compensate the operator for the standstill. In addition, TSOs are to put up a yearly offshore grid development plan detailing the location, timing and size of new grid connection cables (EnWG, 2012).

5.4. Methodology

To investigate policy-making processes addressing systemic problems and how they influence TIS, we chose a qualitative approach. This allows, first, for a detailed analysis of these processes and their style, such as how certain decisions were taken and executed, and for an in-depth investigation of the processes' impacts on the TIS. Second, such an exploratory approach is particularly suited for areas of research that have not yet been systematically studied, which is the case for the relevance of the style of policy processes for TIS (Yin, 2009). Our methodological approach therefore is based on expert interviews and supplemented by desktop research providing secondary data for triangulating our interview findings.

For our expert interviews we selected stakeholders who – either in person or via their organization – played a crucial role in the respective policy-making process. This enabled us to get detailed 'insider' information on these processes and on the role they played for the TIS. We interviewed two groups of stakeholders: The first group were experts that were themselves deeply involved in the policy-making processes. Second, we interrogated various other actors who were involved in or knowledgeable about the systemic problems, so as to obtain a detailed understanding of the problems and their contexts. In total we conducted fifteen interviews with experts in the TIS under study, including representatives of the government, public organisations, the transmission system operator, industry associations and NGOs (see Table 17).[42] Interviews took place between July 2013 and January 2014 and on average lasted about eighty-four minutes. All interviews relied on a semi-structured interview guide and were conducted by telephone. We transcribed and coded the interviews with codes for each of the two systemic problems, the policy-making processes, and different actors. In order to safeguard the interviewees' anonymity, throughout this text we reference them with letters from A to N, which were randomly assigned to the interviewees.

TABLE 17: Overview of expert interviews

Actor type	Organization	# interviews
Government	Federal Environment Ministry (BMU)	3
	Federal Maritime and Hydrographic Agency (BSH)	2
	Federal Network Agency (BNetzA)	1
Public organizations	Reconstruction Loan Corporation (KfW)	2
	Center for Wind Energy Research (ForWind)	1
Transmission system operator (TSO)	TenneT	1
Industry associations	Offshore Wind Foundation	1
	German Engineering Association (VDMA)	2
	Wind Energy Agency (wab)	1
Non-governmental organization	World Wide Fund for Nature (WWF)	1
SUM		**15**

In addition, we complemented our interview data with secondary data. For this, we screened relevant documents related to the policy-making processes and their underlying systemic problems. These documents included position papers by industry associations, press releases by involved actors such as the environment department and draft versions of the two legislations.

Building on the insights from the coded interviews and from the documents, we reconstructed the policy processes addressing the two selected systemic problems by identifying common themes from our data. This enabled us to thoroughly understand these systemic problems and to describe at a sufficient level of detail the style of the policy processes that occurred to address them. Finally, this data analysis allowed for identifying patterns of the processes' impacts on the functioning and performance of the TIS.

42 This data collection was embedded in a larger analysis of the German offshore wind TIS (see Reichardt et al., 2016).

5.5. Policy processes and their effects on the German offshore wind TIS

In this section we present our findings in three steps: we first describe the two selected policy processes, starting with their underlying systemic problems (section 5.5.1) and subsequently analyze their style (section 5.5.2), and finally we examine their effects on the TIS (section 5.5.3).

5.5.1. Description of the policy processes

5.5.1.1. The policy process addressing the problem of insufficient level of support of the 2004 offshore wind feed-in tariff

Systemic problem

The adjustment of the offshore wind FIT in the 2009 EEG amendment was the consequence of a severe systemic problem, which developed and increased after launching the first technology-specific FIT in 2004. At the time of its introduction as part of the 2004 EEG amendment, this FIT appeared to be adequate given the state of knowledge and most projects being still relatively far from their realization (Interviewee M). Also, a Danish project planner ensured to be able to immediately start construction with such a FIT, as this interviewee recalls: 'if we fixed the offshore wind feed-in tariff like we then actually did in the law, [...] then they [Danish project planner] could make the decision tomorrow to start construction' (Interviewee M). Nonetheless, soon after the FIT's enactment project planners realized that its level of support would probably not be cost-covering and called for its increase (Interviewees E, K). In particular, during the planning and realization process of Alpha Ventus it became clear that this FIT level was actually too low since project realization costs turned out to be considerably higher than expected (Interviewee L). Although the responsible policy makers from the Federal Environment Ministry (BMU) well knew about the problem they did not change the FIT before the next EEG amendment in 2008. Therefore in the years between approximately 2006 and 2008, this low FIT was a major reason why relatively well developed offshore wind projects were not started. This considerably delayed the further development of the German offshore wind TIS and therefore constituted an important systemic problem. In the following we zoom into the policy processes that addressed this problem and that led to the offshore wind FIT adjustment in the 2009 EEG amendment.

5

The policy process addressing the systemic problem

Although many stakeholders, e.g. industry lobby groups, had called for a higher FIT soon after the 2004 EEG amendment, the offshore wind FIT was not adjusted until 2009: the

German government did not even want to make small changes within the EEG, fearing that in such a case all different technology interest groups also wanted their FIT or other EEG regulation adjusted (Interviewee M). Waiting with such an adjustment had thus been a political decision. It had to do with the relatively formalized overall EEG amendment processes, in which the EEG is regularly adjusted as package for all technologies it covers. Each amendment is usually preceded by a so-called experience report on the functioning of the current EEG. This report is required by law every three to four years (see §65 EEG) and is to be done by the government. In fact it is drafted by the environment ministry mainly based on scientific studies that evaluate the effectiveness of the current EEG. After parliament has noticed the report and the government has released it, the environment ministry elaborates an EEG amendment draft, which again needs to be enacted by the government and is then fed into the parliamentary process to be adopted. While the experience report is mandatory by law, the EEG amendments are not. Yet due to stakeholder pressure – mainly by industry associations such as the German Engineering Association (VDMA) – to fix the aspects that needed improvement according to the experience report, and probably also to improve the situation for their constituency, policy makers have so far always amended the EEG following such a report (Interviewee M).

In the particular amendment process for the 2009 EEG, the environment ministry elaborated the regular experience report in 2007, whose offshore wind part was mainly based on studies that the ministry in 2005 had contracted to the operator consortium of the demonstration project Alpha Ventus, the German Offshore Test Field and Infrastructure Society (DOTI), and to the Deutsche Windguard, a German consultancy for wind energy. Already in the process of developing the experience report, industry associations tried to take influence. However, they were excluded from the official drafting of this report (Interviewee M). Instead the environment ministry (BMU) and the Federal Ministry of Economics (BMWi) closely collaborated when elaborating the report, discussing it "sentence by sentence" (Interviewee M) during about six to eight months. The report was released by the federal cabinet in November 2007, and given to parliament for notice. It proposed to raise the initial offshore wind FIT – at that time 9.1 ct / kWh for twelve years – to a level ranging between 11 and 15 ct / kWh and after twelve years that a plant had received this FIT lower it to 3.5 ct / kWh (BMU, 2007a). Independent from the experience report, interest groups had also posed their claims for a new FIT. Most prominently, the Offshore Wind Foundation in June 2007 had published a statement on how to alter the FIT, demanding a raise of the initial remuneration to 14 ct / kWh and after twelve years a lowering to 6.19 ct / kWh (Offshore Forum Windenergie et al., 2007).

As is usually the case, after release of the 2007 EEG experience report the political pressure to amend the EEG rose. Thus, the environment ministry in 2007/8 worked out an amendment to the EEG suggesting an increase of the offshore wind FIT corresponding to the range proposed in the report (BMU, 2007b). Following the formalized policy process, this amendment draft was again discussed with the involved ministries, i.e. the environment and economics ministries and the Federal Ministry of Finance (BMF), as well as with the federal chancellery during several months before it was enacted by the federal cabinet and sent to parliament. The FIT in this parliamentary version from February 2008 was set to 12 ct / kWh for the first twelve years with an additional 2 ct / kWh for projects starting operation before 2014 (Deutscher Bundestag, 2008). This FIT level is exactly within the range proposed in the first EEG draft (BMU, 2007b).

As a next step, the responsible parliamentary committee dealt with the EEG draft, before it went back to be finally discussed within the coalition parties (CDU, SPD) and the three involved ministries (environment, economics, finance). These last negotiations were 'an emotional discussion in which all involved actors wanted to bargain the best deals for their clientele' (Interviewee M). Regarding offshore wind, pro-offshore government members were able to increase the FIT by one additional cent compared to earlier propositions, achieving 13 ct / kWh (plus a "sprinter bonus" of 2 ct / kWh). Figure 9 illustrates this process, with the systemic problem as starting point, the moments of problem identification by project planners and policy makers, and an indication of the period of inaction by the latter actor group. It further depicts the stepwise changes in the FIT and ends with the altered policy mix element, i.e. the EEG amendment with the final level of support granted by the adjusted offshore wind FIT.

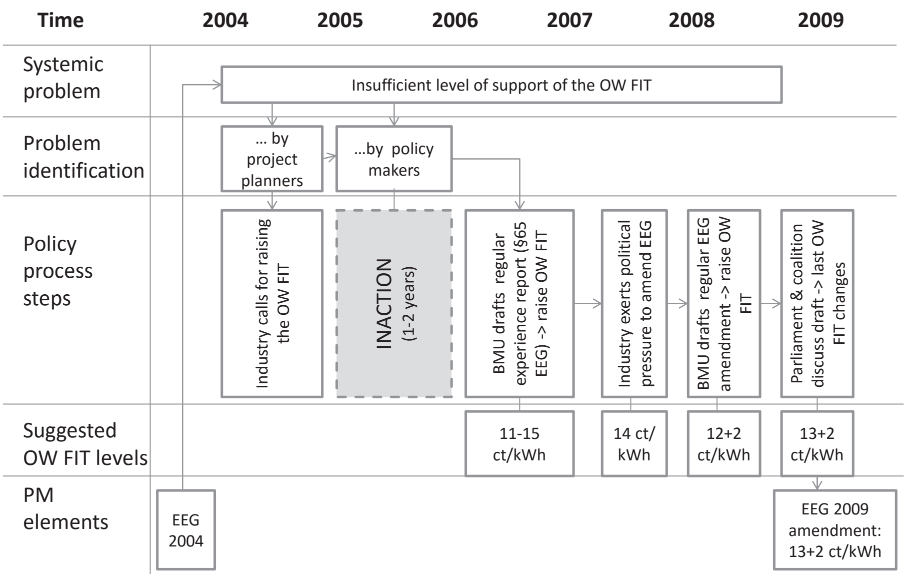

FIGURE 9: Policy process adjusting the offshore wind FIT in the 2009 EEG amendment

In sum the policy process leading to the 2009 EEG amendment was a rather lengthy process (almost five years) with interaction particularly between different government actors, and with industry groups trying to influence the FIT according to their interests. Within these frequent interactions the level of the proposed offshore wind FIT changed several times – over several political rounds it was increased step by step, with the highest level being finally adopted.

5.5.1.2. The policy process addressing the problem of delayed grid accesses after 2009

Systemic problem

The grid access regulation from 2006 left undefined which park should be connected in which order by the transmission system operators (TSOs), which is why the TSO TenneT – in charge of grid connections in the German North Sea – put up a list of criteria the projects had to fulfill in order for the TSO to become active (Interviewee H). These criteria on the one hand made the situation clearer, but on the other hand led to a new problem for project planners, known as the chicken-egg-problem. It referred to the mutual dependence of the grid access and finance commitments – each one was only possible to be attained against production of the other one (Interviewees H, J). The Federal Network Agency (BNetzA), in charge of implementing the grid access policy instruments, addressed the problem in a position paper in 2009, in which it clarified the criteria that project planners were to deliver so that the TSO had to start constructing the grid connection (Interviewee J). This facilitated a first wave of investment decisions for around three GW of installed capacity that were, besides this position paper, mainly triggered by the then increased FIT for offshore wind (Interviewee J).

However, this improved grid access situation did not last long. When planning and implementing cables for this first wave of parks, TenneT began to encounter a number of problems (Interviewees J, L; Spiegel Online, 2011). First, technical difficulties occurred, e.g. with converter stations for which TenneT's suppliers were responsible. Second, crossing the Wadden Sea National Park implied conflicts with nature protection and thus was accompanied by high administrative requirements TenneT had to fulfill. Third, TenneT experienced financial bottlenecks as well as shortages with human resources. These problems were the reason why the whole process of cable planning and realization by TenneT took much longer than anticipated and in most cases was not finished when the offshore wind farm was ready to start operation. As a consequence, offshore wind projects were delayed causing high costs for the planners, which risked to render their projects inefficient. This also meant that the future of the offshore wind TIS remained highly uncertain (VDI Nachrichten, 2013). This problem, which can be said to have its roots both in inappropriate regulatory provisions (originally in the InfrStrPlBeschlG from 2006, which did not sufficiently clarify grid access criteria for parks) and in bottlenecks with TenneT, constituted at that time the most severe systemic problem. As a consequence, in 2011 and partly in 2012 many TIS developments were put on hold (Interviewees I, J), despite the just recently resolved problem of an insufficient FIT level. In other words, solving one important systemic problem was not enough to get the TIS development going again since another systemic problem had come up. This situation can be described as inconsistency between the EEG and the grid access regulation, in which the latter policy instrument hindered the working of the former one.

The policy process addressing the systemic problem

The above described grid access problem was not adequately addressed by the responsible economics ministry (BMWi) and over time became so severe that it escalated in an urgent letter (a so-called "Brandbrief") to the government by the TSO TenneT in November 2011. In this letter TenneT argued it would be no longer able to connect offshore wind farms to the grid under the current circumstances, and asked for political help. Being forced to react due to TenneT's inaction and thus a standstill of projects waiting for grid access, the economics ministry – together with the environment ministry – took a decisive step convening a high-level meeting with the ministers in charge, Rösler and Röttgen (Interviewees H, J). They discussed possibilities for solving the grid access problem with the result that both ministries set up a working group with all affected actors, the so-called working group 'Acceleration' ('AG Beschleunigung')[43] (Interviewee J). The reason for addressing the problem in such a working group was to come up with a joint solution to which all relevant stakeholders agreed. The Offshore Wind Foundation constituted a central actor in this process since it volunteered to moderate the group (Interviewees E, L). Under the moderation of the Foundation, this working group met several times discussing possible improvements for preventing such delays in the future and working out concrete suggestions. Involved actors described the atmosphere in the group as very cooperative with much support from all sides, since actors were interested in a timely solution to this then pressing problem. Moreover the discussions were characterized as a joint dialogue aiming to address different interests (Interviewees H, J). Probably due to this strong joint aim of finding an appropriate solution, the working group in only eight weeks elaborated a proposition for improving the grid access regulation, which the Offshore Wind Foundation formulated into a policy paper by March 2012 (Stiftung Offshore Windenergie, 2012).

In this paper the Foundation made detailed and concrete suggestions for a system change in grid access, which industry representatives had long been calling for (Interviewee E). The responsible ministries took this paper as basis for changing the grid access regulation, adopting most of its suggestions and partly further developing some of them, and feeding the proposal into the formal political process. This process resulted in an amendment of the EnWG in December 2012, which was very positively absorbed by affected actors despite

43 These actors were: the environment (BMU), economics (BMWi) and finance ministries (BMF), the network agency (BNetzA), the Federal Maritime and Hydrographic Agency (BSH), the two affected TSOs and their suppliers (Siemens, ABB, Alstom), planners, operators, investors, the German Engineering Association (VDMA) representing technology providers, and other associations.

some remaining uncertainties regarding its effectiveness. Figure 10 depicts this amendment process with the systemic problem and its escalation, the identification of the problem by policy makers and the main steps in the policy process that finally ended in an amendment of the Energy Economy Law (EnWG).

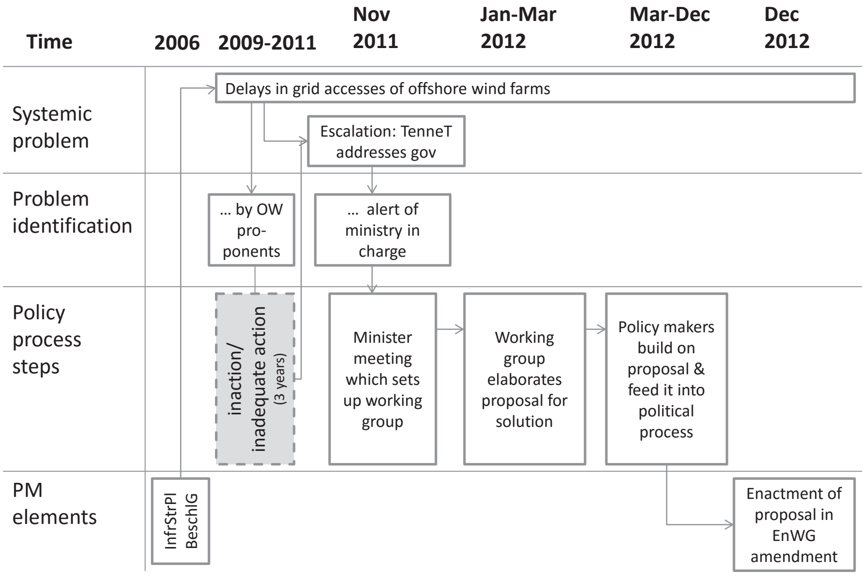

FIGURE 10: Policy process leading to the 2012 EnWG amendment

In sum, the policy process addressing the problem of delayed grid access is characterized by relatively long inaction (three years) and inadequate action despite problem awareness, but comparatively quick – about one year's time – concerted action subsequent to problem escalation. Next to the Offshore Wind Foundation as central actor, affected industry stakeholders were mainly involved in developing this solution – with the responsible economics ministry and the environment ministry accompanying the process.

5.5.2. Style of the policy processes

The style of the EEG amendment process greatly resembles the adaptive policy process approach: policy makers set a certain FIT level, monitor and evaluate its effects, and subsequently adjust it to better fit actual developments (Marchau et al., 2010; Walker et al., 2001). The particular 2009 offshore wind FIT adjustment process occurred within the formalized, regular and thus foreseeable overall EEG amendment process. Yet policy action was not flexible enough in a dynamically changing TIS: although the problem of the FIT's too low level of support was long known, policy makers stuck to the foreseen EEG amendment process and therefore only reacted after this problem had already prevented several offshore wind developments. Furthermore, the process was participatory in a rather formal way, i.e. by incorporating stakeholders in the amendment process via official hearings and consultations. Thus, the EEG amendment process can be described as a formal, government-led process that was open for input from stakeholders. As the outcome suggests, particularly industry associations were quite successful in exerting influence, for which an important reason may have been the potential contribution of offshore wind to the achievement of climate, renewable energy and industry policy objectives (evidenced also in the UK by Kern et al. (2014)).

Somewhat differently, the policy process that addressed the grid access delay problem shows parallels to Lindblom's (1979) 'muddling through' approach since policy makers from the economics ministry were preoccupied with remedying a huge problem rather than proactively seeking positive goals, such as much earlier establishing a well-functioning grid access regulation. Concerted reaction to this problem was tardily reactive: it occurred with great delays – only when it had escalated and nothing worked any more – and in an ad-hoc fashion. This tardy reactiveness might partly be explained with constraints in time and resources. Yet, once taken up the political process of identifying a solution to the problem was particularly participatory and cooperative, with an important reason probably being the high pressure to alleviate the situation. All affected stakeholders were involved in a working group and they jointly worked out a solution. Therefore, this solution-oriented process equally involved non-policy makers and policy makers, with the latter ones by and large adopting the outcome of this participatory process when designing the new grid access regulation.

In sum, a commonality of the style of the studied policy processes is that they both can be characterized as participatory. Yet while the EEG amendment process involved stakeholders in a formal way, the EnWG amendment process in a later phase featured particularly proactive stakeholder involvement (see Table 18). Furthermore, while the EEG amendment process was adaptive (albeit to a limited extent), the EnWG amendment process with its ad-hoc character and tardy reactiveness very much resembled muddling through. In the following section we will discuss the implications of these processes for the technological innovation system.

TABLE 18: Style of the studied policy processes 'EEG' and 'EnWG'

	EEG	EnWG
Muddling through (tardy reactiveness)		✓
Adaptiveness	✓	
Stakeholder participation	✓	✓

5.5.3. Effects of the policy processes on the TIS

5.5.3.1. Effects on TIS functioning

For the examination of the effects of the style of policy processes on TIS functions we consider two important aspects: First, such effects on TIS functions tend to occur in combination with other factors, such as policy instruments or policy mix characteristics. Second, this interaction of the style of policy processes and other factors affects entrepreneurs by making them more cautious or more enthusiastic regarding innovative activities. Through such chains of effects and feedback loops within the TIS, policy processes can have negative or positive impacts on several – rather than single – system functions.

Therefore, rather than presenting a simple model of cause and effect, we will discuss some general patterns of how the policy processes were impacting TIS functioning (see Table 19). One is the *participatory* style of both policy processes and the related actor influence in these processes. This participation contributed to increased trust by actors in the political commitment towards offshore wind and reconfirmed expectations in the creation of supportive policy instruments. These effects then positively contributed to several TIS functions, especially to entrepreneurial activities (F1) and knowledge development (F2) (Interviewees A, H, J). The tight actor contact in the working group of the EnWG process paired with the severity of the problem motivating actors to strive for a quick solution also positively influenced TIS functioning (Interviewees H, J). However, overall these positive implications appear to have been overcompensated by negative effects arising from the other more detrimental policy style aspects, notably the tardy reactiveness in the EnWG process and negative aspects of the adaptiveness of the EEG process, which will be explained in the following.

A second pattern concerns the tardy reactiveness of the EnWG amendment process, i.e. the long time until (concerted) action was taken to address the problem, and the overarching *muddling through* character of this process, which had – even in combination with more positive factors such as the participatory style –negative effects. It increased uncertainties among entrepreneurs regarding the outcomes of the systemic problems. This in turn had negative implications for TIS functions, particularly for entrepreneurial activities (F1) and knowledge development (F2) (Interviewee L).

A third pattern is associated with the *adaptiveness* of the EEG amendment process, which, by the fact that the EEG is adapted to changed circumstances from time to time, might have contributed to higher planning certainty. Yet the particular nature of this adaptiveness only to a limited extent contributed to such higher planning certainty for entrepreneurs – rather to the contrary: First, uncertainties remained due to tough debates on the contents and design features of the amendments and corresponding feed-in tariffs, which had long left open the outcome of these debates. Second, the relatively short amendment cycles paired with inconsistencies in the instrument mix increased uncertainties, since they implied very short periods in which particular contents and design features were actually applicable (Reichardt and Rogge, 2016). These uncertainties about investment conditions negatively affected system functions, among them entrepreneurial activities (F1) in the form of started offshore wind projects (Interviewees H, J).

TABLE 19: Main effects of the style of the EEG and EnWG amendment processes on TIS functions (F1-F7)

	Stakeholder participation *(EEG, EnWG)*	**Muddling through)** *(EnWG)*	**Uncertainties in adaptiveness** *(EEG)*
F1 (entrepreneurial activities)	+	-	-
F2 (knowledge development)	+	-	-
F3 (knowledge exchange)	+		
F4 (guidance of the search)	+		-
F5 (market formation)			
F6 (resource mobilization)		-	-
F7 (creation of legitimacy)	+		

In addition to these three patterns we find that the overall uncertainty inherent in any policy process seemed to be particularly high in the studied processes due to their muddling through character and their adaptiveness. This observed policy making style appears to have strongly influenced the function guidance of the search (F4). For example, the long time of inaction in the EnWG amendment process signaled a lack of guidance, since the grid access problem was not addressed timely and systematically but rather sporadically. When concerted political action was finally taken, i.e. the EnWG amendment process initiated, this positively contributed to the guidance function as it was interpreted as a signal of the still existing political will to support offshore wind (Interviewees A, J).

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5.5.3.2. Effects on TIS performance

As is the case for the impact of the policy processes on TIS functions, their impact on TIS performance does not correspond to a simple model of cause and effect. Therefore, we focus our discussion on three main patterns, which emerged from the data. First, the question arises whether the perceived muddling through character of the policy process addressing the grid access issue, where only incremental steps were taken towards problem solution, or problems were fixed only when they became unbearable, has been disadvantageous for TIS development. On the one hand, ad hoc action was at some point the only alternative to solve the urgent problem, which, however, would certainly not have been the case if the economics ministry had taken earlier concerted action. Even more, a certain degree of incrementalism or muddling through may generally be unavoidable due to incomplete foresight regarding effects of policy measures (Rothmayr Allison and Saint-Martin, 2011) or of technological or other innovation system developments. On the other hand we argue that a more systemic and forward-looking but also proactive perspective would have been beneficial in the overall grid access policy process since it may have prevented the grid access delay problem from escalating (Reichardt and Rogge, 2016).

Second, in both examples policy makers reacted with considerable delays to the systemic problems (tardy reactiveness), which negatively affected technology diffusion. That is, having been bound to the formalized EEG amendment process caused delays: offshore wind might have taken off earlier if policy makers had not been restrained by fears of opening the whole EEG – which treats all renewable energy technologies in one package – for adjusting it for one technology only, but instead had reacted immediately. Also, the belated concerted action when addressing the grid access problem significantly contributed to delays in offshore wind projects, thereby increasing project costs and delaying technology diffusion (Reichardt and Rogge, 2016).

A third effect is the positive influence of the participatory nature of the two policy processes on TIS development, i.e. on investors' activities in offshore wind and thus on the use and diffusion of the technology. This influence largely occurred via strengthened guidance of the search in the form of trust, credibility and positive expectations. It is thus another example of how policy processes may impact innovation without explicitly changing the policy mix elements such as specific policy instruments (Rogge and Reichardt, 2015).

5.6. Conclusion

Our analysis of policy processes in TIS suggests that such processes impact the functioning and performance of emerging TIS. However, this influence does not occur in isolation but rather through the interaction of policy processes with other factors. We identify two sets of emerging patterns of how the style of the analyzed policy processes impacted the TIS: First, regarding system functioning we find negative implications of the muddling through character (especially the tardy reactiveness), rather positive implications of the participatory nature of the policy processes and rather negative effects of the formalized adaptive style of the EEG amendment process. Thereby entrepreneurial activities (F1) and knowledge development (F2) appeared as particularly affected functions. Second, with respect to TIS performance the incremental ad hoc style of the EnWG amendment process was at some point vital for a further successful TIS development and may generally be – at least to some extent – unavoidable given inherent uncertainties in emerging TIS, which call for frequent policy mix adjustments. Yet a more systemic perspective would have been beneficial. Furthermore, the tardy reactiveness in concerted policy reaction had a rather negative influence and stakeholder participation a rather positive one on TIS performance.

In addition to their impacts on TIS functioning and performance, further aspects justify an increased consideration of policy processes in TIS analyses. First, a focus on policy processes sheds light on how policy makers interact with the rest of the innovation system. For instance, for the studied policy processes policy makers were closely involved in what occurred in the innovation system. Nonetheless problems were addressed with considerable delays, having negative implications for the functioning and performance of the system. Second and as a consequence of the former point, analyzing policy processes elucidates how well an innovation system is organized in terms of its institutions, i.e. how well specific problems can be brought to the surface, how seriously these problems are taken by policy makers and how policy makers finally deal with these problems. For example, the two studied policy processes reveal that the underlying problems were long known by most actors and that they were actively debated, indicating a good ability of the TIS to put problems on the political agenda. Yet policy makers – particularly from the economics ministry – long did not seriously enough address these problems. When they finally took concerted action, they dealt with the problems in a cooperative and rather constructive fashion. That is, although the interaction between policy makers and the remaining TIS can be assessed as good and the discussion culture as open and cooperative, delays in (concerted) reactions to problems are an aspect of malfunctioning of the TIS.

Our findings entail two key implications for TIS scholars. First, understanding policy processes in TIS reveals important additional information on how the TIS functions. By analyzing how systemic problems are being addressed by policy makers the existing scheme of analysis for TIS is taken one step further than studying TIS functions and proposing adjustments in the instrument mix. Second, while the feasibility of implementing policy recommendations has often been disregarded in TIS studies, accounting for policy processes will allow for supplementary recommendations on a suitable policy-making style. For example, recommendations on the introduction of a novel policy instrument for grid access should be accompanied by guidance on how the processes for the set up, monitoring, evaluation and amendment of the instrument should be designed in terms of their style.

Building on our findings we derive three main implications for policy makers interested in promoting emerging technologies. First, an implication from the negative effects of tardy reactiveness of the policy processes is that systemic problems should be addressed faster and in a more proactive manner, thereby striving for effective solutions early on. Such solutions might sometimes only be possible when they tackle the problem in an encompassing and systemic manner. While this might prevent these problems from escalating, for political reasons such problem solving may not always be feasible. Second, a precondition for such faster reactions to problems seems to be a regular monitoring of the appropriateness of existing policy instruments regarding actual TIS developments, which was lacking in the EnWG amendment process. Such an adaptive policy style might be prescribed in the regulation of the policy instrument. However, as evidenced in the EEG amendment process, adaptiveness alone is by no means a guarantee for preventing problem escalations but might help accelerating problem awareness by policy makers. Third, the set up of a temporary technology-specific expert task force could speed up policy processes and increase policy acceptance. This might be particularly useful for jointly addressing systemic problems and finding compromise solutions.

Clearly, our exploratory analysis of two exemplary policy processes within the technological innovation system of offshore wind in Germany is not free from limitations, and thus points to future research needs. Future TIS studies should consider policy processes and their implications more systematically, e.g. by zooming into 'institutions' or by labeling policy issues as 'policy mix issues', thereby indicating the consideration of both policy mix elements and processes. Regarding the latter, studies should not only analyze processes responding to systemic problems but, for instance, also those occurring in a proactive fashion. Finally, greater attention should be paid to politics and actor positions and how they influence policy processes and their outcomes.

Chapter 6

Conclusions

6.1. Findings

The objectives of this thesis are, first, to develop an extended concept of the policy mix, and second, to study the innovation impacts of such an encompassing policy mix. For doing so, the following research questions were posed:

1. How can policy mixes for innovation be conceptualized?
2. What is the impact of the conceptualized policy mix on innovation in offshore wind in Germany?
   2a. How does the policy mix affect corporate innovation activities in offshore wind in Germany?
   2b. Which role does the policy mix play for the technological innovation system of offshore wind in Germany?
      2b.1) What is the impact of the policy mix on the German offshore wind TIS and how do TIS developments influence the evolution of the policy mix?
      2b.2) What are the effects of policy processes on the German offshore wind TIS?

Based on the findings from the above presented chapters, in the following these research questions will be answered. The second main research question will be answered based on its subquestions.

RQ 1: How can policy mixes for innovation be conceptualized?

An overarching concept of the policy mix for sustainability transitions more generally, also encompassing innovation in renewable energy technologies, was developed. This was based on a review of the literature streams innovation studies, environmental economics and policy analysis, which in terms of policy mixes are still largely disconnected and display considerable heterogeneity regarding the policy mix notion. The developed concept consists of three main building blocks: policy mix elements, policy processes and policy mix characteristics. Furthermore, the policy mix can be delineated by overarching dimensions.

The elements comprise, first, the policy strategy with long-term targets and principal plans. An example of the former is the long-term target for offshore wind in Germany, targeting 6.5 GW of installed capacity until 2020 and 15 GW until 2030. An example for a principal plan, which outlines the general path that governments propose to take for achieving the envisaged targets, constitutes the German Energy Concept ('Energiekonzept'). The other principal component of policy mix elements is the instrument mix, which consists of several policy instruments each featuring a goal, type and design features. The Renewable Energy Act (EEG), a demand-pull instrument (instrument type) with technology-specific feed-in tariffs each featuring a particular level of support (design feature), is an important policy instrument in the policy mix for offshore wind in Germany.

The second building block, policy processes, refers to the ‘political problem-solving process among constrained social actors in the search for solutions to societal problems’ and as such involves power, agency and politics. Policy processes cover all stages of the policy cycle, such as problem identification, agenda setting and policy formulation. An example for policy processes is the regularly occurring process of amending the EEG, starting with evaluating the effectiveness of the previous EEG and often resulting in adjusted design features of the policy instrument.

Policy mix characteristics constitute the third building block – they describe the nature of the overall policy mix and include consistency, coherence, credibility and comprehensiveness. Thereby, consistency captures how well the elements of the policy mix are aligned with each other and can be analyzed at three levels. The first level covers consistency of the policy strategy, i.e. the policy strategy components should be consistent with each other, while the second level concerns consistency of the instrument mix – policy instruments should not undermine each other. Third-level consistency comprises the interplay of the policy strategy and the instrument mix and is characterized by their ability to work together in a unidirectional fashion so as to achieve overarching policy objectives. In contrast to consistency, coherence characterizes policy processes and refers to synergistic and systematic policy processes that directly or indirectly contribute to the achievement of policy objectives. Besides consistency and coherence, credibility and comprehensiveness have been identified as important policy mix characteristics. Credibility captures the extent to which the policy mix is believable and reliable, and comprehensiveness encompasses how extensive and exhaustive the policy mix is.

The three building blocks can be specified along four key dimensions, which capture the space in which interactions can occur. These dimensions include the policy field, governance level, geography and time. For instance, this thesis focuses on offshore wind in Germany (geography dimension) and considers policy mix components from – among others – energy and innovation policy (policy field dimension).

Figure 11 illustrates this concept of the policy mix with its three building blocks

RQ 2a: How does the policy mix affect corporate innovation activities in offshore wind in Germany?

The policy mix for offshore wind in Germany affected innovation in different ways. The effects were dependent on the particular policy mix component, e.g. the policy strategy or policy mix characteristics, and the kind of innovation, such as corporate research, development and demonstration (RD&D) versus adoption activities. Regarding effects of the policy mix on corporate innovation activities (RQ 2a), the main findings can be summarized by different patterns of how the policy mix impacted RD&D and adoption activities, respectively. In terms of RD&D activities, the policy strategy with its ambitious long-term target for offshore wind and the target's consistency with overall renewable energy targets were central. In terms of adoption activities, the instrument mix and its internal fit, such as of the policy instruments EEG and EnWG, was vital, with the most important policy instrument being the EEG with its investment-triggering level of support.

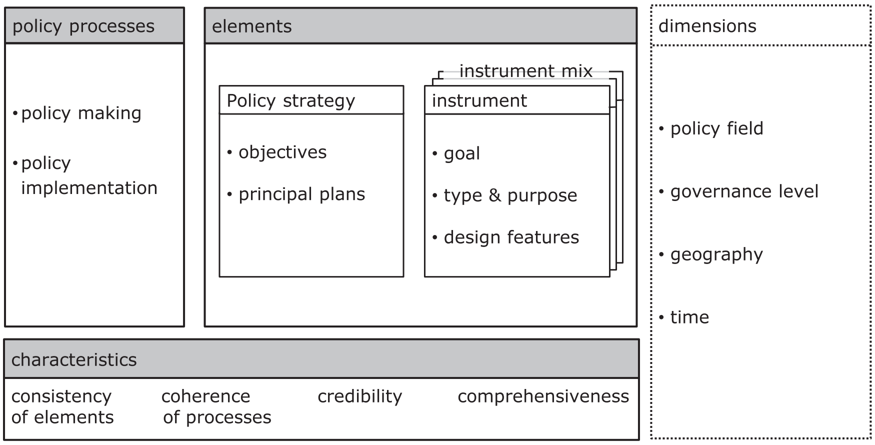

FIGURE 11: The extended policy mix concept

These overall findings can be detailed by further zooming into the innovation impact of individual policy mix components. The **policy strategy** played a reinforcing role for firms' adoption via the consistent, credible, stable and ambitious offshore wind long-term targets. Furthermore it positively influenced RD&D since the ambitiousness of this target was perceived as sign of a growing market and as such triggered firms' market expectations.

The **instrument mix** turned out to be crucial for adoption. While the EEG with its investment-triggering level of support and long-term predictability was the most influential policy instrument, other instruments were also important, such as the EnWG with its provision that grid operators build and operate the grid connection for offshore wind parks. Regarding RD&D, the EEG with its high level of support has been an important complement to the policy strategy, while RD&D support played a supplementary role to demand-pull instruments, guiding or deepening some RD&D projects.

Regarding policy mix characteristics, **consistency** has been found to be an important determinant of innovation. More specifically, first-level consistency (the internal fit of the policy strategy) and third-level consistency (the fit of the policy strategy with the instrument mix) were key drivers for RD&D activities. Second-level consistency, i.e. a consistent instrument mix, in which policy instruments do not contradict each other, was essential for adoption. The effects of the inconsistency of two important policy instruments underline this importance: the EEG and the EnWG (grid access regulation) were inconsistent since the level of support of the feed-in tariff in the EEG was sufficient, so it worked well, but there were severe problems with the grid access regulation, so the EnWG did not function properly. The mal-functioning of the EnWG consequently impeded the effectiveness of the EEG, since temporarily almost all offshore wind adoption activities were put on hold. Therefore, the theoretically well-functioning EEG was actually powerless.

Another fundamental innovation effect accrues from the policy mix characteristic **credibility**. On the one hand it was a prerequisite for adoption: If power generators perceived a high political will towards offshore wind, they were likely to start adoption. On the other hand credibility partly compensated for a lack of consistency and comprehensiveness in terms of RD&D. Regarding the lack of consistency firms continued some RD&D since they perceived the overarching policy mix as credible, expecting that it would fix upcoming issues. Also, despite the initial lack of comprehensiveness of the instrument mix – important policy instruments were lacking – firms invested in RD&D since they trusted policy makers' commitment to support offshore wind.

The policy mix characteristic **comprehensiveness** played a major role for adoption, since only in combination did the policy instruments appear to be able to overcome the most important market and system failures and any other bottlenecks and thus provide a basis for corporate adoption activities.

Besides the policy mix, there existed other essential determinants of corporate innovation activities in offshore wind, including market factors as well as technology and firm characteristics. For instance, firm characteristics such as firms' growth strategies, their renewable energy goals and the propensity of large power generators to invest in large-scale technologies constituted vital adoption drivers. Also, the immaturity of the offshore wind technology – a technology characteristic – was a main reason for firms' RD&D activities.

RQ 2b: Which role does the policy mix play for the technological innovation system of offshore wind in Germany?

The sub research question on the role of the policy mix for technological innovation systems (RQ 2b) was examined in two steps. First, the impact of several policy mix components on TIS evolution and the influence of TIS developments on the evolution of the policy mix were analyzed (research question 2b.1). Second, policy processes were zoomed into, studying effects of these processes' style on the TIS (research question 2b.2).

RQ 2b.1: What is the impact of the policy mix on the German offshore wind TIS and how do TIS developments influence the evolution of the policy mix?

Regarding the first step, not only the role of the policy mix in TIS evolution was analyzed, but also how the TIS shaped the coming about of the policy mix. Dynamic interdependencies in the evolutions of the German offshore wind TIS and its policy mix were found and examined. In fact, the evolutions were a continuous cycle in which the TIS constantly influenced the policy mix and vice versa. Two main patterns of interdependencies were identified.

First, the policy mix enabled TIS developments to take off. More specifically, some early entrepreneurial activities occurred without an offshore wind policy mix being in place but these activities were not sufficient for the TIS to take off. The set up of some early policy mix components subsequently enabled these activities to continue (F1) and thereby permitted further important TIS developments. One example is the Sea Plant Ordinance, a systemic policy instrument, which facilitated permits for offshore wind parks and thus the continuation of entrepreneurial activities. Another example is permit standards – as a prescription by a public authority being a policy implementation component – which detailed the rules on how permission requests were to be handled. Their introduction enabled a standardized permit process, which eventually facilitated technology use.

A second pattern, which occurred much more frequently, is that later on in TIS evolution systemic problems triggered an alteration of the policy mix, aiming to solve or remedy the problems. The newly set up or altered policy mix components in most cases alleviated the problems and thereby enabled further technology use and diffusion. An example is the problem that in the mid 2000s the offshore wind TIS did not take off. This was addressed by the publicly set up demonstration project Alpha Ventus, which can be categorized as a technology-push instrument. It increased actors' expectations of the feasibility of offshore wind projects (F4) and thus attracted new players – utilities – into the TIS (F7). In doing so, it also stimulated entrepreneurial activities in the form of new offshore wind construction projects (F1). However, in some cases an altered policy mix component did not work well and despite at first remedying a problem it contributed to a prolongation or an eventual worsening of this problem. An example is the 2004 EEG amendment, which introduced an offshore-wind-specific feed-in tariff (FIT). At first this FIT appeared to be appropriate, but it soon turned out that its level of support was not sufficient so that consequently new offshore wind projects were not started.

Besides these patterns, actors – as an important policy mix dimension – and their role in the policy mix-TIS-evolution were considered. Several actors were found to be vital for the successful development of the TIS. For instance, early on innovative and risk-taking entrepreneurs were crucial. Subsequently single policy makers together with industry representatives and associations greatly contributed to the design and implementation of favorable policy mix components, thereby advocating the TIS. Finally, with the entering of large utilities into the TIS a formerly opposing actor turned into an offshore wind proponent.

It can be summarized that the policy mix did not only stimulate positive TIS developments but also contributed to the emergence of new systemic problems or to the reinforcement of existing ones, both promoting and hampering TIS functioning and performance. On the other hand, systemic problems in the TIS and their envisaged solutions shaped the evolution of the policy mix in that they determined the contents and design of policy mix components. All of these developments were greatly shaped by some key actor groups.

RQ2b.2: What are the effects of policy processes on the German offshore wind TIS?

Turning to the second step on the effects of policy processes on the TIS, insights were gained into the style of such processes and its impact on the offshore wind TIS. For doing so, two exemplary processes were chosen that each addressed one of the above identified severe systemic problems. These are, first, the policy-making process responding to the problem of an insufficient level of support of the offshore wind feed-in tariff and resulting in the 2009 EEG amendment. Second, the policy-making process addressing the problem of delays in grid access for offshore wind parks and leading to an amendment of the Energy Economy Law (EnWG) in 2012 was selected. The style of the processes can be described as follows. A central feature of both processes is that stakeholders were involved in a participatory manner. While in the EEG amendment process this occurred in a rather formal way, the EnWG amendment process proactively and cooperatively involved stakeholders, e.g. in a joint working group. Furthermore, the EEG amendment process can be described as adaptive, albeit it appeared not flexible enough: policy instrument effects were monitored, evaluated and – with some delays – accordingly adjusted. In contrast, the EnWG amendment process was not just incremental but even resembled so-called muddling through – policy makers were preoccupied with remedying a huge problem rather than proactively seeking positive goals. Also, concerted reaction to the problem occurred in a tardily reactive manner.

The policy processes have been found to be influential determinants of TIS functioning and performance. Yet there is no simple model of cause and effect, which is why two important qualifications were made. First, effects of the style of policy processes tended to occur in combination with other factors, such as policy instruments or policy mix characteristics. Second, effects did not only occur on single TIS functions but rather on several ones, e.g. via chains of effects. Through such chains of effects, policy processes could have had negative or positive impacts on several system functions. Therefore overarching patterns of the impact of the policy style on the TIS are being discussed.

Regarding TIS functions, the interviews indicated three main patterns of effects. First, the participatory nature of both processes, i.e. giving stakeholders a say in policy making, contributed to increased trust by entrepreneurs in policy makers' commitment towards offshore wind. This positively influenced particularly entrepreneurial activities (F1). However, these positive implications appeared to have been foiled by the other more detrimental policy style aspects, which are described below. That is, the second pattern is that the tardy reactiveness and thus the muddling through character of the EnWG amendment process had negative effects, even in combination with more positive aspects such as the participatory nature of the processes. The time lag with which policy makers seriously reacted to the grid access problem increased uncertainties among entrepreneurs, which led to a poorer fulfillment particularly of the functions entrepreneurial activities (F1) and knowledge development (F2). Third, the adaptiveness of the EEG amendment process did not contribute to higher certainty for planners – rather the opposite occurred. This is due to great uncertainties as to the outcome of debates on the level of support of the feed-in tariff and to short EEG amendment cycles. These uncertainties contributed to a poorer fulfillment of the functions knowledge development (F2), entrepreneurial activities (F1) and resource mobilization (F6). Besides these three patterns, the function guidance of the search (F4) seemed to be negatively impacted by the muddling through character of the EnWG process and the adaptiveness of the EEG process. The reason may be the high degree of uncertainty that comes along with such a policy style.

Impacts of the policy processes' style on TIS performance were found to be similar to those on TIS functions. First, while a certain degree of incrementalism – e.g. stepwise action according to the current situation – might have been indispensable for successful TIS development, the muddling through character of the EnWG amendment process was rather detrimental. Second, the delays in (concerted) policy reaction and thus the tardy reactiveness particularly of the EnWG process increased delays in TIS development: if policy makers had reacted earlier, entrepreneurial activities and the TIS might have taken off earlier. Finally, the participatory nature of both policy processes positively contributed to TIS development via increased expectations and trust.

In sum, the particular style of the studied policy processes contributed both positively and negatively to TIS functioning and performance. That is, the muddling through character of the EnWG process and the formalized adaptive style of the EEG process negatively affected TIS functioning, while the participatory nature of both processes had a positive impact. Thereby entrepreneurial activities and knowledge development appeared as particularly affected functions. Regarding TIS performance, although the incremental ad-hoc style of the EnWG amendment process may have been unavoidable given inherent uncertainties in emerging TIS, a more systemic perspective might have been beneficial. Also, the tardy reactiveness of concerted policy reaction to the grid access delay problem had a rather negative influence and the stakeholder participation of both processes a rather positive one on TIS performance.

With these findings the study demonstrated that policy processes do impact technological innovation systems and it gave an example of the scope of such impacts. Such processes should therefore increasingly be considered when attempting to understand TIS dynamics.

Summary and discussion of the findings

The findings of this thesis on the impact of the policy mix on innovation in offshore wind in Germany can be condensed to four main insights, which are discussed below.

First, the whole policy mix plays a role for innovation, not just policy instruments that are most often focused on in existing studies, but rather also the policy strategy, policy mix characteristics and policy processes. For example, as demonstrated by the company case studies on the German offshore wind case (chapter 3), the policy mix and its consistency play an important role for corporate innovation activities. Furthermore, as chapter 5 on the role of policy processes in TIS suggests, such policy processes and their style exert a considerable influence on technological innovation systems, i.e. on TIS functions and performance. While certain features of these processes, including their tardy reactiveness and related muddling-through character, had rather negative effects, their participatory style was found to be highly beneficial for TIS development.

Second, linkages between the policy mix and innovation are complex; they are shaped by a number of conditions. To begin with, each policy mix component exerts specific innovation effects, which are influenced by (the effects of) other policy mix components. A prime example for this from offshore wind in Germany is the credibility of the policy mix that influenced the effect of policy mix inconsistency in that it partly compensated for inconsistencies between the policy instruments EEG and EnWG. Impacts of the policy mix further depend on the particular innovation focus. For instance, for the German offshore wind case different policy mix effects were found on corporate RD&D and adoption activities, since these activities had different features and therefore different requirements regarding policy support. An illustrative example is that inconsistency of the instrument mix could bring adoption to a halt, while the effects of this did not seem to be so severe for RD&D activities. This might be grounded in the more overarching nature of RD&D activities, which are therefore less dependent on the concrete instrument mix and which occur in the longer term, so that they can withstand temporary inconsistencies. Another aspect reflecting the complexity of policy mix effects on innovation is the dynamic nature of both. Frequent changes in the policy mix and innovation activities lead to often changing effects, e.g. in terms of which policy mix components exert influence on which innovation activity or TIS function and the kind of this influence.

Third, the policy mix and the TIS are tightly interwoven. While the policy mix can both induce and solve systemic problems, stimulate and hinder TIS developments, these TIS developments greatly shape the coming about of the policy mix. These interdependencies are likely to occur in a continuing cycle, which makes them highly dynamic. Nonetheless these dynamics considerably depend on the political commitment to support the emerging technology and on other TIS actors' activities and support of the TIS. For example, the generally successful development of the German offshore wind TIS can greatly be attributed to positive contributions and commitment by several actor groups.

Fourth and finally, despite the large importance of the policy mix for innovation and TIS more generally, the success (or failure) of the latter does not merely depend on the policy mix but also on a number of other factors or conditions in the TIS, such as technology characteristics, company specifics and – of course – actors. The company case studies showed that firms did not invest in offshore wind solely because there was a favorable policy mix in place, but rather since in addition to the policy mix they were used to such large-scale technologies and disposed of the corresponding know how. If such factors would not have existed, the policy mix might not have triggered (successful) innovative activities. Similarly, regarding the German offshore wind TIS, if there would not have been several actor groups that favored the offshore wind technology – besides policy makers who are mainly responsible for designing the policy mix – the TIS might not have succeeded. This is so since on the one hand diverse actor groups influence policy mix components and their design, not just policy makers. These other actors do have an impact on the extent to which the policy mix is favorable regarding a certain technology. On the other hand, even in the absence of a supportive policy mix, e.g. in an early TIS phase, there were actors who drove the TIS, such as innovative and risk-taking entrepreneurs. These entrepreneurs might be less reliant on the policy mix compared to other actors.

6.2. Implications for policy makers aiming to advance offshore wind

Based on the above findings on offshore wind in Germany, some key policy recommendations will be derived for how to advance the offshore wind technology.

Of key importance for guiding offshore wind innovation activities may be the existence of a long-term and stable technology-specific policy strategy, e.g. in the form of a long-term target, which is consistent with the overall energy and climate targets. In the German case, the ambitious technology-specific long-term target, which has been stable over about twelve years, has greatly contributed to a positive development of the TIS. Yet the recent reduction of the target may well slow down TIS development, which might imply negative effects of lowering such otherwise stable long-term targets.

Furthermore, a comprehensive instrument mix for fostering the technology consisting of demand pull, technology push and systemic instruments appears essential, particularly for technology adoption. That is, the instrument mix should address the most important system barriers and should timely be adjusted to address newly emerged problems. For offshore wind in Germany the instrument mix has been relatively comprehensive in the last few years (covering demand pull, technology push and systemic aspects) but at times considerable inconsistencies such as between the FIT and grid access regulation were in place. These inconsistencies subsequently also decreased the positive effects of the instrument mix comprehensiveness. Therefore, if such inconsistencies occur, they should be addressed more timely to render other policy mix components, such as its comprehensiveness, more effective again and thereby avoid delays in TIS development as happened in Germany.

When aiming to foster offshore wind, not only policy instruments and their design should be considered but the whole policy mix including policy mix characteristics and policy processes, since it is the policy mix as a whole that affects innovation. Regarding policy mix characteristics, credibility and consistency tend to play important roles. Credibility is of particular importance for innovation and therefore should be maintained at a high level. For instance, a stable long-term target can contribute to policy mix credibility as well as a comprehensive instrument mix and generally coherent policy processes including active stakeholder involvement. In the German case, the electricity price brake discussion in 2013 greatly decreased actors' trust in policy makers' dedication to support offshore wind and renewable energies more generally and thus severely damaged the so far high credibility. Policy makers should be aware of the destructive character of such discussions and should strive to avoid them. Besides credibility a certain degree of consistency of the policy strategy, of the instrument mix and of the policy strategy with the instrument mix seems to be conducive to innovation in offshore wind. That is, the policy strategy and the instrument mix for offshore wind should at a minimum be free of contradictions each for itself and mutually. Although it might be difficult to maintain high degrees of consistency, this policy mix characteristic should be considered when designing new or when altering existing policy mix elements, thus ensuring greater effectiveness of these elements.

Awareness is also needed for the fact that policy processes and the way in which they occur have direct effects on innovation. Regarding such policy processes, it is beneficial to involve stakeholders in a participatory fashion. This can help to increase the effectiveness and acceptance of the outcomes of the policy process, e.g. of new or altered policy instruments. With respect to offshore wind in Germany, involving stakeholders in a proactive fashion, like was done particularly in the policy-making process leading to the 2012 EnWG amendment, ensured that the resulting policy instrument was better tailored to the needs of target actors and that there was a higher acceptance of the instrument by these actors. Incrementalism in policy making, i.e. step-by-step actions rather than acting on the basis of a comprehensive master plan, might in most cases be indispensable and is acceptable as long as there is a general roadmap including overarching milestones. In addition, for incrementalism to work out, credibility should be maintained and a minimum level of coherence and consistency should be tried to be restored once having drifted out of alignment. Nonetheless, as far as possible more systemic action should be taken that does not only address single problems but a broader setting. Such systemic action also requires that other policy mix elements are considered when altering a certain element. In the case of offshore wind in Germany, incremental policy making resembling muddling through took place regarding, e.g., the grid access issue, yet more systemic action was not taken. Therefore, when regulating grid accesses for offshore wind, measures should be introduced early on that account for consequences of the way grid accesses are provided. This can be accomplished by a greater centralization of grid access planning, which might avoid problems of uncoordinated grid planning for single parks and might be more cost-effective.

6.3. Contributions of the thesis

This thesis contributes to the literature in three main ways. First, a comprehensive and interdisciplinary concept of the policy mix for sustainability transitions and technological change more generally, including RET, is developed. It accounts for the complexity and dynamics of real-world policy mixes and provides a uniform terminology, which has been lacking in the literature so far. Also, the usefulness of this concept as analytical framework in empirical policy studies is demonstrated. On the one hand, applying an overarching policy mix in empirical policy analyses enables a more encompassing policy understanding, since the concept accounts for often neglected policy mix components such as policy mix characteristics. On the other hand, the concept enables precise and unambiguous distinctions of the various policy mix components and provides guidance for defining the boundaries of a study in terms of its scope and unit of analysis.

A second contribution is that the thesis provides for a more encompassing understanding of the role the policy mix plays for innovation in offshore wind in Germany and in emerging RET more generally. That is, it provides insights into the effects of the policy mix with its elements, characteristics and policy processes on corporate innovation activities. Furthermore, it sheds important light on the impact of the policy mix on the German offshore wind TIS. It does so, on the one hand, by exploring the impact of policy mix components including the policy strategy, policy instruments and policy processes, on the development of the TIS, also considering how the TIS influences the evolution of the policy mix. On the other hand, it devotes particular attention to the investigation of the role of so far largely disregarded policy processes in TIS, exploring the influence of their style on TIS functioning and performance. Altogether, such a deeper understanding of the impact of the policy mix on innovation, applied to the case of offshore wind in Germany, sheds light on the importance and impact of the policy mix in the envisaged energy transition.

The third contribution the thesis makes is that it takes a first step to empirically incorporate the policy mix into the TIS approach. It does so by analyzing interdependencies between the policy mix – as part of the structural components of a TIS – and TIS functioning and performance, and by studying the influence of policy processes that address systemic problems on the TIS. This empirical incorporation facilitates a greater clarity of the 'policy' notion in TIS and consequently contributes to a better understanding of the role policy mixes play in TIS, including their dynamic interdependencies with the TIS. It might also constitute the basis for a conceptual incorporation of the policy mix into the TIS approach.

Besides these main contributions, the thesis lays a basis for more comprehensive policy recommendations at the level of the policy mix. Suggestions at this level exceed single policy instruments and account for aspects such as policy mix characteristics and policy processes. Such encompassing recommendations might ultimately contribute to designing policy mixes – including coherent policy processes – that more effectively foster innovation in RET.

6.4. Avenues for future research

This thesis is novel regarding its conceptualization and empirical application of the policy mix. Due to this novelty there remain several paths for future research. At a conceptual level, the policy mix concept should be further developed by exploring some of its building blocks in more detail. On the one hand, this applies to policy mix characteristics and their role in the concept. Questions worth of further investigation include: How are individual policy mix characteristics linked to policy mix elements, such as the policy strategy, and which role do they play for these elements? How do the different policy mix characteristics, such as consistency and credibility or consistency and comprehensiveness depend on each other? On the other hand, policy processes and their coherence should be investigated in greater depth regarding their role in the policy mix, such as their interactions with policy mix elements. Additionally, with this thesis being a first step, the policy mix concept should further be incorporated into the TIS approach, e.g. by conceptually integrating these two approaches. This would further facilitate a more systematic analysis of the influence of the policy mix on TIS. Similarly, the policy mix concept might be integrated also in other transition approaches, such as the multi-level perspective (MLP). Such an integration suggests considering policy mix components that do not only support an emerging technology or niche but that have the ability to destabilize existing regimes characterized by inertia and lock-in (Kivimaa and Kern, 2016). In this way the policy mix concept would fruitfully complement existing transition approaches by a more detailed framework for analyzing policy aspects in transitions.

At an empirical level, the operationalization of the policy mix should be further developed, for example by establishing standard variables for operationalization. Furthermore, empirically applying the policy mix to other renewable energy and environmental technologies and problems is likely to contribute to a better comprehension of policy mix effects and might help in further developing the policy mix concept. Regarding the empirical analysis of policy mix components, the role particularly of policy mix characteristics and their interplay, and of policy processes and their coherence for innovation in renewable energy technologies should be studied in greater depth, both for innovation at a firm and a system level. Finally, it might be useful to complement qualitative analyses on the role of the policy mix for innovation such as in this thesis with more quantitative methodological approaches, such as statistical analyses based on a large-scale survey. This allows for testing the findings of this thesis with methodologies that rely on broader data bases.

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Appendices

Appendix for chapter 2

Explanation of the elements of the policy mix for renewable energies in Germany (policy strategy and instrument mix) listed in Figure 2

POLICY STRATEGY	
Kyoto Protocol	- International treaty with binding obligations to reduce greenhouse gas emissions for participating industrialised countries (DE: -21% by 2012, compared to 1990) and flexible mechanisms (international emission trading, Clean Development Mechanism, Joint Implementation).
20/20/20 targets	- Targets: 1) 20% RES in EU energy consumption by 2020 2) 20% improvement in EU energy efficiency by 2020 3) 20% GHG emissions reduction in EU by 2020 (compared to 1990)
SET-Plan	- Target: Accelerate innovation in cutting-edge European low carbon energy technologies, enhance the coordination of national and European research and innovation efforts - Launch of industry-led European Industrial Initiatives (EII); initiatives exist for different RES (e.g. European Wind Initiative/ EWI)
Energy Roadmap 2050	- Target: 80-95% GHG emissions reduction in Germany by 2050 (compared to 1990)
Energy Concept	- Targets: 1) 35% RES in Germany's energy consumption by 2020 2) 30-40% GHG emissions reduction in Germany by 2020 (compared to 1990)
RES-Directive / NREAP	- The RES-Directive requires each Member State to adopt a national renewable energy action plan (NREAP). These plans are to set out Member States' national targets for the share of energy from renewable sources consumed in transport, electricity, and heating and cooling in 2020 and adequate measures to achieve these targets.
Atomic Energy Act	- The phase out strategy from 2002 was terminated in 2010. This lifetime extension was revoked again in 2011 after the Fukushima incident. Until 2022 the remaining nuclear power plants will gradually be shut down.
INSTRUMENT MIX	
EEG	- The Renewable Energy Act (EEG) replaced the Electricity Feed-In Act (StrEG) from 1990. It contains feed-in tariffs for all renewable energy sources and is a key instrument of the Energiewende.
KfW RES-Programme	- The KfW Renewable Energy Programme offers advantageous terms on loans for renewable energy power plants (solar, wind, hydro, biomass).
EnEconLaw	- The Energy Economy Law (EnWG) sets the fundamental framework conditions for energy supply in Germany, including regulations on power grid development.
Energy Research Programme	- The 6th Energy Research Programme funds R&D measures in energy efficiency, renewable energies and nuclear power (permanent disposal, fusion technology).
NER 300	- The New Entrants' Reserve (NER 300) uses 300 mio allowances of the EU ETS to support renewable energy and CCS projects in the EU.
EU ETS / TEHG	- The EU Emission Trading System (EU ETS) is a cap-and-trade system for greenhouse gas emissions for large emitters in the energy and industry sectors, with a pilot phase 2005-07, and subsequent trading phases 2008-12, 2013-2020, … The TEHG is the implementation of the EU ETS into German legislation, for each trading period concretized by the ZuG 2007 and ZuG 2012.
InfrStrAccAct/ PowerLineDevAct/ GridExAccAct	- The Infrastructure Planning Acceleration Act (InfraStrPlanVBeschlG), the Power Line Development Act (EnLAG) and the Grid Expansion Acceleration Act (NABEG) complement existing legislation and accelerate the grid expansion in Germany, which is required to integrate large quantities of renewable energy into the grid.
ElectrTacAct	- The Electricity Tax Act (StromStG) is a consumption tax on electricity. Direct consumption of electricity from renewable energy sources with a capacity below 2 MW is tax-exempt.
HardCoalFinAct	- The Hard Coal Financing Act (SteinkohleFinG) regulates the subsidies for hard coal extraction in Germany. These are lowered gradually and are phased out in 2018.
Habitats- / Birds-Directive	- The Habitats-Directive and the Birds-Directive ensure wildlife and nature conservation in the EU. They restrict the land-use for energy production in certain areas. The Birds-Directive replaces the Directive 79/409/EEC on the conservation of wild birds from 1979.
FedNatConsAct	- The Federal Nature Conservation Act (BNatSchG), among other things, defines several types of protected areas in Germany, including Natura 2000 sites.

Appendices for chapter 3

Appendix 3.1

Overview of the German offshore wind market: (1) turbine developers and (2) farm owners sorted by German capacity (sum of installed and in pipeline)

(1) Turbine developers active in the German offshore wind (OW) market

Firm	Capacity as of December 2012 (MW)				OW turbine types (in MW)	Year of first OW turbine/ prototype	Year of market exit	Markets	Headquarters
	Germany		Worldwide						
	Installed	Pipeline	Installed	Pipeline					
Siemens Wind	48	3,296	3,014	6,729	2.3, 3.6, 4, 6	1991	-	UK, DK, NO, DE, SE, FI, NL, CN, US, CA	Europe: Brande, DK International: Hamburg, DE
Areva Wind	30	1,810	30	1,810	5	2004	-	DE	Bremerhaven, DE
REpower	30	1,218	405	1,341	5 , 6	2004	-	DE, BE, UK	Hamburg, DE
BARD	305	500	305	775	5 , 6.5	2007	-	DE, NL	Bremen, DE
Enercon	4.5	0	4.5	0	4.5	2002	2004	DE	Aurich, DE
Nordex	2.5	0	4.8	0	2.3 , 2.5	2003	2012	DE, DK	Hamburg, DE

(2) Offshore wind farm owners in Germany

Firm	Firm type	Capacity as of December 2012 [MW] *				Year of first OW turbine (worldwide)	Markets	Headquarters
		Germany		Worldwide				
		Installed	Pipeline	Installed	Pipeline			
DONG Energy	Utility	0	1,610	1,300	4,873	1991	UK, DK, DE, NL	Fredericia, DK
EnBW	Utility	48	1,180	48	1,180	2011	DE	Karlsruhe, DE
E.ON Climate & Renewables	Utility	60	1,168	511	2,391	2001	UK, DK, DE, SE	Duesseldorf, DE
BARD Holding GmbH	Technology provider and farm operator	305	500	305	500	2008	DE	Emden, DE
SWM	Utility	0	688	0	1,264	2006	DE, UK	Munich, DE
Vattenfall	Utility	60	576	1,018	1,945	2007	UK, DK, SE, NL, DE	Stockholm, SE
RWE Innogy	Utility	0	627	869	1,609	2003	UK, BE, DE, NL	Essen, DE
Blackstone Group	Financial services	0	608-672	0	608-672	-	DE	New York, US
Axpo International S.A.	Utility	0	400	0	400	2013	DE	Baden, CH
HSE AG	Utility	0	400	0	400	2012	DE	Darmstadt, DE

Firm	Firm type	Capacity as of December 2012 [MW] *				Year of first OW turbine (worldwide)	Markets	Headquarters
		Germany		Worldwide				
		Installed	Pipeline	Installed	Pipeline			
Iberdrola Renovables	Utility	0	400	0	400	-	DE	Bilbao, ES
Ocean Breeze Energy GmbH & Co. KG.	Power generator	0	400	0	400	-	DE	Munich, DE
Trianel	Utility & consulting	0	400	0	400	2004	DE	Aachen, DE
Windreich	Project developer	0	400	0	400	2013	DE	Wolfschlugen, DE
Erste Nordsee-Offshore-Holding	Holding	0	395-553	0	395-553	-	DE	Pressbaum, AT
Windland Energie-erzeugungs GmbH	Project developer	0	288	0	288	2013	DE	Berlin, DE
wpd offshore solutions	Project developer	0	288	0	918-953	-	FI, DE, SE	Bremen, DE
Kirkbi A/S	Holding and investment	0	277	0	277	-	DE	Billund, DK
EWE AG	Utility & telecommunication	65	108	65	108	2004	DE	Oldenburg, DE
Energiekontor AG	Project developer	0	111	0	111	-	DE	Bremen, DE

Sources: own compilation based on 4C Global Offshore Wind Farms Database, Fraunhofer IWES (2013), firm web pages, further online sources

Note:

- Depicted are firms that are active in the German market, i.e. that have sold turbines or operate farms there (Appendix 3.1(1)).
- Due to their low ownership shares (below 20%) in offshore wind farms, ten further firms are not depicted in Appendix 3.1(2).

Legend:

- * = Double counting: Depicted are the overall capacities of offshore wind farms a firm owns or has shares in, not the capacities a firm holds according to its shares.

Appendix 3.2

Typical interview guide as used in the company interviews

Category	Exemplary questions
Innovation activities	What are your innovation activities in the area of offshore wind? How do offshore wind innovations in your company typically come about?
Innovation effects of the policy mix – open question	What role does the political framework, that is targets AND instruments, play in your specific offshore wind innovation activities?
Innovation effects of the policy strategy and first-level consistency	What is the role of • specific political target-setting (that is, renewables, climate, offshore wind targets) • political framework concepts for your innovation activities? How consistent do you find the • targets • framework concepts? What effect does each have on your innovation activities? How consistent do you think the discussed targets are with the framework concepts? What influences the effect on your innovation activities of the positive/negative interaction of the discussed targets with the discussed framework concepts? How credible do you find the targets? What role does their credibility play in your innovation activities?
Innovation effects of the instrument mix and second-level consistency	Which policy instruments influence your innovation activities and in what way? How well do the discussed instruments go together? How does this interplay influence your innovation activities?
Innovation effects of third-level consistency	How well do the discussed instruments fit with the discussed targets (contradictions, gaps, synergies)? What consequences does this have for your innovation activities?
Innovation effects of context factors	Apart from the discussed policy framework, are there other reasons why you are active in offshore wind (e.g. characteristics of the technology, market-related factors, social acceptance)? How important are these reasons relative to the policy mix?
Innovation effects of firm characteristics	When you compare yourself with your competitors, how do you distinguish your innovation activities from those of your competitors? What do you think is the influence of your firm's size on your innovation activities? How does it affect your innovation activities that you have a number of technologies in your portfolio/ that you are only active in offshore wind?

Notes:

- The questionnaire is a general one. In fact, the questions varied between power generators and technology providers as well as between individual firms and interviewees due to their different characteristics and competencies.
- We asked for the offshore wind policy mix and offshore wind innovation activities, but for reasons of simplicity, here we only refer to policy mix elements and innovation activities.

Appendix for chapter 4

Policy mix components considered in the analysis

Type of component	Policy mix component	Acronym
Policy strategy	Policy strategy	PS
Instrument mix	Policy instrument	In
Instrument type	Demand-pull instrument	In.dp
	Technology-push instrument	In.tp
	Systemic instrument	In.sys
Policy mix characteristics	Policy mix comprehensiveness	PM.compr
	Policy mix credibility	PM.cred
Policy processes	Policy implementation	P.impl
	Policy making	P.mak

Summary

Background and objectives

In the light of challenges such as climate change, depletion of fossil fuels or security of energy supply, the transition from current energy systems towards low-carbon technologies has become a key political agenda item. Renewable energy technologies (RET) play a crucial role for such a transition, but most of these technologies are still immature and not yet cost-competitive. In order to become more competitive and achieve greater levels of diffusion, an acceleration of innovation in these technologies is paramount. Yet multiple market, system and transformative failures, such as knowledge spillovers, lack of financial resources or market power of incumbents, hinder innovation.

This multitude of failures requires multiple policy intervention in the form of packages of policy instruments – so-called policy mixes – with each instrument addressing a particular failure. In practice policy mixes are often in place to promote particular technologies or address specific environmental problems. At the same time, there is a growing conceptual literature on policy mixes, acknowledging that these comprise aspects that exceed a simple accumulation of single instruments, such as instrument interactions or policy processes. Nonetheless there is a lack of conceptual clarity about what policy mixes actually are, and a common understanding regarding the scope and terminology of policy mixes is also lacking. This might render comparisons and assessments of policy mix studies difficult and thus may generate ambiguous findings and policy recommendations. Therefore, there is a need for a comprehensive conceptualization of the policy mix with a uniform terminology that considers their complexity in terms of the plethora of aspects they comprise.

Furthermore, in order to successfully foster RET it is important to better understand the effects of real-world policy mixes on innovation in these technologies. In this regard, several empirical studies have analyzed policy effects on innovation in the broader field of environmental technologies. Most of these focus on the effects of single policy instruments, including their instrument type or design features, while only few studies consider other policy mix components, such as instrument interactions or policy processes. However, impacts of the policy strategy or overarching policy mix characteristics have rarely been analyzed at all. This neglect might lead to an insufficient understanding of policy mixes and their effects and potentially result in fragmentary policy recommendations. Therefore, policy mix effects on innovation should be analyzed more comprehensively.

Effects of policy mixes can be examined at different levels of innovation, including the micro and the meso levels. Studies dealing with innovation at the micro level mainly focus at firms as key innovators and their several innovation activities including research, development and demonstration as well as adoption, while studies at the meso level often analyze innovation systems. In the case of emerging renewable energy technologies, the latter studies frequently analyze technological innovation systems (TIS) with their actors, networks, institutions and infrastructure. They further study the dynamics of these systems in terms of seven or eight system functions, subsequently deriving system strengths and weaknesses and tailor-made policy recommendations. Yet the impacts of comprehensive policy mixes on innovation at both levels have rarely been looked at, although this would enable important insights. Regarding innovation at the firm level, based on the insights gained on effects of the policy mix, recommendations can be derived for policy mix improvements with regard to the key innovators. Stimulating such key innovators to become active is essential when the goal is to foster technological innovation. Regarding innovation at the TIS level, studying effects of policy mixes allows for a more encompassing understanding of the role of such policy mixes or parts of these in TIS. This is a prerequisite for designing policy mixes that appropriately foster the development of a whole TIS.

Against this background, this thesis has two main goals. First, it aims at developing a comprehensive concept of the policy mix for RET and technological change in general that exceeds single instrument considerations and accounts for more overarching aspects, such as policy mix characteristics. Second, it aims at exploring the influence such a more comprehensive policy mix exerts on innovation in RET. This influence will be analyzed for innovation both at the firm and the system level.

For this second objective the research case of offshore wind in Germany was selected. Offshore wind is a technology with great potentials, mainly due to its relatively large scale and higher wind speeds offshore than onshore. It therefore is to play an important role in the transition towards more RET. The rich policy mix in place for offshore wind in Germany including, e.g., an ambitious long-term target, and at the same time apparent problems with technology diffusion make this case a particularly worthwhile example for analyzing the role of the policy mix.

In line with the thesis' objectives, the following research questions are addressed:

1. How can policy mixes for innovation be conceptualized?
2. What is the impact of the conceptualized policy mix on innovation in offshore wind in Germany?
    - 2a. How does the policy mix affect corporate innovation activities in offshore wind in Germany?
    - 2b. Which role does the policy mix play for the technological innovation system of offshore wind in Germany?
        - 2b.1) What is the impact of the policy mix on the German offshore wind TIS and how do TIS developments influence the evolution of the policy mix?
        - 2b.2) What are the effects of policy processes on the German offshore wind TIS?

Overview of main chapters of the thesis

In *chapter 2* the policy mix is conceptualized in a comprehensive manner based on an extensive study of the literature mainly of environmental economics, innovation studies and policy analysis. The major building blocks of the policy mix are identified and assembled in an overarching concept. This concept is developed for technological change in general and also applies to innovation in renewable energy technologies. It provides an interdisciplinary analytical framework for empirical studies examining the impact of the policy mix on innovation. As such, it may also help in more clearly defining the boundaries of a policy mix study regarding the main building blocks and their scope and unit of analysis. Ultimately, due to its clear terminology and boundary setting the concept may contribute to a fruitful exchange of still largely disconnected policy mix research streams.

In the following chapters, the previously developed policy mix concept is empirically applied to study the innovation impacts of the policy mix for the case of offshore wind in Germany. In doing so, these chapters address the second research question. Each chapter has a different policy mix and / or innovation focus.

In *chapter 3*, the role of policy mix elements, i.e. the policy strategy and instrument mix, and of policy mix characteristics is analyzed for innovation at the firm level, including research, development and demonstration (RD&D) as well as adoption activities. The policy strategy refers to policy objectives and principal plans to achieve these and the instrument mix consists of interacting policy instruments. Characteristics such as consistency or credibility describe the nature of the policy mix. Despite considering several policy mix components, consistency is particularly focused on since it captures an overarching characteristic, namely the interplay and fit of the policy strategy, of the instrument mix and of the policy strategy with the instrument mix. Qualitative company case studies were conducted, with in-depth interviews as the principal data source. In doing so, representatives of turbine manufacturing firms and power generation companies with knowledge on corporate innovation strategies and the relevant policy mix were interviewed, providing substantiated insights into the effects of the policy mix on these firms' innovation activities. With the findings suggesting a vital role of the policy mix for innovation, this study points to considering such policy mix components that exceed single policy instruments, such as characteristics, since these are important determinants of innovation. Overall, the study constitutes the first empirical application of the policy mix concept and as such enables a more thorough understanding of the effects of the policy mix on corporate innovation activities.

C*hapter 4* examines the effects of the policy mix on innovation at the level of the technological innovation system, focusing on interdependencies in the evolutions of the policy mix and the TIS. That is, the role of policy mix components including the policy strategy, policy instruments, and policy-making and -implementation processes is analyzed for TIS functioning and performance, and the effects of certain TIS developments such as systemic problems on the coming about of the policy mix are explored. An event history analysis provided the basis for an analysis of the evolution of the TIS including TIS functioning and performance, while policy documents allowed for insights into policy mix evolution. The interdependencies of the policy mix and the TIS were subsequently illustrated with expert interviews. The study constitutes a first step of incorporating the policy mix concept into the TIS approach, enabling a better comprehension of the role of policy mix elements and processes – and not just of single policy instruments – in TIS. In addition, by illustrating the close interdependencies between the policy mix and TIS evolutions, the study contributes to a better understanding of the dynamics occurring in TIS.

Similarly as the previous chapter, *chapter 5* examines the impact of the policy mix on the TIS, this time focusing on so far largely neglected policy processes. Policy processes refer to political problem-solving processes to solve societal problems. The effects of the style of two exemplary policy processes on TIS functioning and performance are examined. These processes have addressed important systemic problems in the German offshore wind TIS, namely the problem of an insufficient level of support of the feed-in tariff and the problem of sustained delays in grid access for offshore wind parks. The empirical basis of this chapter is constituted of interviews with actors involved in the policy processes and supplementary documents on these processes, such as draft laws and industry position papers. Influential effects of the style of the studied policy processes on the TIS were found and described, illustrating the importance of their consideration in TIS analyses. The key contribution of this chapter is to shed light on so far mostly undiscovered policy processes in TIS and their influence on the TIS. It constitutes a further step incorporating the policy mix into the TIS approach.

Findings and conclusions

Based on the findings of the above introduced chapters, *chapter 6* presents the overall findings of the thesis by answering the research questions. It derives implications and states the thesis' contributions.

Regarding the first research question on the conceptualization of the policy mix (RQ 1), a concept of the policy mix was developed that consists of elements, processes and characteristics. In addition, the policy mix can be delineated by several dimensions. While policy mix *elements* include the policy strategy with overall policy objectives, such as long-term targets, and the instrument mix with several interacting policy instruments, policy *processes* refer to political problem-solving processes. Thereby policy processes greatly shape the policy mix elements. Policy mix *characteristics* describe the overall nature of the policy mix: Consistency refers to the absence of contradictions or the existence of synergies between the policy mix elements and can be described at three levels: the level of the policy strategy, of the instrument mix and of the instrument mix with the policy strategy.

In contrast, coherence deals with synergic and systematic policy processes that contribute to achieving overall policy objectives. Credibility refers to the believability and reliability of the policy mix, and comprehensiveness captures how extensive and exhaustive the policy mix is. Finally, *dimensions* define the scope of the policy mix regarding, for instance, its geographical delineation or policy field.

The second research question on the impact of the policy mix on innovation in offshore wind in Germany was addressed for two levels of innovation:

First, the effects of the policy mix on corporate innovation activities were studied (RQ 2a), with the following main findings. Regarding RD&D activities, the policy strategy, notably the offshore wind long-term target, and its consistency with overall renewable energy targets and with the instrument mix had a positive influence. Furthermore, the policy mix characteristic 'credibility' featured a positive effect. Regarding adoption activities, the instrument mix consisting of a technology-specific feed-in tariff with an investment-triggering level of support and several systemic instruments were found to be especially important. Similarly, the consistency of this mix and high credibility appeared central.

Second, the impact of the policy mix on innovation in offshore wind in Germany was examined at the TIS level (RQ 2b). In a first step (RQ 2b.1), the role of several policy mix components in the evolution of the German offshore wind TIS was explored, but also the reverse effect of how the TIS shaped the coming about of the policy mix, resulting in an analysis of policy mix-TIS-interdependencies. Two main patterns of interdependencies were identified. The first one is that policy mix components enabled early TIS developments to take off, providing a basis for entrepreneurial activities that required political guidance in order to continue. The second pattern is that systemic problems in the TIS triggered an alteration of the policy mix, which aimed to solve or remedy the problems. The newly set up or altered policy mix components often enabled the continuation of TIS developments but sometimes increased the reluctance to invest, so that further policy mix changes were needed to support innovation. In sum the results indicate close interlinkages of the policy mix evolution with the development of the TIS. In a second step (RQ 2b.2), the effect of the style of two policy processes addressing systemic problems on the offshore wind TIS in Germany was examined. These processes' style was found to be an influential determinant of TIS functioning and performance. Most strikingly, the tardy reactiveness of one the policy processes had negative effects on several TIS functions, such as entrepreneurial activities, and on technology diffusion. In contrast, both processes' participatory nature had a positive influence on TIS functioning and performance, e.g. via actors' increased trust and expectations.

Based on the findings on offshore wind in Germany, policy recommendations for fostering the offshore wind technology were derived. Of key importance may be the existence of a long-term and stable technology-specific policy strategy, e.g. in the form of a long-term target. However, retrospectively lowering the ambition level of such a target may have negative consequences, slowing down TIS development. Furthermore, a comprehensive instrument mix for fostering the technology consisting of demand pull, technology push and systemic instruments appears essential. This instrument mix should also address the most important system barriers and should timely be adjusted to address newly emerged problems. In terms of policy mix characteristics, credibility and consistency should be maintained at high levels. Regarding credibility, discussions like the electricity price brake discussion in Germany had destructive effects and should therefore be avoided. Regarding consistency, particularly when designing new or when altering existing policy mix elements, these should at a minimum be free of contradictions with existing elements. Finally, the effects policy processes can have on innovation should be considered. For instance, involving stakeholders in policy making in a participatory fashion might increase the effectiveness and acceptance of the outcomes of the policy process, e.g. of new or altered policy instruments.

This thesis makes three major contributions. First, it proposes a comprehensive concept of the policy mix, applicable to technological change more generally. Second, it provides for a more encompassing understanding of the role of the policy mix for innovation in RET. This includes not only the effects of policy mix elements but also of policy mix characteristics and policy processes, both for corporate innovation and the technological innovation system. Third, the thesis provides a first empirical incorporation of the policy mix into the TIS approach, thus facilitating a better understanding of policy mixes in TIS. Besides these main contributions, the thesis lays a basis for more comprehensive policy recommendations at the level of the policy mix.

Samenvatting

Achtergrond en doelstellingen

Als gevolg van hedendaagse uitdagingen, zoals klimaatverandering, uitputting van fossiele brandstoffen en de veiligheid van de energievoorziening, is de overgang van het huidige energiesysteem naar het gebruik van koolstofarme technologieën hoog op de politieke agenda komen te staan. Hernieuwbare energietechnologieën (HET) spelen een cruciale rol in dergelijke transities, maar de meeste van deze technologieën zijn nog niet volledig ontwikkeld en concurreren nog niet wat de kosten betreft. Om concurrerender te worden en een hogere mate van diffusie te bereiken, is het essentieel dat innovatie met betrekking tot deze technologieën wordt versneld. Toch is er ook sprake van markt-, systeem-, en transitiefalen, zoals kennisspillovers, een gebrek aan financiële middelen en de marktmacht van gevestigde bedrijven die dergelijke innovatie belemmeren.

Deze belemmeringen vereisen gemengde beleidspakketten met daarin verschillende beleidsinstrumenten – zogenaamde beleidsmixen – waar elk instrument zich op een van de falen concentreert. In de praktijk worden beleidsmixen echter vaak gebruikt om een bepaalde technologie te stimuleren of om een specifiek milieuprobleem aan te pakken. Toch is inmiddels een groeiende hoeveelheid conceptuele literatuur gewijd aan beleidsmixen. Daarin wordt erkend dat beleidsmixen aspecten bevatten, waarbij geldt dat de som meer is dan zijn losse delen, zoals de interacties tussen instrumenten of beleidsprocessen. Desalniettemin is er te weinig conceptuele eenduidigheid over wat beleidsmixen precies zijn. Ook ontbreekt er een gedeelde opvatting over de reikwijdte en terminologie van beleidsmixen. Dit kan vergelijkingen en evaluaties van studies over beleidsmixen moeilijk maken, wat weer kan leiden tot de formulering van ambigue bevindingen en beleidsaanbevelingen. Daarom is er behoefte aan een volledige conceptualisering met betrekking tot de beleidsmix, met een uniforme terminologie die rekening houdt met complexiteit betreffende de overvloed aan aspecten die het concept bevat.

Om hernieuwbare energietechnologieën succesvol te bevorderen is het verder belangrijk om de effecten van echte beleidsmixen op innovatie van deze technologieën beter begrijpen. Met betrekking tot het voorgaande hebben veel empirische studies de beleidseffecten op innovatie in het bredere veld van milieutechnologie geanalyseerd. Een groot aantal van deze studies richten zich op de effecten van losse beleidsinstrumenten, inclusief het instrumenttype of de designfeatures. Slechts een paar studies nemen ook andere beleidsmixcomponenten in acht, zoals instrumentinteracties of beleidsprocessen. De effecten van beleidsstrategie of overkoepelende beleidsmixkarakteristieken zijn echter nog nauwelijks geanalyseerd. Deze verwaarlozing kan leiden tot onvoldoende begrip van beleidsmixen en hun effecten, wat tot gefragmenteerde beleidsaanbevelingen kan leiden. Daarom moeten de effecten van de beleidsmix op innovatie uitvoeriger worden geanalyseerd dan tot nu toe het geval was.

Effecten van beleidsmixen kunnen op verschillende innovatieniveaus worden onderzocht, inclusief het micro- en het mesoniveau. Studies met betrekking tot het microniveau richten zich vooral op bedrijven als sleutelinnovators en hun diverse innovatie-activiteiten, inclusief onderzoek, ontwikkeling en demonstratie en ook adoptie, terwijl studies op het mesoniveau vaak innovatiesystemen analyseren. In het geval van opkomende, hernieuwbare energietechnologieën analyseren meso-studies vaak technologische innovatiesystemen (TIS) met hun actoren, netwerken, instituties en infrastructuur. Verder bestuderen zij ook de dynamiek van deze systemen met betrekking tot zeven of acht systeemfuncties om vervolgens systeemsterktes en –zwaktes af te leiden en op maat gemaakte beleidsaanbevelingen te maken. Toch is er op beide niveaus nog nauwelijks gekeken naar de gevolgen van uitgebreide beleidsmixen voor innovatie, hoewel dit tot belangrijke inzichten kan leiden. Wat innovatie op het bedrijfsniveau betreft: op basis van de inzichten van beleidsmixeffecten kunnen aanbevelingen worden gedaan voor het verbeteren van de beleidsmix met betrekking tot de sleutelinnovators. Het stimuleren van zulke sleutelinnovators om actief te worden is essentieel wanneer er wordt gestreefd naar de bevordering van technologische innovatie te bevorderen. Met betrekking tot innovatie op het TIS-niveau kan het bestuderen van beleidsmixeffecten zorgen voor een meer omvattend begrip van de rol van dergelijke beleidsmixen of delen ervan binnen een TIS. Dit is een vereiste bij het ontwerpen van beleidsmixen die op een passende manier de ontwikkeling van de gehele TIS bevorderen.

Tegen deze achtergrond worden in dit proefschrift twee belangrijke doelen gesteld. Het eerste doel is het ontwikkelen van een totaalconcept van de beleidsmix voor HET en technologische verandering in het algemeen, die overwegingen over losse instrumenten overschrijdt en rekening houdt met meer overkoepelende aspecten, zoals beleidsmixkarakteristieken. Het tweede doel is het onderzoeken van de invloed van een dergelijke uitgebreidere beleidsmix op HET-innovatie. Dit wordt onderzocht op zowel het bedrijfs- als ook op het systeemniveau.

Voor de tweede doelstelling werd de onderzoekcase van offshore-windenergie in Duitsland geselecteerd. Offshore-windenergie is een technologie met veel potentie, vooral dankzij de relatief grote schaal en de hogere windsnelheden op zee dan op het land. Deze technologie zal daarom een belangrijke rol vervullen bij de transitie naar het gebruik van meer hernieuwbare energietechnologieën. De rijke beleidsmix die zich richt op offshore wind in Duitsland, inclusief een ambitieuze langetermijndoelstelling en de duidelijke problemen met de technologiediffusie, maken dit een bijzonder waardevol voorbeeld voor het analyseren van de rol van de beleidsmix.

In overeenstemming met de doelstellingen van dit proefschrift, worden de volgende onderzoeksvragen beantwoord:

1. Hoe kunnen beleidsmixen worden geconceptualiseerd voor innovatie?
2. Wat zijn de gevolgen van het concept van beleidsmix op innovatie in offshore-windenergie in Duitsland?
   a. Hoe beïnvloedt de beleidsmix zakelijke innovatie-activiteiten in offshore-windenergie in Duitsland?
   b. Welke rol speelt de beleidsmix voor het technologisch innovatiesysteem van offshore-windenergie in Duitsland?
      i. Wat zijn de gevolgen van de beleidsmix op de Duitse offshore-windenergie-TIS en hoe beïnvloeden TIS-ontwikkelingen de evolutie van de beleidsmix?
      ii. Wat zijn de effecten van beleidsprocessen op de Duitse offshore-windenergie-TIS?

Overzicht van de hoofdstukken van het proefschrift

In *Hoofdstuk 2* wordt de beleidsmix op een uitvoerige manier geconceptualiseerd door middel van een omvangrijke literatuurstudie, vooral door studies uit de milieueconomie, innovatiestudies en beleidsanalyse. De belangrijkste bouwstenen van de beleidsmix worden geïdentificeerd en samengebracht in een overkoepelend concept. Dit concept wordt ontwikkeld voor technologische verandering in het algemeen en geldt ook voor innovatie op het gebied van hernieuwbare energietechnologieën. Het concept biedt een interdisciplinair analytisch kader voor empirische studies naar het effect van de beleidsmix op innovatie. Daardoor kan het ook helpen bij het duidelijker definiëren van de grenzen van een beleidsmixstudie met betrekking tot de belangrijkste bouwstenen, hun *scope* en de analyse-eenheid. Uiteindelijk kan het concept vanwege de duidelijke terminologie en scopevaststelling bijdragen aan een vruchtbare uitwisseling van de tot nu toe grotendeels losgekoppelde beleidsmixonderzoeken.

In de volgende hoofdstukken wordt het eerder ontwikkelde concept beleidsmix empirisch toegepast om de innovatie-impact van de beleidsmix te onderzoeken, specifiek in het geval van offshore wind in Duitsland. Deze hoofdstukken gaan daarbij in op de tweede onderzoeksvraag. Elk hoofdstuk heeft een eigen beleidsmix en/of innovatiefocus.

In *Hoofdstuk 3* wordt de rol van beleidsmixelementen, i.e. de beleidsstrategie en instrumentenmix, en van beleidsmixkarakteristieken geanalyseerd voor innovatie op het bedrijfsniveau, inclusief onderzoek, ontwikkeling, en demonstratie (RD&D), en adoptie-activiteiten. De beleidsstrategie heeft betrekking op beleidsdoelstellingen en de belangrijkste plannen om deze te bereiken. Verder bestaat de instrumentenmix uit de interactie tussen beleidsinstrumenten. Karakteristieken als consistentie en geloofwaardigheid beschrijven de aard van de beleidsmix. Ondanks andere beleidsmixcomponenten ligt de nadruk vooral op consistentie, omdat die een overkoepelend karakteristiek beslaat, dat wil zeggen de wisselwerking en fit van de beleidsstrategie, van de instrumentenmix en van de beleidsstrategie met de instrumentenmix. Kwalitatieve bedrijfscasestudies zijn uitgevoerd, met diepte-interviews als belangrijkste databron. Vertegenwoordigers van turbinefabrikanten en energieopwekkingsbedrijven met kennis van de zakelijke innovatiestrategieën en de relevante beleidsmix werden geïnterviewd. Dit heeft geleid tot een onderbouwd inzicht in de effecten van de beleidsmix op innovatieactiviteiten van deze ondernemingen. Terwijl de bevindingen een vitale rol van de beleidsmix op innovatie in het algemeen suggereren, benadrukt deze studie juist het belang van de mix van beleidscomponenten die losse beleidsinstrumenten overschrijden. Voorbeelden hiervan zijn de beleidsmixkarakteristieken, die een aanzienlijke invloed op innovatie kunnen uitoefenen. Over het algemeen vormt deze studie de eerste empirische toepassing van het concept beleidsmix, wat tot een grondiger inzicht in de effecten van beleidsmix op zakelijke innovatieactiviteiten leidt.

Hoofdstuk 4 gaat in op de effecten van de beleidsmix op innovatie op het niveau van het technologisch innovatiesysteem, specifiek op de onderlinge afhankelijkheden in de evolutie van de beleidsmix en de TIS. Dat wil zeggen, dat aan de ene kant de rol van de beleidsmixcomponenten, waaronder de beleidsstrategie, -instrumenten, -vorming en -implementatie, wordt geanalyseerd met betrekking tot het functioneren en de prestatie van de TIS. Aan de andere kant worden de effecten van bepaalde TIS-ontwikkelingen verkend, zoals systemische problemen bij de totstandkoming van de beleidsmix. Een eventgeschiedenisanalyse vormde de basis voor de analyse van de evolutie van de TIS inclusief het functioneren en de prestatie van de TIS, terwijl beleidsdocumenten zorgden voor inzichten in de beleidsmixevolutie. De onderlinge afhankelijkheden van de beleidsmix en de TIS zijn vervolgens geïllustreerd op basis van expertinterviews. Deze studie is een eerste stap in het opnemen van het concept beleidsmix in de TIS-benadering, waardoor een beter begrip ontstaat van de rol van beleidsmixelementen en -processen in de TIS, in tegenstelling tot slechts losse beleidsinstrumenten. Bovendien draagt dit onderzoek bij aan een beter begrip van de dynamieken binnen een TIS door het illustreren van de nauwe onderlinge afhankelijkheden tussen de beleidsmix en TIS-evoluties.

Evenals in het vorige hoofdstuk, wordt er in *Hoofdstuk 5* ingegaan op de invloed van de beleidsmix op de TIS, ditmaal gericht op de tot nu toe nog grotendeels genegeerde beleidsprocessen. Beleidsprocessen verwijzen naar politieke, probleemoplossende processen die gebruikt worden om maatschappelijke problemen op te lossen. De effecten van de stijl van twee exemplarische beleidsprocessen op het functioneren en de prestatie van de TIS worden onderzocht. Deze processen belichten belangrijke systemische problemen in de Duitse offshore-wind TIS, met name het probleem van een onvoldoende ondersteuning van het feed-in tarief en het probleem van aanhoudende vertragingen bij de toegang tot het elektriciteitsnet voor offshore-windparken. De empirische basis van dit hoofdstuk wordt gevormd door interviews met actoren die betrokken zijn bij de beleidsprocessen, aangevuld met documenten over deze processen, zoals wetsontwerpen en industriepositiepapers. Invloedrijke effecten van de stijl van de bestudeerde beleidsprocessen op de TIS zijn gevonden en beschreven. Die illustreren het belang van het gebruik van deze effecten in TIS-analyses. Het grootste belang van dit hoofdstuk is licht te werpen op de tot nu toe grotendeels onontdekte beleidsprocessen in een TIS en hun invloed op de TIS. Dit is een verdere stap in de integratie van de beleidsmix in de TIS-aanpak.

Bevindingen en conclusies

Op basis van de bevindingen van de hierboven geïntroduceerde hoofdstukken presenteert *Hoofdstuk 6* de algemene bevindingen van het proefschrift door de onderzoeksvragen te beantwoorden. Daarna worden de afgeleide implicaties en de belangrijkste bijdragen van het proefschrift vermeld.

Met betrekking tot de eerste onderzoeksvraag over de conceptualisering van de beleidsmix (OV 1), is een concept van de beleidsmix ontwikkeld dat bestaat uit elementen, processen en karakteristieken. Bovendien kan de beleidsmix op meerdere dimensies worden afgebakend. Terwijl *beleidsmixelementen* de beleidsstrategie met algemene beleidsdoelstellingen omvatten, zoals langetermijndoelstellingen en de instrumentenmix met diverse beleidsinstrumenteninteracties, verwijzen *beleidsprocessen* naar politieke probleemoplossende processen. Beleidsprocessen vormen de beleidsmixelementen in hoge mate. Beleidsmixkarakteristieken beschrijven de algemene aard van de beleidsmix: ‘consistentie’ verwijst naar de afwezigheid van tegenstellingen of het bestaan van synergiën tussen de beleidsmixelementen. Dit kan worden beschreven op drie niveaus: het niveau van de beleidsstrategie, van de instrumentenmix, en van instrumentenmix met de beleidsstrategie. Contrasterend daarmee refereert ‘coherentie’ naar synergetische en systematische beleidsprocessen die bijdragen aan de verwezenlijking van de algemene beleidsdoelstellingen. ‘Geloofwaardigheid’ verwijst naar de betrouwbaarheid van de beleidsmix en ‘volledigheid’ beschrijft hoe uitgebreid en uitputtend de beleidsmix is. Tot slot definiëren de dimensies de scope van de beleidsmix met betrekking tot bijvoorbeeld de geografische afbakening van het beleidsterrein.

De tweede onderzoeksvraag over de impact van de beleidsmix op innovatie in offshore-windenergie in Duitsland is beantwoord voor beide innovatieniveaus:

Ten eerste zijn de effecten van de beleidsmix op zakelijke innovatieactiviteiten bestudeerd (OV 2a), met de volgende belangrijke bevindingen. Met betrekking tot RD&D-activiteiten had de beleidsstrategie, vooral de offshore wind langetermijndoelstelling en zijn samenhang met de algemene doelstellingen voor hernieuwbare energie en met de instrumentenmix, een positieve invloed. Verder werd de beleidsmixkarakteristiek ‘geloofwaardigheid’ gekenmerkt door een positief effect. Met betrekking tot adoptie-activiteiten bleek de instrumentenmix vooral belangrijk te zijn. Die bestond uit een technologie-specifieke feed-in tarief met een investeringsprikkelend niveau van ondersteuning en meerdere systematische instrumenten. Ook de consistentie van deze mix en de hoge geloofwaardigheid bleken van centraal belang.

Ten tweede is de impact van de beleidsmix op innovatie in offshore-windenergie in Duitsland onderzocht op het TIS-niveau (OV 2b). In de eerste stap (OV 2b.1) is de rol van de verschillende beleidsmixcomponenten in de evolutie van de Duitse offshore-windenergie TIS onderzocht, maar het omgekeerde effect naar hoe de TIS de totstandkoming van de beleidsmix heeft gevormd werd eveneens onderzocht. Dit alles resulteerde in een analyse van de onderlinge afhankelijkheden tussen de beleidsmix en de TIS. Twee hoofdpatronen van onderlinge afhankelijkheden werden geïdentificeerd. De eerste is dat de beleidsmixcomponenten de start voor vroege TIS-ontwikkelingen mogelijk maakten, wat zorgde voor een basis voor ondernemingsactiviteiten die politieke richting nodig hadden om gecontinueerd te worden. Het tweede patroon is dat systemische problemen in de TIS leidden tot wijzigingen van de beleidsmix om zo bepaalde problemen op te lossen of te verhelpen. De nieuw opgerichte of gewijzigde beleidsmixcomponenten maakten vaak de voortzetting van TIS-ontwikkelingen mogelijk. Dit verhoogde echter soms ook de terughoudendheid om te investeren, zodat verdere beleidsmixveranderingen weer nodig waren om de innovatie te ondersteunen. Samengevat geven de resultaten aan dat er nauwe verbanden bestaan tussen beleidsmixevolutie en de ontwikkeling van de TIS. In de tweede stap (RQ 2b.2) is het effect onderzocht van de stijl van twee beleidsprocessen, die zich richtten op de systemische problemen in de offshore-windenergie TIS in Duitsland. Het is gebleken dat de stijl van deze processen een invloedrijke determinant was van het functioneren en de prestatie van de TIS. Het opvallendste was dat de late reactiviteit van een van de beleidsprocessen negatieve effecten had op meerdere TIS-functies, zoals ondernemingsactiviteiten en technologiediffusie. De participatieve aard van beide processen hadden in tegenstelling daartoe wel een positieve invloed op het functioneren en de prestatie van de TIS, zoals het toegenomen vertrouwen en de verwachtingen van actoren.

Op basis van de bevindingen van offshore-windenergie in Duitsland zijn beleidsaanbevelingen afgeleid voor het bevorderen van de offshore-windtechnologie. Het bestaan van een langdurige, stabiele, technologie-specifieke beleidsstrategie, zoals in de vorm van een langetermijndoelstelling, kan van kernbelang zijn. Het met terugwerkende kracht verlagen van het ambitieniveau van een dergelijke doelstelling kan echter negatieve gevolgen hebben, die de TIS-ontwikkeling vertragen. Bovendien lijkt een uitgebreide instrumentenmix, bestaande uit demand-pull, technology-push en systemische instrumenten, essentieel voor het bevorderen van de technologie. Deze instrumentenmix moet ook de belangrijkste systeembarrières aanpakken en moet tijdig worden aangepast aan nieuwe problemen. Wat de beleidsmixkarakteristieken betreft, moeten geloofwaardigheid en consistentie op een hoog niveau worden gehandhaafd. Met betrekking tot geloofwaardigheid hadden discussies als de elektriciteitsprijsrem-discussie in Duitsland destructieve gevolgen; dergelijke discussies moeten daarom worden vermeden. Met betrekking tot consistentie, vooral bij het ontwerpen van nieuwe beleidsmixelementen, of het wijzigen van bestaande beleidsmixelementen, moeten deze zo vrij mogelijk zijn van tegenstrijdigheden met bestaande elementen. Ten slotte moet er rekening worden gehouden met de effecten van beleidsprocessen op innovatie. Het betrekken van stakeholders in beleidsvorming op een participatieve manier kan bijvoorbeeld de effectiviteit en acceptatie van de uitkomsten van het beleid van nieuwe of aangepaste beleidsinstrumenten vergroten.

Dit proefschrift levert drie belangrijke bijdragen. Ten eerste stelt het een algemeen concept van de beleidsmix voor, dat toepasbaar is voor technologische verandering in het algemeen. Ten tweede voorziet het in een meer omvattend begrip van de rol van de beleidsmix voor innovatie in hernieuwbare energietechnologieën. Dit bevat niet alleen de effecten van beleidsmixelementen, maar ook die van beleidsmixkarakteristieken en beleidsprocessen, zowel op innovatieniveau van bedrijven als ook op het niveau van het technologisch innovatiesysteem. Ten derde biedt dit proefschrift een eerste empirische opname van de beleidsmix in de TIS-benadering, wat een beter begrip van beleidsmixen in een TIS faciliteert. Naast deze belangrijke bijdragen legt dit proefschrift ook een basis voor uitgebreidere beleidsaanbevelingen op het niveau van de beleidsmix.

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While usually having sufficient energy even for long runs, the endurance for my ‘PhD run’ was almost exhausted when it suddenly turned from a marathon to a more than 50 km run. At this point I was not sure whether I could bring up the energy to finish this unexpectedly lengthy endeavor.

I am now all the more relieved I did finish it, and I want to thank a number of people supporting me on the way.

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Curriculum Vitae

Kristin Reichardt was born in 1983. From 2003 to 2009 she studied business administration and economics at the Friedrich Schiller University in Jena, Germany, with a major in innovation economics. She earned her diploma degree (Master equivalent) in economics, having written her diploma thesis on two German regional innovation systems – Karlsruhe and Aachen – analyzing social networks based on patent data. During her studies she completed internships, among others, in the German Federal Ministry of Economics (Department of Structural Policy for Eastern Germany) in Berlin, Germany, and the Boston Consulting Group (Energy Knowledge Group) in Hamburg, Germany. From 2006 to 2009, she received a scholarship by the German National Academic Foundation. From October 2009 until September 2014, Kristin worked as a researcher in the Competence Center Energy Policy and Energy Markets at the Fraunhofer Institute for Systems and Innovation Research (Fraunhofer ISI) in Karlsruhe, Germany. During this time she was involved in several EU-funded and German research projects, including RESPONSES (Mitigation of and adaptation to climate change in the EU) and GRETCHEN (Impact of the policy mix on technological and structural change in the renewable energy sector). In parallel to her work at Fraunhofer ISI, Kristin started her PhD at the Chair of Sustainability and Technology at the ETH Zurich, Switzerland, in October 2010. After a two-month sabbatical in 2013, she transferred to the Innovation Studies group at the Copernicus Institute of Utrecht University, the Netherlands. Since September 2014 she has been working for a Swiss utility company.

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